Modeling and calibration of BRAMS antenna systems

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Because of the geometry associated with the forward-scatter method for observing meteors via radio, knowing the radiation pattern of the involved antennas is essential to obtain parameters of scientific interest such as the meteoroid flux density. In this paper results of simulations of the antennas belonging to the Belgian RAdio Meteor Stations network (BRAMS) that are directly managed by the Belgian Institute for Space Aeronomy (BISA) are presented, as well as plans for verifying their patterns using an Unmanned Aerial Vehicle (UAV).

1 Introduction

BRAMS is a project coordinated by BISA under the frame of the Solar–Terrestrial Centre of Excellence (STCE) that, based on *forward-scattering* techniques, aims to study the meteoroid population. Currently BRAMS comprises a network of 26 radio receiver stations mostly hosted by Belgian radio amateurs or groups of amateur astronomers, and a dedicated beacon located at Dourbes Geophysical Centre (Southern Belgium) acting as a transmitter radiating on 49.97 MHz (Calders and Lamy, 2012).

One of the main goals of BRAMS is calculating meteoroid flux densities for meteor showers and mass indexes for meteor showers and sporadic meteors. The meteoroid flux density $Q(m_0)$ is a parameter which measures meteoroid abundance in the vicinity of the Earth's orbit and it can be calculated from the statistics of a set of observed meteors, without requiring detailed information on the occurrence of an individual meteor. It is important to obtain precise meteoroid flux density values in order to compare results of different radio systems.

However, due to the geometry involved in the *forward-scatter* method, this calculation requires knowledge of specific technical characteristics of each transmitter-receiver pair or *set-up* (Suleymanova et al., 2007). Among other figures, the antenna gain value for both transmitter and receiver systems in the direction of the reflection point are required. Because the reflection point's spatial location is virtually random in the sky, full antenna directional patterns need to be known.

Antenna systems can be modeled to obtain their theoretical directional patterns. In Section 2, the approach and results of modeling the directional antenna patterns for the BRAMS beacon and the stations directly managed by BISA are presented.

Nevertheless, a real antenna directional pattern is actually influenced by many factors, from its own building features (geometry, connections, materials, etc.) to the environmental characteristics of the location (conductivity of the ground, nearby buildings, humidity, etc.) In Section 3, a strategy for verifying the obtained antenna patterns based on the usage of an UAV is introduced, as well as a report on the status of this development.

2 Modeling of BRAMS antenna systems

Numerical Simulation Approach

Many applications in science and technology rely increasingly on electromagnetic (EM) field computations, meaning solving Maxwell's equations. Nevertheless, in complex systems, complicated differential equations cannot be solved by analytical methods. Antenna engineering is among the major electrical engineering areas of complex EM problems where numerical simulation approaches are increasingly being used.

An antenna is a device that provides a transition from a *guided wave* on a transmission line to a *free-space wave* (or vice versa). Most antennas are reciprocal devices and behave the same while transmitting and receiving.

One of the most powerful techniques, which has been in use for more than three decades in frequency domain, is the Method of Moments (MoM). A MoM code synthesizes the far field of an antenna by integrating the Green's functions of individual metallic surface patches. The technique is based on solving complex integral equations by reducing them to a system of linear equations and by applying the *method of weighted residuals* (Weiland et al., 2008).

Table 1 – Features of the modeled BRAMS antenna systems
(ε and σ are the relative permittivity and conductivity of the ground, respectively).

Location	ε	σ [mS/m]	Antenna systems	Azimuth [º]	Elevation [º]	Height (driven el.) [m]
Uccle	3	0.6	Yagi 3-el X-Yagi 3-el	165	35	3.75
Humain	15	9.0	Yagi 3-el ×4 X-Yagi 3-el	N/A	90	2.62
Dourbes	15	2.0	Turnstile	N/A	2.0	1.41

Table 2 – Parameters used in modeling the BRAMS antenna systems.

Type	No. Wires	No. Segments	Loads
Yagi 3-elements	8	584	Al
X-Yagi 3-elements	16	1168	Al
Turnstile & Reflector Plane	44	1028	Al & SS

The Numerical Electromagnetic Code (NEC) is a software package which uses a MoM technique for analyzing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. The code was initially written in FORTRAN and developed in the 1970s by the Lawrence Livermore National Laboratory, under the sponsorship of the Naval Ocean Systems Center and of the Air Force Weapons Laboratory (Burke and Poggio, 1981). For the simulation of BRAMS antenna systems, the latest version of the code within the public domain without license (officially called NEC-2) has been selected in its C compiled version from Neoklis Kyriazis[1] named NEC2C.

BRAMS Antennas and NEC Models

The radiating system of the Dourbes beacon consists of a turnstile antenna arranged in normal mode, with an 8 m × 8 m grid acting as reflector plane disposed between the antenna elements and the ground. The size of each aluminum element of the turnstile is 2.82 m, with 14 mm in diameter. The grid is made of stainless steel (SS).

The antenna used in every standard receiving station is a 3-element Yagi with a director of 2.67 m, a driven element of 2.81 m, and a reflector of 2.97 m in size. Additionally, the receiving stations directly managed by BISA have a 3-element crossed Yagi (X-Yagi) antenna, built with two standard Yagis in which main axes overlap but elements are arranged perpendicularly. The diameter of each aluminum element is 15 mm.

Additional relevant features of these antenna systems and the environment of their location are shown in *Table 1*.

To improve the quality of the results of the simulations, the gamma matches were included in the models and adjusted to obtain an input impedance of Z_{in} = 50 Ω.

The map of *Figure 1* shows the locations of the analyzed antenna systems in Belgium, and Figure 2 shows some pictures of them.

Figure 1 – Locations of the modeled BRAMS antenna system.

NEC-2 assumes any metallic object to be a superposition of small segments on which the current distributions are of interest, therefore the software works with individual straight *wires*, although complex geometric shapes can be formed joining those wires at their ends. Then each wire in an element should be segmented. Since MoM is based on the calculation of currents on small segments and since it is formulated as a matrix system, the memory and computation time requirements drastically increase as the number of segments increases. The number of segments depends on the size of the structure and the frequency. *Table 2* shows the definite segmentation values applied as well as the material (characteristic impedance) of the antenna structures.

[1] "Readme file for nec2c", http://www.qsl.net/5b4az/pkg/nec2/nec2c/README, Ham Radio Station 5B4AZ webpage.

Figure 2 – Images of BRAMS antenna systems directly managed by BISA (*Top left:* Yagi at Humain Radio Astronomy Station. *Top right:* Crossed Yagi at BISA facilities, Uccle. *Bottom:* Turnstile at Dourbes Geophysical Centre).

The convergence of the simulations' results and the Average Gain Test (Miron, 2006) over free space were applied to verify the reliability of the numerical simulations.

Simulation Results

The original results of a NEC-2 simulation is a structured text file with details of the model, including partial EM field calculation results and the antenna gain values in different directions for the far field centered on the antenna location. From this information, visualizations can be built to graphically show the shape of the antenna pattern in a convenient and more intuitive way.

MayaVi is a general-purpose 3D scientific visualization package (Ramachandran and Varoquaux, 2008) which uses the Visualization Toolkit (Schroeder, Martin and Lorensen, 2002) and it is entirely written in Python. *Figures 3 – 5* show still images of the visualizations obtained after processing the simulation results with MayaVi.

3 Approach for verification of the antenna patterns

Measurement system

The next step in increasing the knowledge of the BRAMS antenna patterns is characterizing them in their real environment. In this regard, a low-cost antenna pattern verification method based on an Unmanned Aerial Vehicle (UAV) device was devised.

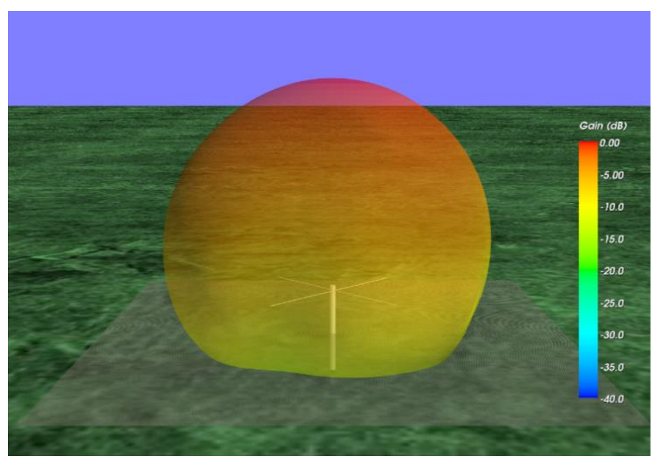

Figure 3 – Antenna pattern of the BRAMS beacon antenna obtained from numerical simulation (turnstile antenna and reflective plane).

The chosen aircraft– an OktoXL ARF-Mikrokopter (HiSystems, 2013) – is shown in *Figure 6*. Its electronic boards (FlightCtrl V2.1, NaviCtrl V2.0, and MKGPS V2.1) and a software interface allow for loading arbitrary GPS-controlled autonomous flight with a stable orientation of the aircraft during the overall flight. A fully charged LiPo (Lithium Polymer) battery offers a maximum

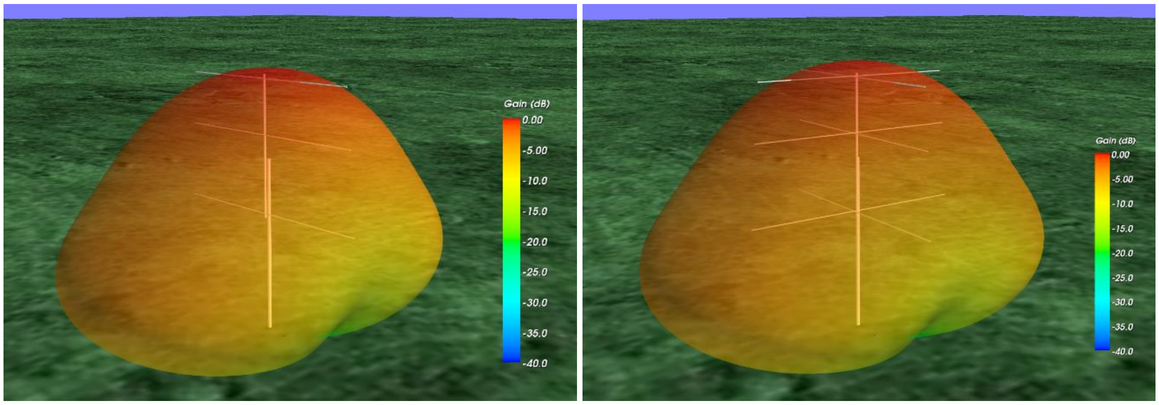

Figure 4 – Antenna patterns of the BRAMS Humain station obtained from numerical simulation (*left:*Yagi antenna, *right:* X-Yagi antenna).

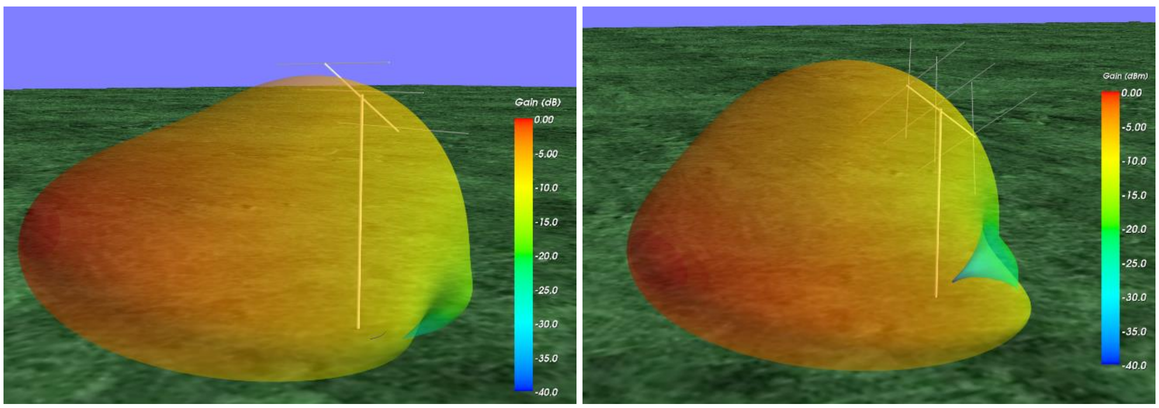

Figure 5 – Antenna patterns of the BRAMS Uccle station obtained from numerical simulation (*left:*Yagi antenna, *right:* X-Yagi antenna).

autonomy of 15 minutes. For the takeoff and landing operations, a remote pilot is needed instead. The position and orientation angles (bearing, pitch, and roll) of the aircraft during the flight are available for post-processing.

A continuous-wave RF generator, designed and built at BISA[2], has been adapted below the battery holder on the bottom of the UAV aluminum frame set. The RF generator, which is tuned at the BRAMS beacon frequency with a maximum output power of -6 dBm, is powered by an independent battery bank through a USB standard connector. A shortened monopole antenna (Z_{in} = 50 Ω) is connected to the RF generator, disposed vertically downward the UAV. A metallic mesh has been inserted between the UAV battery holder and the RF signal generator in order to reduce the EM influence of the UAV frame set over the radiation pattern of the RF generator antenna. Land gear extensions were necessary to guarantee room enough for the antenna when the aircraft is grounded (see *Figure 6*).

The signal from the RF generator must be recorded with accurate timestamps to allow matching the position of the UAV and the total received power. Although during the first testing flights the receivers employed were a spectrum analyzer and a software defined radio (SDR) based receiver, the current BRAMS receiving hardware and software configuration (Calders and Lamy, 2012) is suitable to accomplish this task.

Measurement strategy

In order to guarantee that the measured values of the received signal power are suitable for determining the antenna pattern, it is necessary to locate the RF generator in the far–field range of the corresponding antenna under test (AUT). The basic idea is to fly around each AUT outside the minimum far–field distance boundary (Balanis, 2005), following successive circular paths at different altitudes until completing a semi-spherical shape centered on the AUT.

The far field distance for the Yagi and X-Yagi antennas is 2.94 m, and for the beacon’s turnstile is 42.67 m, way less than the maximum remote control distance for the aircraft. Test flights have been performed to verify the accuracy of the GPS-controlled positioning of the UAV. The preliminary results show a typical drift of 3–5 m off the desired stable way-point of the flight path. These results show that the variation depends mainly on weather conditions, specifically on the wind strength.

2 “Calibrator for BRAMS”, http://brams.aeronomie.be/files/BRAMS_annualmeeting_2014_MichelAnciaux_calibrator.pdf, BRAMS webpage.

Figure 6 – Measurement system (*Top*: UAV OktoXL in flight equipped with RF signal generator, battery bank, transmitting antenna and isolating metallic mesh; *bottom-left*: Screenshot of the control software with the flight plan and the tracking of the actual flight; *bottom-right*: RF signal generator).

It is worth mentioning that, taking into account that some UAVs are capable of performing flights over 1000 m in altitude, the Belgian government (as well as many other countries) is currently discussing a legal framework to regulate the Remote Pilot Aircraft Systems (RPAS) activities. Because the final instrument is not ready yet, the STCE obtained a special permission from national air navigation authority (BELGOCONTROL) for flying the UAV up to 150 m above ground, only for research purposes.

4 Future work

Simulated antenna patterns of the BRAMS stations directly managed by BISA are already available for processing of observations of radio meteors. In the next months, the received power pattern of the antennas in their real environment will be derived from a series of measurements to be performed by the system previously described.

The reliability of the results will rely on a statistical analysis over a relatively large set of measurements. This implies carrying out intense measurements campaigns to collect enough information which allows reconstructing the antenna patterns and comparing them to the simulated ones. Measurements taken under high and low environmental humidity conditions will be classified and analyzed separately. On the other hand, the ongoing acquisition of extra resources (batteries and a multiple battery charger) to extend the effective flight time per day aims to increase the performance of the measurement campaign day.

Currently the characterization effort is focused only on stations directly managed by BISA. However, to be able to characterize the whole BRAMS network, a similar procedure must be performed at the rest of the stations. Numerical simulations for every station antenna can be carried out as long as the critical information is available for modeling, but the power measurement through the UAV is constrained by the permission from BELGOCONTROL which currently allows flying only at the locations of the stations included in this work.

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