Pulse radar transmitter for the Humain BRAMS array?

Lucas Maurice[1], *Adrien Manuel Mascarenhas*[1], *Antonio Martínez Picar*[2,3], *and Christophe Marqué*[2]

As part of the development stages of SPADE, the addition of a transmitter at the Humain Radio Astronomy Station is planned to calibrate the instrument. This implementation will use Software-Defined Radio, which allows for enhanced functionality by leveraging the automation and connectivity options associated with this technology. This paper explores the feasibility of configuring this transmitter as a pulse generator to convert the BRAMS interferometer in Humain into a radar for observing radio meteor echoes.

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1 Introduction

Observations of meteor echoes using radio techniques have been reported since mid-1920s (Appleton et al., 1925), but it was Schafer and Goodall (1932) who demonstrated that received radio echoes were directly associated with the passage of bright meteors.

It is commonly accepted that systematic radio meteor observations began just after WWII. Initially, powerful systems were used to detect the presence of enemy aircraft.

However, some of the received radio echoes were actually the result of meteor activity (McKinley, 1961). The reception of radio meteor echoes is usually classified into two techniques: *back-* and *forward*-scatter. As shown in Figure 1 the backscatter method requires that the transmitter and receiver of the system be located in the same place (see e.g., Wislez, 2006).

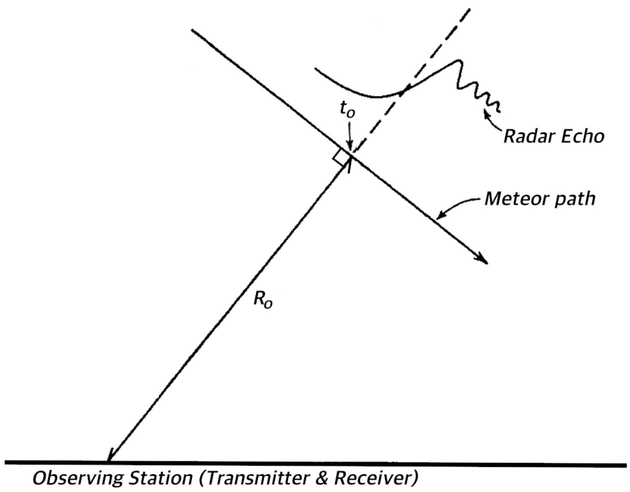

Figure 1 – Geometry of the meteor path relative to the observing station based on radio back-scatter.

2 The Humain Radio-Astronomy Station

Located in the south of Belgium, the Humain Radio-Astronomy Station (HuRAS) was founded in 1953 by the Royal Observatory of Belgium (ROB) specifically to host a 48-antennas radio interferometer dedicated to observing the Sun. Although this large instrument was decommissioned in the 2000s, HuRAS remains operational today, and now shares its facilities with the Belgian Institute for Space Aeronomy (BISA) and the Royal Meteorological Institute, allowing the observation of the Sun, the sky, Earth's space environment and its atmosphere.

BISA develops and operates the Belgian RAdio Meteor Stations (BRAMS) project: a network of radio receiving stations using the forward-scatter method to study the meteoroid population by observing radio meteor echoes.

The system comprises a dedicated transmitter located in Dourbes, emitting a continuous sine wave of 130 W at $f = 49.97$ MHz, and more than 40 receiving stations that are spread across Belgium and neighbouring countries (Lamy et al., 2023).

Based on a 5-antenna design described by Jones, Webster and Hocking (1998), the BRAMS station located at HuRAS has interferometric capabilities. An already scheduled upgrade will change its receivers to Software-Defined Radio (SDR) technology (Anciaux et al., 2020).

Also hosted at HuRAS, the Small Phased-Array DEmonstrator (SPADE) is an instrument designed and operated by ROB to observe solar radio activity in the frequency range of 20 to 80 MHz. As shown in Figure 2, its layout consists of eight perpendicular pairs of *inverse thick Vees* antennas (or array elements), seven arranged in an evenly spaced circle, with an additional one in the center (Mouhaou et al., 2024).

Figure 2 – View of the SPADE array field.

[1]ELISA Aerospace, Saint-Jean-d'Illac 33, Bordeaux, France. Email: l.maurice@elisa-aerospace.fr and a.manuel-mascarenhas@elisa-aerospace.fr

[2]Royal Observatory of Belgium, Av. Circulaire 3, 1180 Bruxelles, Belgium. Email: antonio.martinez@oma.be and christophe.marque@oma.be

[3]International Meteor Organization, Mattheessenstraat 60, B-2540 Hove, Belgium. Email: martinez.picar@gmail.com

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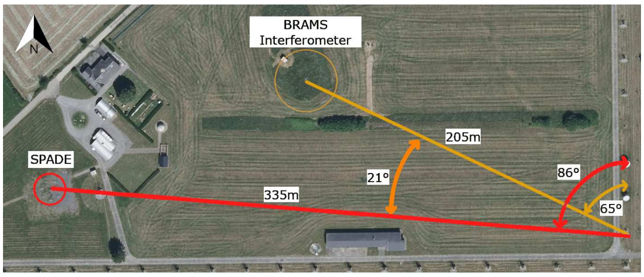

Figure 3 – Relative location of SPADE array field, its calibration transmitter, and BRAMS interferometer at HuRAS.

Since the elements of SPADE are fixed, tracking is not achieved through mechanical action but rather through careful phase management of the received signal at each element. When these signals are combined, they steer the main beam in the desired direction. However, phase synchronization issues can affect the accuracy of the final pointing.

To ensure the correct functioning of the tracking system, the receivers of SPADE require calibration. To achieve this, a transmitter is being developed at HuRAS. This transmitter will emit a precisely controlled signal, both in power and phase, towards SPADE.

Since the planned transmitter will likely be used for SPADE calibration purposes during brief periods (e.g., a few minutes weekly), it is practical to share its operational time with the BRAMS meteor radar. The challenge on this project is to meet the requirements for both scenarios.

3 Humain Meteor Radar Design

Power and network availability as well as physical support to install the antenna leads the SPADE design team to build the transmitter next to a technical cabinet located in the southernmost antenna pillar of the North-South axis of the former solar radio interferometer of HuRAS.

That locates this equipment at 94° in azimuth and 335 m distance from SPADE center element, and at 115° in azimuth and 205 m distance from the BRAMS interferometer center antenna (see Figure 3). In terms of meteor science, the potential radar transmitter and the receiver (i.e. BRAMS interferometer) are virtually located in the same place.

Calibrating SPADE requires a broadband transmitting antenna to cover its operational frequency range. A Log-Periodic Dipole Array (LPDA) is a suitable option for this task and it was the choice of the design team at ROB.

On the other hand, the radar will operate in a single frequency[a], which can certainly be set near the Dourbes beacon frequency. Since the BRAMS receivers can *listen* over a bandwidth of more than 2 kHz, the radar frequency can be easily set at ≈ 500 Hz below that of the BRAMS beacon.

The resulting pattern for the BRAMS interferometer (Figure 4) suggests improved reception of radio echoes when the meteor appears at or nearby the zenith. Consequently, the radar transmitting antenna should also direct power towards the zenith. This reasoning indicates that the LPDA should be oriented vertically.

Simulations conducted with NEC2++ (Molteno, 2014) for the LPDA demonstrated an optimal arrangement with its largest dipole elevated 4.5 m above the ground, and aligned along the N-S direction. Figure 5 shows the radiation pattern for the LPDA at that heigh. A smooth antenna gain lobe ensures good coverage of an area approximately 60° around the zenith, while a low elevation side lobe warranties simultaneous illumination of SPADE array.

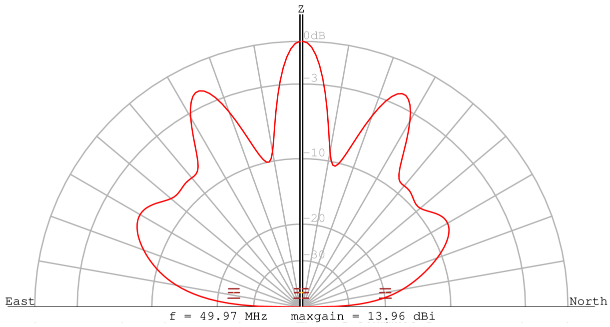

Figure 4 – Simulation results for the vertical radiation patterns of the BRAMS interferometer (Martínez Picar et. al, 2016).

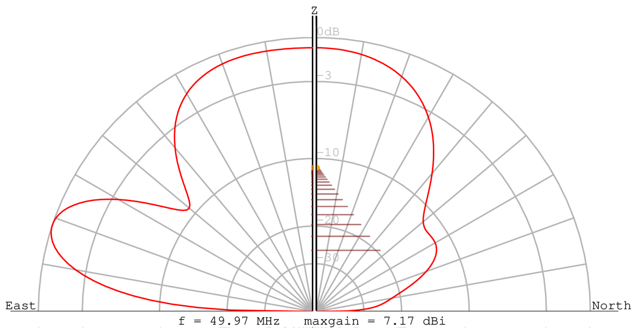

Figure 5 – Simulation results for the vertical radiation patterns of the LPDA antenna at 4.5 m height.

The system will employ a transmitter based on *Software-Defined Radio* (SDR) technology, which uses software to control its operation (see, e.g., Collins et al., 2018.). The script will be developed using *GNU Radio*[b] platform, enabling the generation of a modulated sine wave at the BRAMS beacon frequency as a pulse-like rectangular signal with a specific width and repetition time.

Calculations have shown that, in a demanding meteor-echo detection scenario, the round trip duration of the signal — from the transmitter, to the meteor trail and back to the receiver — is approximately 1 ms. The parameters shown on Table 1 were selected to prevent range ambiguity. A suitable SDR transmitter will most likely be controlled by a Single Board Computer, which will manage pulse generation.

Precise range determination in a pulse radar demands high timing precision. This requires that the

[a] Actually, a narrow-band frequency range.

[b] `https://www.gnuradio.org`

Table 1 – Parameters for the proposed pulse radar.

Parameter	Value	Unit
Pulse Repetition Freq.	900	pps
Pulse width	70	μs
Duty cycle	6.3	%

transmitter and receiver be carefully synchronized to minimize time errors, which has traditionally been achieved by sharing a local oscillator signal between the two devices.

However, when the devices are located a few hundreds meters apart, sharing electrical signals is not convenient due to potential noise, cable loss, and other practical factors. White Rabbit[c], an Ethernet network-enabled technology based on an enhanced version of the IEEE 1588 Precise Time Protocol and Sync-E, appears to fulfill this need, achieving sub-nanosecond accuracy while compensating for network-induced delays.

For electron densities slightly below 2×10^{14}, a height detection range of 70–120 km can be achieved when transmitting with a power of 12 kW. However, typical output power for SDR transmitters is around 10 dBm (10 mW), so power amplification is required.

4 Discussion

Various alternatives for an SDR transmitter have been considered, with *HackRF One*[d] emerging as a suitable option, as it can cover the SPADE operating frequency range. However, the power budget of the system required to meet the design constrains necessitates a transmitting power gain of $\approx$ 60 dB. This represents an additional economical challenge, as power amplifiers with such specifications are uncommon and tend to be expensive.

The feasibility study and design process for the installation of a pulse radar transmitter at HuRAS have been conducted. The result of this study is an SDR-based system, which can be programmed to switch between configurations as a pulse generator for a potential BRAMS meteor radar, and as a calibration signal transmitter for SPADE. This flexibility offers a practical solution that optimizes technical resources utilization.

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[c] https://www.white-rabbit.tech/
[d] https://greatscottgadgets.com/hackrf/one/