A 5GHz survey of the Galactic Polarized Emission

Rui Fonseca[1,2,3], Domingos Barbosa[1,3], Luis Cupido[4], Dinis M. Santos[1,2], Miguel Bergano[1], Francisco Fernandes[1,3], Camilo Tello[5], George Smoot[6], Ana Mourão[3]

rfonseca@av.it.pt, dbarbosa@ist.utl.pt, cupido@av.pt, dms@det.ua.pt, jbergano@av.it.pt, ff@av.it.pt, tello@das.inpe.br, gfsmoot@lbl.gov, amourao@ist.utl.pt

(1) Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal.

(2) Departamento de Electrónica, Telecomunicações e Informática, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

(3) CENTRA, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

(4) Centro de Fusão Nuclear, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

(5) Divisão de Astrofísica, Instituto Nacional de Pesquisas Espaciais (INPE), CP 515, São José dos Campos, 12201-970, Brazil

(6) Lawrence Berkeley National Laboratory, University of California, 1 Cyclotron Road, Bldg. 50, MS 205, Berkeley, CA 94720, USA

Abstract- **The Galactic Emission Mapping collaboration is proceeding towards the survey of the polarized emission at 5GHz of the whole sky from antennas located in Portugal - covering the North Hemisphere - and Brazil - covering the South Hemisphere.**

The obtained maps will be used in the subtraction and component separation of the galactic foreground emission to the Cosmic Microwave Background observations carried by the ESA Planck Surveyor mission (ESA launch by 2008) and other future probes. We present the status and goals of the GEM-P (Portugal) project.

I. Introduction

The Cosmic Microwave Background Radiation (CMBR), is the paramount cosmological tool to look into the early Universe. The study of its temperature and polarization diminutive fluctuations and variations, allows for a reconstitution of the cosmic history with great precision [7, 8]. However, the Milky Way, with respect to CMBR surveys, works towards partially obscuring the emitted background radiation. To surpass this problem, detailed maps of the galactic foreground emissions are needed to suitably remove this information from CMBR observations. The GEM (Galactic Emission Mapping) collaboration [9, 10, 11] aims at mapping the sky with high sensitivity and absolute calibration at low frequencies both in Brazil (GEM-B) and Portugal (GEM-P).

GEM will be an important contribution for foreground removal to present and future CMBR experiments.

II. Project Outline

GEM-P will map the North Hemisphere sky to map and deliver templates that will enrich the knowledge on the galactic synchrotron polarization fraction and substructure at scales down to 0.5º. It will provide a coverage of scales important for future CMB polarization probing experiments, like those in the framework of ESA Cosmic Vision 2015-2025 (Europe) and Einstein Probes programme (USA) allowing a better polarized foreground subtraction from large sky data sets obtained by experiments like the satellite Planck Surveyor and obviously contributing to the galactic structure knowledge.

GEM makes use of Cassegrain antennas with alt-azimuthal mountings and employs a similar scanning strategy to the one used for Planck Surveyor satellite. The antenna steady, slow azimuthal rotation of 1rpm at fixed elevation of 30º angle from zenith, combined with Earth rotation, permits a 60º sky band scan. This scanning strategy is quite useful to minimize the striping problems in the map-making process.

The GEM-P project uses a 9m antenna with ~30 arcmin resolution and will operate in central Portugal at latitude of ~40º allowing a good coverage of high galactic latitudes [5] (Fig. 1). North and south hemispheres templates will be merged resulting in an >80% sky coverage. For the long observational season, GEM-P will benefit from a carefully chosen site, where RFI contamination is absent in the working bands [5]. It will observe in a 200MHz bandwidth centred at 4.9GHz, a band protected after request to the Portuguese spectrum ruling board ANACOM.

Coupled to the corrugated feed, a receiver polarimeter with a novel high sensitivity design will provide I, Q and U Stokes parameters with absolute calibration down to a 0.5 mK sensitivity.

III. Optics

The GEM-P antenna is an adapted 9-meter high performance telecommunications from Vertex RSI , graciously offered by PT (Portuguese Telecom), originally intended for C-Band reception. The antenna optical specifications are presented in Table 1 and its overall expected performance is reflected by the parameters therein.

A. Feed design

To meet the more stringent requirements necessary to the high sensitive, a new feed horn – corrugated, silver coated, highly symmetric, with low polarization cross-talk - is being designed with Ansi HFSS to complete the optical configuration in accordance. Besides the optical requirements, the feed interface is meant to facilitate the receiver integration and access into the antenna hub.

Antenna	
Primary aperture	8.99 m
Primary depth	1.53 m
Secondary aperture	1.17 m
Secondary half-angle of illumination	18º
Surface rms	0.5 mm
Polarization	Circular
Beamwidth	~ 30 arcmin
Gain	~ 50 dB
G/T	~ 40 dB/K
Central Frequency	5GHz
Receiver Bandwidth	200MHz

Feed	
Sidelobe level	< -35dB
Cross-polarization	< -40dB
Insertion loss	< 0.05 dB

Table 1. *Antenna optical configuration and feed requirements.*

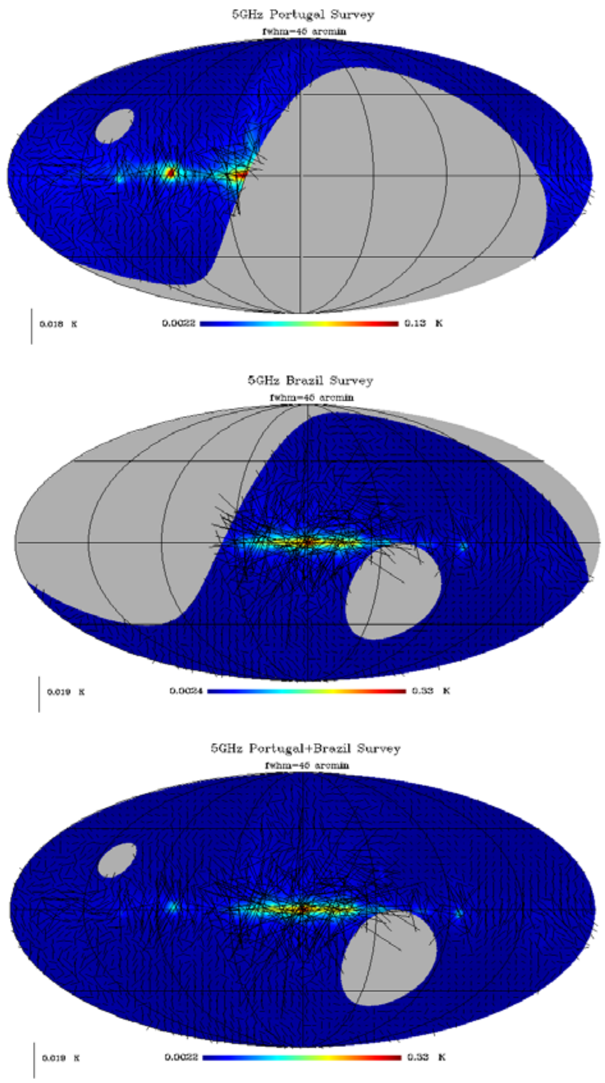

Fig. 1. Separated and combined north and south hemispheres templates simulations.

IV. Receiver

The GEM-P receiver currently developed is a high sensitivity double-arm super-heterodyne receiver (Fig. 2) with a base-band complex correlator. The incoming wave is decomposed through a circular OMT into two circular polarization components and then amplified, IF transformed and digitally correlated. The first amplification stage uses cryogenically cooled PHEMT preamplifiers from Mitsubishi. After frequency down-conversion to zero-IF intermediate frequency, each channel passes through a Phase and Quadrature Modulation, is digital converted by ADCs at 250 Msamples and is processed by an FPGA (Field Programmable Gate Array) based back-end correlator. The IF part and correlator will be contained in the usual stable and controlled temperature shield.

Details concerning receiver cryogenically cooled front-ends, IF section [4] and the FPGA based correlator will be published elsewhere.

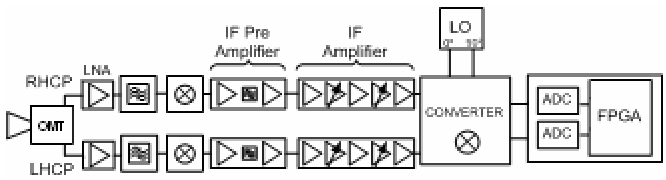

Fig. 2. Receiver overall block diagram.

A. *Receiver output*

The signal correlations are coded in to the FPGA and the I, Q and U Stokes parameters describing the signal polarization are calculated through the following expressions, where R and L means "right" and "left" receiver chains,

$$\text{Stokes U} \rightarrow RL = \Re e\left(E_{rcp} E_{lcp}^{*}\right) \tag{1}$$

$$\text{Stokes Q} \rightarrow LR = \Re e\left(E_{rcp,-\frac{\pi}{2}} E_{lcp}^{*}\right) \tag{2}$$

$$\text{Stokes I} \rightarrow RR + LL = \left\langle E_{rcp} E_{rcp}^{*}\right\rangle + \left\langle E_{lcp} E_{lcp}^{*}\right\rangle \tag{3}$$

B. *System noise temperature*

The relation between system sensitivity and integration time is given by [1], and described in equation 4. For the system parameters (Tsys<20K, B=200MHz), its instantaneous sensitivity is ~2 mK $s^{1/2}$

$$\Delta T = kT_{sys}\sqrt{\frac{1}{B\tau}} \tag{4}$$

$$T_{sys} = T_{ant} + T_{rec} \tag{5}$$

where k is √2 for our polarimeter. Having the bandwidth, B, already established, sensitivity is limited by system noise temperature, T_{sys} and integration time, τ. With these parameters, we will achieve a 0.5 mK in about 160 days.

C. Antenna noise temperature

To reduce the antenna noise temperature, we rely in two main factors, careful feed design to reduce sidelobes level, as mentioned previously, and a ground shield around antenna (Fig. 3). Ground shield will be made of aluminium mesh with the proper mesh size to attenuate ground pick up by at least 20dB. Design has been done by considering antenna pattern, mesh size, diffraction, angle and wind load [6]. Additionally, besides the antenna site being RFI clean [5], this shield will offer protection against eventual RFI signal lurking through the horizon. With this careful setup, we do expect an antenna temperature of ~10K.

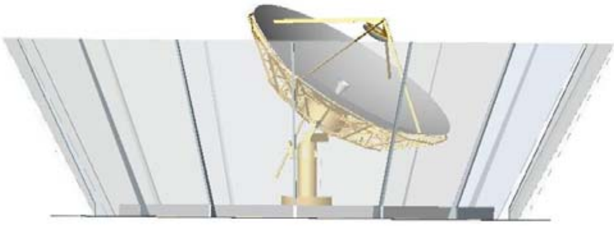

Fig. 3. GEM-P antenna and ground shield protection.

D. Receiver noise temperature

Receiver temperature, as in any cascading electronic chain, is largely influenced by the first receiver chain components noise temperatures and gains, accordingly to the expression [1],

$$T_{rec} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \frac{T_4}{G_1 G_2 G_3} + \dots \qquad (6)$$

For this purpose, the front end PHEMT preamplifiers will be cryogenically cooled to ~70K by means of a cryocooler, obtaining a ~4K of noise temperature. Insertion loss control in feed, waveguide polarizer and connections to preamplifiers will be of prime importance. With all this, receiver noise budget is accounted to be ~12K.

V. Mechanical Design

The original antenna pedestal, - by definition, intended for geosynchronous communications and thus movement limited to a small azimuth angle - didn't allow full rotation as demanded for GEM survey. As such, a new design was in demand for a fast scanning strategy. This strategy – fast rotation at ~1rpm – minimizes both *1/f* noise influence from the HEMT 1st-stage LNAs and minimizes atmospheric fluctuations during a circular scan (atmosphere H_2O vapour fluctuations have a typical timescale of <10 min.). New design is limited by certain requirements that need to be satisfied and which mainly concern: survey operational winds, pointing accuracy and rotation constancy form a 3ton-antenna in a fast rotation, and above all mechanical resistance to severe conditions.

A. Pedestal

The new pedestal design is shown in Fig. 4. In brief, the pedestal stands over a bearing and its rotation is obtained by a 1.1KW motor-reducer to the gear common with the pedestal by means of a pinion, in a total of 1000:1 transmission ratio.

To assure a stable and high precision 1rpm rotation speed, low backlash and stable motor speed is requested. Low backlash is met by using an intermeshing of 3 teeth between gear and pinion and a gear ratio of 1:100, in addition to this, a motor-reducer compliant with this need was chosen. The motor speed control is obtained by using a VFD (variable frequency driver). For the elevation, the original elevation motor was kept and the same VFD set is used for it's control. A slip-ring at the azimuth axis guarantees the signals connection between rotating and fixed sides.

Additionally, protection of electronics and precision mechanical parts against static charges and induced electric currents arising from an eventual lightning discharge in the vicinity was accounted for, by diverging currents away from sensitive components with proper choice of materials and paths.

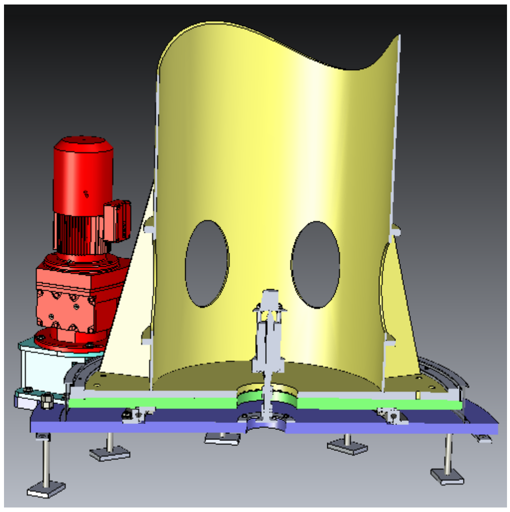

Fig. 4. GEM-P pedestal base modification.

B. Precision Requirements

Azimuth and elevation position are both measured by 17 bits encoders, which guaranties the pointing accuracy of 1 arc min and also rotation speed measurement and control.

The pointing precision will be conditioned by the antenna resolution for the highest operating frequency that will be used, 10GHz. The minimum demanded is 1/10 of the antenna resolution, which is 1.4 arcmin and a value of 1 arcmin was chosen for this purpose. This accuracy is dependent of pedestal mechanical response to wind load, which implies a boundary for antenna operation with full requirements. A computer analysis was done and results guarantee that within full requirements, operational winds will be of at least 20 Km/h for 10GHz and 25 Km/h for 5GHz. Also with dish in horizontal position, the structure will stand at least 160 Km/h without suffering any inelastic distortion.

Pointing accuracy	1 arc min
Azimuth travel	0º-360º
Elevation travel	35º-90º
Operational winds	≥ 20 Km/h
Survival winds	> 160 Km/h

Table 2. Pedestal specifications.

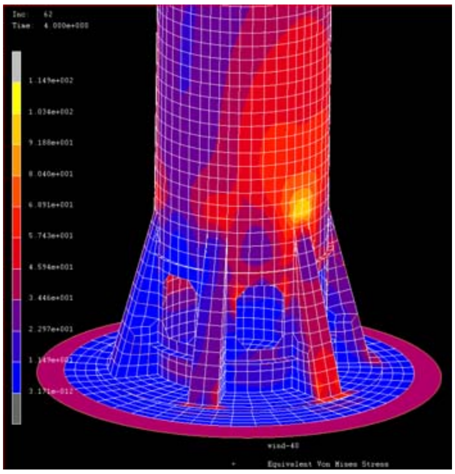

Fig. 5. Von Mises stress simulations for 40 Km/h wind speed load.

VI. SUMMARY

The study of the cosmic background and the associated polarimetric measurements at 5GHz for the galactic emission mapping led us to develop a novel instrument with all polarimetric measurements being performed in the digital domain. In order to achieve this objective, a super-heterodyne receiver with a digital baseband complex correlation polarimeter is being developed. Additionally, studies and modifications to the original antenna optics, mechanics and control where in demand to achieve the requirements needed for that purpose, as well as observational site preparation to receive the GEM-P antenna.

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