An Atlantic Network of Geodynamical and Space Stations
The RAEGE Project

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Abstract The National Geographic Institute (IGN) of Spain and the government of the autonomous region of Açores (Portugal) are jointly deploying an "Atlantic Network of Geodynamical and Space Stations" (project RAEGE). The first two radio telescopes of RAEGE were finished in Yebes (Spain) and Santa María (Açores islands, Portugal). The network will be completed with two additional stations on Tenerife (Canary Islands) and Flores (Açores). The RAEGE radio telescopes are of VGOS kind: azimuth/elevation turning head telescopes, reaching azimuth and elevation slew speeds of 12°/s and 6°/s, respectively. The optical design is based on a 13.2-m ring focus reflector. In its basic configuration, the observation frequency is in the range of 2–40 GHz. It can be enhanced up to 100 GHz by using additional options. First light at the Yebes radio telescope was achieved on February 9, 2014 on the tri-band receiver (S/X and Ka bands) developed at the laboratories at the Yebes Observatory. The RAEGE Santa María site will be in full swing in early 2015. The infrastructure project of RAEGE in Santa María includes the construction of the main control building, access roads, and a power distribution building scheduled for summer 2014. The Santa María site will include a completely isolated gravimetry pavilion, buried in a small hill, on top of which a permanent GNSS station will be installed. The Tenerife and Flores stations are scheduled for 2016. They also include new radio telescopes, permanent GNSS receivers, and gravimeter stations.

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2. IGN Yebes Observatory
3. DSCIG Açores

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1 Introduction

The deployment of an Atlantic Network of Geodynamical and Space Stations (RAEGE, for "Red Atlántica de Estaciones Geodinámicas y Espaciales") consists of the construction of four Fundamental Geodetic Stations, in Yebes (Guadalajara, Spain), Tenerife (Canary Islands, Spain), and Santa María and Flores (Açores Islands, Portugal). Each RAEGE station is to be equipped with a VGOS-kind radio telescope, a permanent GNSS receiver, a gravimeter, and (at least at Yebes) an SLR instrument. The construction of the RAEGE station in Yebes is very advanced, since the VGOS 13.2-m radio telescope is already in place and first-light was obtained; therefore it is expected that it will start operations for IVS in the summer of 2014. The RAEGE station in Santa María (Açores) is progressing well; the radio telescope is erected, and the control and auxiliary buildings are being finalized. Once the receiver is installed, commissioning will start in order to become operational early in 2015.

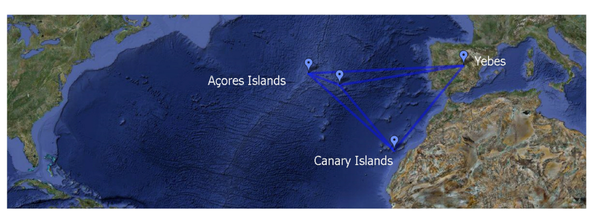

Fig. 1 Location of the RAEGE stations.

2 The RAEGE Radio Telescope

The RAEGE radio telescopes follow the specifications for VGOS: azimuth/elevation turning head telescopes, with maximum azimuth and elevation slew speeds of 12°/s and 6°/s, respectively. The optical design is based on a 13.2-m ring focus reflector.

These radio telescopes were built under the supervision of MT Mechatronics. The concrete pedestal, which hosts an inner independent concrete pillar, is built by a local construction company. The mechanical elements are built by the Spanish company Asturfeito (following their design for the ALMA telescopes in Chile), and the reflector panels are provided by the Italian company COSPAL.

Fig. 2 The RAEGE VGOS radio telescope “Jorge Juan” at Yebes, Spain. At the back, the IGN 40-m radio telescope which is currently a network station in IVS.

3 RAEGE Receivers

The RAEGE radio telescopes in Yebes and Santa María are being equipped with cryogenic high-performance receivers of the S, X, and Ka bands (see Figure 5 and the paper by López-Fernández et al., in this volume).

IGN engineers at the Yebes Observatory are developing a VGOS broadband receiver. Low-noise amplifiers have been successfully developed at the Yebes laboratories for the 4–8 and 4–12 GHz bands, and research on broadband feeds is progressing (see the paper by López–Fernández et al., in this volume).

Table 1 RAEGE instrumentation parameters.

Parameter	Value	
RT Diameter	13.2 m	
Optics	Ring focus	
Surface RMS	180 μm	
Designer	MT Mechatronics GmbH	
Az/El slew speed	12°/sec / 6°/sec	
Receivers	triband (S, X, Ka)	
	dual pol (RCP+LCP)	
Band	Frequency (GHz)	Trec (K)
S band	2.2–2.7	21
X band	7.5–9.0	23
Ka band	28–33	25
DBBC type	European DBBC (IRA/INAF)	
Recorder	Mark 5B+/Mark 5C	
Yebes connectivity	10 Gbit/s fiber	

Fig. 3 The RAEGE VGOS radio telescope in Santa María, Açores Islands.

4 Other Instrumentation and Works Towards the Observatory Local-tie

4.1 GNSS

IGN has developed and maintained since 1998 a network of 41 permanent GNSS stations in Spain (ERGNSS), 20 of them included in EUREF. Two of these stations are part of the International GNSS Service (IGS): Yebes Observatory (YEBE) and La Palma (in Canary Islands, LPAL). IGN has also been a local Analysis Center for EUREF (known as IGE) since 2001 and processes the data of 50 stations in

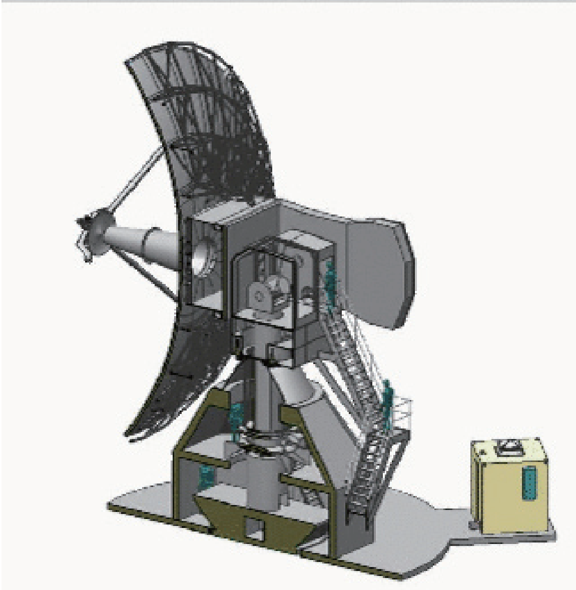

Fig. 4 Design of the RAEGE VGOS radio telescopes by MT Mechatronics (Germany).

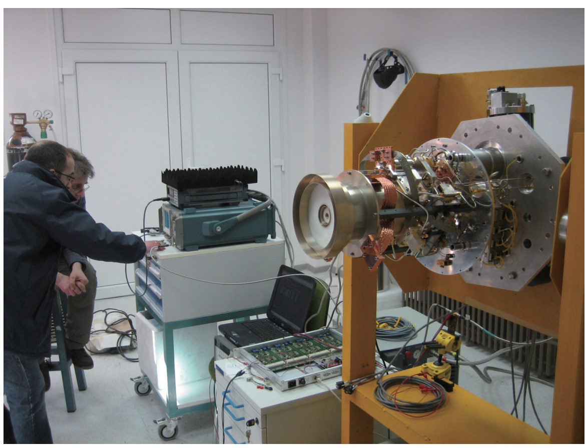

Fig. 5 Tri-band (S/X/Ka) receiver for RAEGE radio telescopes, designed and built at the IGN Yebes Observatory.

Spain, Portugal, Morocco, France, Italy, and Great Britain.

4.2 Gravimeter

IGN Yebes Observatory hosts a state-of-the-art gravimetry pavillion, allowing very controlled thermal behavior (double chamber with air conditioning system in the external one) and structural behavior (isolated concrete pillars). Specially designed to host gravimeters given the high sensitivity of these instruments, it is offered for regional AG comparisons (RICAGs) for up to six instruments. The laboratory hosts a GWR Superconducting Gravimeter (permanently installed)[4], and also available (but not always installed because they participate in different measurement projects) are an FG5 absolute gravimeter [3], an A10 absolute gravimeter, an L&R (LaCoste and Romberg) relative gravimeter, gPhone, Scintrex, etc. An artistic view of the gravimeter pavillion can be seen in the 2011 IGN annual report to IVS.

4.3 Satellite Laser Ranging

We have started studies aimed towards the construction of an SLR facility at the Yebes Observatory. Due to the current trends in the new SLR stations and the GGOS project, the future Laser Ranging Station at Yebes (CYLAR, Cdt Yebes LAser Ranging) should fulfill the main characteristics of the Next Generation Systems: low energy laser (taking into account the possibility of participating in one-way ranging and transponder experiments), high repetition rate (1000 to 2000 Hz), few picoseconds (ps) pulse width, pico event timer, single photon detection (CSPAD or APD detector) and high automation. The station should have the capacity to observe all satellites, from 400 to 24,000 km (navigation satellites: GPS, GLONASS, Compass, and Galileo). Other characteristics would be a lightweight biaxial Cassegrain-Coudé telescope for laser pulse transmission and reception ($\sim$ 50 cm and 10 cm respectively), Nd:YAG laser (532 nm), night and day operation, and air traffic protection, compatible with other activities at the observatory (VGOS and 40-m radio telescope). See Vaquero-Jiménez and López-Fernández (2011) for details [2].

4.4 Measurement of the Invariant Reference Point of the RAEGE Radio Telescope at the Yebes Observatory

The position of the invariant reference point (IRP) is very important in the determination of the local tie, which connects all the geodetic techniques in an observatory[1,5]. It is defined as the intersection between the azimuth axis and the elevation axis of a radio telescope if this intersection exists. Otherwise it is defined as the projection of the elevation axis on the azimuth axis. Usually this point is inaccessible or it is not materialized. There are several methodologies for calculating it [6,7]. The most classic method, which we have used, is based on the adjustment from measurements points on the radio telescope frame under circles in 3D constrictions. In this model, the radio telescope is rotated around one of its axes keeping the other one fixed; thereby the track of each target describes a circle. This process is repeated for different orientations of the radio telescope and for both axes. The details and measurement results are described in Appendix A.

5 Conclusions

The RAEGE network is being deployed, with important developments in infrastructures and instrumentation. The first VGOS antenna, in Yebes (Spain), will be operational for the IVS already in 2014 with a triband (S/X/Ka) receiver. Other developments towards a complete broadband system are underway and are described in other papers by the IGN team in this volume.

Appendix A: Measurements of the IRP at the RAEGE Radio Telescope at Yebes

The measurements at the 13-meter RAEGE radio telescope at the Yebes Observatory were performed inside the cabin with a Leica TS30 robotic total station, with an angular and distance accuracy of 0.5 and 0.6 mm respectively, located on the central pillar of the radio telescope pedestal. To do this, a tripod with optical plummet tribrach was established over the marked centered screw of the pillar. A measurement was taken of the position of a corner cube reflector “RRR Hexagon” with a manufacturing precision of 0.0001 mm, which was attached magnetically to the inner sides of both antenna counterweights. Measurements of the reflector (CCR) were taken every 30 seconds for the right counterweight by moving the antenna around the elevation and azimuth axis. The movement of the antenna taken in azimuth and elevation was performed in increments of 20^o. The sequence of actions were carried out by fixing one azimuth out of 18 possible azimuths and moving the telescope to five elevation positions (7^o, 27^o, 47^o, 67^o, 87^o). Then the azimuth angle was increased by 20^o and the procedure was done again but decreasing the elevation angle from 87^o to 7^o. The previous steps were repeated but placing the CCR at the left counterweight. A total of 180 (18*5*2) points were measured every 30 seconds, resulting in an automated observation of 90 minute duration. For each counterweight, it was possible to adjust five azimuth circles and 18 elevation arcs. For both counterweights, a total of ten azimuth circles and 36 elevation arcs were adjusted. From this, the 18 elevations axes were calculated.

The TS30 station was controlled by a laptop connected via Bluetooth, running software made by the observatory staff that handled the tasks of orientating, targeting, measuring, recording, and synchronization with the control center of the antenna.

The determination of the IRP for both the azimuth and the elevation axes was performed by adjusting the observation data with a Mixed Model Least Squares with constraints.

In the case of the azimuth axis, observations to the targets on the rotation of the radio telescope around the azimuth axis for different elevations were taken. Observations have been adjusted to circles in space, that is, the intersection of a sphere and a plane. Also, the center of the sphere must satisfy the plane equation. In this adjustment, the parameters for each sphere (center and radius) and for each plane were determined. A total of five circles for each counterweight (ten in total) were adjusted. Each circle was adjusted from 18 observed points. 52 parameters were adjusted from 360 observation equations.

In the case of the elevation axes, observations to the targets on the rotation of the radio telescope around the elevation axes for different azimuths were taken. Observations had to be adjusted to circular arcs in space. For each azimuth, measurements for both counterweights were done. Centers from both circular arcs generated the elevation axes. A total of 18 circular arcs for each counterweight (36 circular arcs in total) and 18 elevation axes were adjusted.

The obtained accuracy is below one millimeter, so we are in the required range to be able to relate the different available geodetic techniques in the observatory in the future by the local tie vector.

Table 2 Results from the measurements of the Yebes RAEGE radio telescope Invariant Reference Point.

	Value			Standard deviation		
IRP coordinates (m)	99.99774	199.99226	301.314795	0.00005	0.00005	0.000014
Eccentricity	0.000127			0.000074		
Azimuth axis inclination from the vertical ($''$)	-8.326001			0.320035		
Non-orthogonality angle between azimuth and elevation axes ($''$)	5.589358			0.901273		

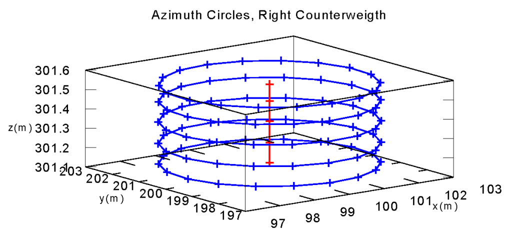

Fig. 6 Azimuth adjustments for the Yebes 13-m radio telescope IRP.

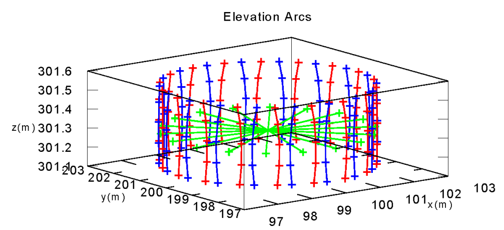

Fig. 7 Elevation adjustments for the Yebes 13-m radio telescope IRP.

Fig. 8 Robotic Total Station Leica TS-30 set up above the RAEGE radio telescope central pillar.

References

1. A. Santamaría-Gómez, S. García-Espada, "Simulating the estimation of the 40m radio telescope Invariant Reference Point at the Yebes observatory", IGN Yebes technical report CDT 2011-9
2. B. Vaquero-Jiménez, J. A. López-Fernández, "CYLAR Specifications (CDT Yebes Laser Ranging)", IGN Yebes technical report CDT 2011-11
3. J. M. Serna, P. Vaquero, S. Sainz-Maza, M. Calvo, B. Córdoba, J. López, C. López, J. A. López–Fernández, "FG5 Absolute Gravimeter", IGN Yebes technical report CDT 2012-1
4. J. M. Serna, B. Córdoba, J. López, M. Calvo, C. López, J. A. López–Fernández, P. Vaquero, S. Sainz-Maza, "Observatory Superconducting Gravimeter", IGN Yebes technical report CDT 2012-2
5. J. Dawson, P. Sardi, G. M. Johnston, L. Vittuari, "Indirect approach to invariant point determination for SLR and VLBI systems: an assessment", J. Geody. 81, 433-441, 2007
6. K. Fancher, D. Smith, S. Breidenbach, J. Olsen, N. Paudel, "Recent IERS Site Survey of Multiple Co-located Geodetic Techniques by NGS", in FIG Congress 2010, Facing the challenges- Building the Capacity, 2010
7. P. Starti, P. Sillard, L. Vittuari, "Surveying co-located space-geodetic instrument for ITRF computation", Journal of Geodesy, 78, 210-222, 2004