SPOrt: a Project for Radio Polarimetry from the International Space Station

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Abstract. The Sky Polarization Observatory (SPOrt) program is aimed at making the most sensitive polarization measurements attempted so far, from the International Space Station. SPOrt scientific goals include the first polarization map of the Galaxy at 22, 32 and 60 GHz as well as full sky measurements in the so called *cosmological window* (90 GHz) at unprecedently high sensitivity. The expected pixel sensitivity, in fact, ranges from 5 to 10 μK with FWHM = 7°. The SPOrt payload has been designed expressly both to reduce sources of unwanted spurious polarization and to make easier the removal of residual systematic, taking into account constraints due to the accommodation on International Space Station External Payload Adapters. SPOrt has been selected by the European Space Agency to fly for 18 months (2003-2004), during Early Phase Scientific Utilization of the International Space Station, and will be realized in Italy with the support of the Italian Space Agency, under the responsibility of I.Te.S.R.E.-CNR. The scope of this contribution is to focus the attention on most recent SPOrt development activities.

INTRODUCTION

The Sky Polarization Observatory (SPOrt) is the first instrument expressly designed to make polarimetric observation of both Galactic and extra-Galactic emission in the unexplored 20-90 GHz range (Cortiglioni, 1999a). The International Space Station (ISS) provides the first possibility to perform such new measurements from space, out of the noisy Earth atmosphere. Although the ISS environment is not the best one to attain the limiting performances allowed by the SPOrt instrumental configuration, in our view science is calling now for such measurements, and several experiments are carrying on observations of the Cosmic Microwave Background (CMB) with potential sensitivities to the CMB anisotropy which may be limited by the poor knowledge of the Galactic foreground *polarized* emission (Cortiglioni, 1995). The expected sensitivities of MAP-NASA and the Planck-ESA missions (which will fly in 2001 and 2007 respectively) will allow putting scientific milestones, but no experiment has been specifically designed to observe polarization in the 20-90 GHz region. In this scenario we expect SPOrt to play a complementary role with respect to CMB anisotropy measurements, as well as to exploit new techniques for higher sensitivity polarimetry in the future.

The scientific aims of the Program have been discussed in Fabbri (1999), where it is shown that CMB polarization can be measured or significantly constrained by the higher frequency channels. The detection of CMB polarization would provide important information on cosmological parameters like the duration of the hydrogen recombination, the baryon density Ω_b and the secondary ionization redshift z_{ion}, and on the nature of primordial perturbations as well. Large-scale polarization is enhanced by a significant secondary ionization, which in current models (where τ_{ion}, the optical depth of the cosmic medium reionized by primordial mini-galaxy stars or mini-QSO's, is less than unity) produces a broad local maximum around the angular scale $\theta \sim 90°/z_{ion}^{1/2}$ (see e.g., Haiman, 1999). Thus a better understanding of the thermal history of the Universe, and in particular of the properties of cosmic matter at intermediate redshifts $z \sim 10\text{-}10^2$ can be achieved through direct measurements of the CMB residual polarization with SPOrt beamwidth of 7°. According to such standard modelling, however, the optical depth τ_{ion} is rather small, as confirmed by recent simulations (see Ciardi, 1999, and references therein). The CMB linear polarization being proportional to τ_{ion}, should be accordingly small. At the above angular scale is expected to be ≤ 5% of the rms anisotropy (about 30 μK as detected by COBE-DMR), so that a significant experimental result can be achieved with full sky sensitivity of the order of 1 μK or better. Such sensitivities require long integration times with state of the art technologies (Low Noise Receivers), but also a very efficient design aimed at lowering systematics as well as optimizing residuals removal. It is also crucially important to discriminate non-cosmological signals. SPOrt lower frequency channels are in fact devoted to the other basic goal of the Program, i.e. the detection of the Galactic polarized foreground. This is generally expected to be dominated by synchrotron (except for SPOrt highest frequency) by extrapolation of low-frequency maps (Brouw, 1976). The situation however is not clear. According to recent calculations (Draine, 1998), non-thermal emission from rotating dust grains may be important and possibly dominate synchrotron at those frequencies ≥ 20 GHz where thermal dust emission itself does not dominate. The cosmological window would then be defined by the minimum dust emission around 60-80 GHz. In has been noted (Lopez-Corridoira, 1999) that the models of Draine & Lazarian may imply a substantial contamination of COBE-DMR data not recognized so far and provides some pieces of evidence for this; perhaps some support to this view may also come from the North-Galactic localization of non-Gaussian signals in COBE-DMR (Magueijo, 1999). It is then urgent to check whether the sky distribution of polarized signals at 22 and 32 GHz is consistent with the low-frequency synchrotron maps.

THE EXPERIMENTAL APPROACH

Two main guidelines drove the SPOrt experimental layout:
- optimization of polarimetric performances
- accommodation on the ISS External Payload Adapter (ExPA)

Phase A and A-B Bridging have substantially confirmed the original design of the radiometric part (FIGURE 1), but they emphasized the need of more detailed studies in some critical areas:
- System Noise
- Antenna System (AS)
- Cooling System (CS)
- Overall System Stability (OSS)

targeted to find best solutions for design optimization. The OSS is absolutely needed when long integration times are requested in order to improve the rms noise of the instrument, which is the "conditio sine qua non" to detect signal as small as those expected from the microwave sky.

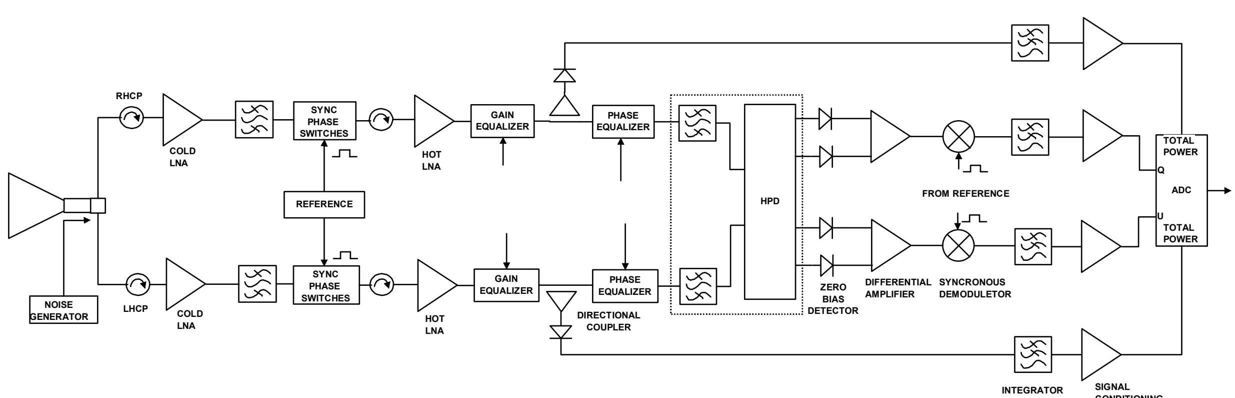

FIGURE 1. Schematic block diagram of a SPOrt channel.

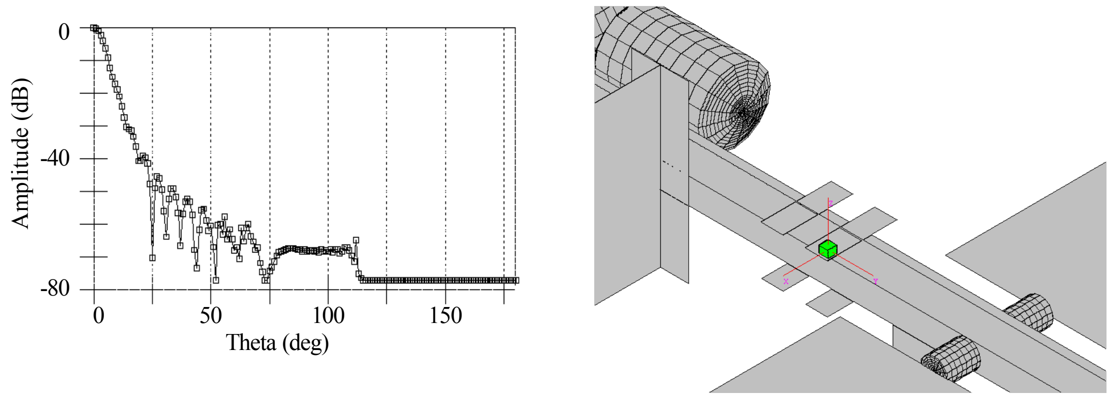

FIGURE 2. An example of the pattern for one of the SPOrt antennas in free space (left) and the SPOrt payload location on the ISS (right).

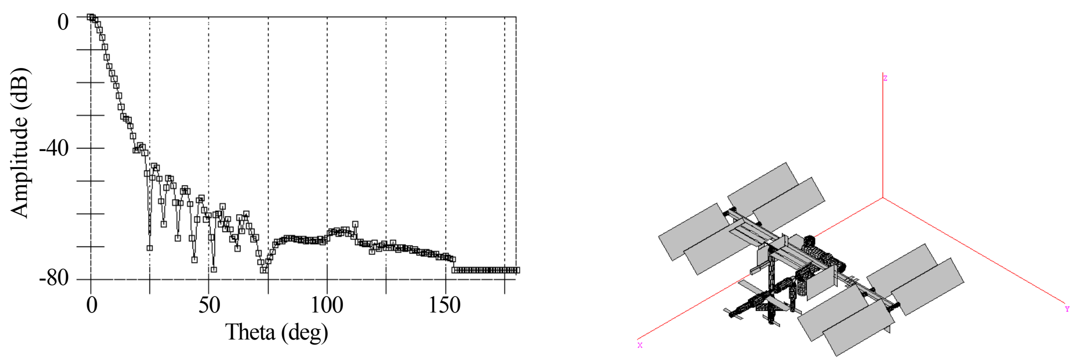

FIGURE 3. An example of the resulting pattern for one of the SPOrt antennas (left) when ISS structures (right) are taken into account.

Another important problem has been faced by the SPOrt Team: the impact of the ISS structures (including onboard RF transmitters) on the performances of the SPOrt payload. Preliminary results of such an investigation show that ISS structures impact on the SPOrt antennas would not be so dramatic, so that the conservative estimate of 50% efficiency (50% of data rejection) which has been taken into account for predicting SPOrt results must be considered as the worst case, liable to increase. FIGURE 2 and FIGURE 3 show examples of the ISS model considered for simulations as well as examples of resulting antenna pattern (Gutierrez, 1999).

The System Noise

The instantaneous sensitivity, that is the rms noise in one second, depends on the System Noise. Anyway, the SPOrt final sensitivity is only virtually depending on this value because the true sensitivity for a real two channel Correlation Polarimeter is represented by the formula:

$$\Delta T_{rms} = \sqrt{\frac{k \cdot T_{sys}^2}{B \cdot \tau} + T_{offset}^2 \cdot \left(\frac{\Delta G}{G}\right)^2 + \Delta T_{offset}^2} \quad , \tag{1}$$

where T_{sys} is the overall System Noise Temperature, B is the bandwidth, τ is the integration time, k is a constant depending on receiver features, T_{offset} and ΔT_{offset} are the contribution due to the real correlation offset (see next section) and its fluctuation respectively, $(\Delta G/G)$ represents system gain fluctuations. System Noise Temperature of few tens of Kelvin are required to match the SPOrt specifications as well as bandwidths of the order of 10 %. This is possible using state of the art Low Noise Amplifiers (LNA), already available, based on cooled MMIC (HEMT) devices. SPOrt plans to use such LNA in its RF Subsystem as it will be realized by the TRW (USA) industry. The System Noise Temperature, however, depends on the LNA noise temperature only for a 40-60 % (depending on the frequency), being the rest due to the contribution from the AS.

The Antenna System

A set of four corrugated feed horns (FWHM=7°) represents the SPOrt eye towards the sky, each of them is followed by both a circular polarizer and an Orthomode Transducer (OMT). The role of such an AS is to provide two circular components to be correlated to obtain instantaneously Q and U Stokes parameters. From the instrumental point of view, the lower is the spurious correlation introduced by the AS the better will be the measure. The cross polarization of the AS must be taken as low as possible because it affects the accuracy on measured Q and U, even though another parameter would assume a key role because of its impact on the overall stability: the offset internally generated by the AS, hereafter the Spurious Polarization (SP).

Spurious Polarization

The offset produced by SPOrt polarimeters is generated both at AS level and receiver level. The lock-in loop (see FIGURE 1) allows to reduce the cross contamination due to components within the loop itself (Monari, 1999), so the most important contribution to SP comes from the AS. It can be seen (Carretti, 1999) that in this case the offset due to SP may be approximated to:

$$T_{offset} \approx C \cdot \left(T_A - T_{env}^{AS}\right) \quad . \tag{2}$$

In this equation T_A and T_{env}^{AS} are the antenna temperature and the Antenna System physical temperature respectively, while C is a coefficient depending on AS features that in the SPOrt case takes the value $C \approx 10^{-3}$. This approximated expression for T_{offset} is valid for the SPOrt AS current design, which has been optimized by using customized components developed within the SPOrt industrial consortium. For an extended discussion about problems related to SP in extremely sensitive polarimetric measurements see Carretti (1999). By considering this result, two main actions have been taken by the SPOrt Team in order to face the effects of T_{offset} on eq. 1: i) SP minimization and ii) SP stabilization. These actions would be achieved by cooling down to 80 K both the polarizer and the orthomode transducer and to keep their temperature stable at level of $\pm$ 0.1 K or better.

The Cooling System

The SPOrt Cooling System has been designed mainly taking into account constraints from the ISS. No cooling liquids or gases are allowed onboard ISS ExPA, so the choice was to adopt mechanical cryo-coolers based on Sterling process. A set of miniaturized cryo-coolers (RICOR K508, FIGURE 4), one for each channel, will provide to

dissipate ≈2 W at about 80 (±0.1 K), and will guarantee the needed temperature stability to the SPOrt cold section during 18 months lifetime.
Ongoing tests show that available cooling power should be enough to allow cooling of both the polarizer and the OMT for all four SPOrt channels, with accuracy better than the one expected (< ± 0.1 K). The temperature stabilization of the AS is extremely important to keep ΔT_{offset} at reasonable level.

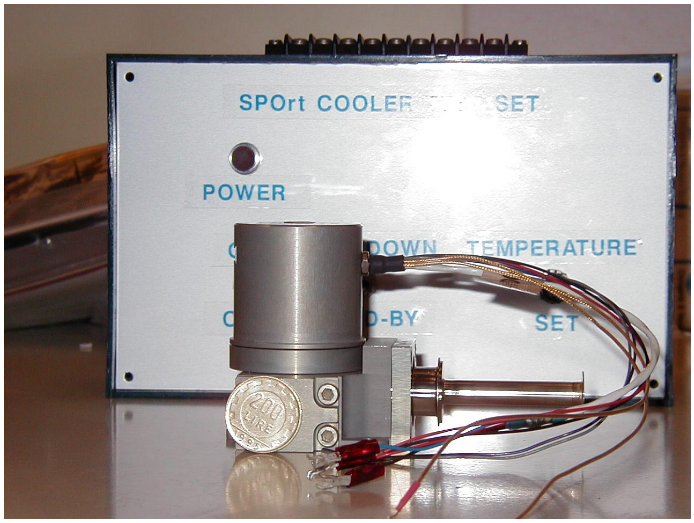

FIGURE 4. One of the SPOrt cryo-coolers.

Overall System Stability

The Overall System Stability is the needed base for residual systematics removal during off line analysis. These residual, in fact, represent the errors which will affect measurements. OSS must be sufficient to allow removing techniques based on:

a) Internal calibration source: the SPOrt design foresees the injection of a calibrated polarized signal into the AS, between the polarizer and the OMT. It will allow gain variation monitoring of the RF subsystem.
b) Destriping techniques: since different orbits will cross each other, it would be possible to remove gain drifts whose time scale is longer than the Orbit Time (Delabrouille, 1998; Wright, 1996).
c) Global fit of time ordered data: it is based on the knowledge of relationships between output signal variation and housekeeping parameters. Time ordered data are fitted leaving as free parameters both values of the function parameters and the real signal from the sky (Janssen, 1992; Kogut, 1992).

Moreover assuming that:

a) There are many uncertainties about the ISS pointing stability/recognition at ExPA location (Treder, 1999).
b) Pointing recognition errors larger than 0.5° may compromise seriously the SPOrt performances

the SPOrt Team is considering to adopt the AMICA (Astro Mapper for Instrument Check of Attitude) Star Mapper (see Trampus, 2000).

Unfortunately there is no room to include AMICA inside the SPOrt box, so both ESA and NASA would be asked to support the accommodation of AMICA somewhere else, on the same ExPA of SPOrt. In such a way AMICA would provide useful data not only for SPOrt but rather to all payload to the same ExPA. Moreover it can be expected data from AMICA to be used both to monitor ISS structure deformation and to provide additional data on the ISS attitude.

CONCLUSIONS

As it has been anticipated at last STAIF-99 Symposium (Cortiglioni, 1999b) SPOrt represents a real opportunity to put both good science and challenging technology onboard the International Space Station. Following the philosophy of "better, cheaper and faster", which is proper of design to cost payloads, SPOrt is going ahead to match the deadline for payload delivery to ESA and NASA in November 2001 (launch on early 2003). Unfortunately the lack of precise information about the ISS status during SPOrt lifetime (which ISS structures will be present, which RF transmitters will be operating, ...) does not allow either more precise simulations or best optimizations for the SPOrt design. Also problems related to the accuracy of pointing recognition at ExPA locations, which are still open, have to be solved in order to allow SPOrt to be successful.

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REFERENCES

Brouw, W.N., Spoelstra, T.A., "Linear Polarization of the Galactic Background at Frequencies between 408 and 1411 MHz Reductions," Astron. Astrophys. Suppl. **26**, 129-146 (1976)

Carretti, E., Orsini, M., Monari, J., Tascone, R., Cortiglioni, S., Orfei, A., "Instrumental Polarization of Antenna System for the SPOrt Experiment," *I.Te.S.R.E./CNR Internal Report #238/99, I.R.A./CNR Internal Report #277/99* (1999)

Ciardi, B., Ferrara, A., Governato F., Jenkins, A., "Inhomogeneous Reionization Regulated by Radiative and Stellar Feedbacks," *preprint astro-ph/9907189* (1999)

Cortiglioni, S., Cecchini, S., Carretti, E., Orsini, M., Fabbri, R., Boella, G., Sironi, G., Monari, J., Orfei, A., Tascone, R., Pisani, U., Ng, K. W., Nicastro, L., Popa, L., Strukov, I. A. and Sazhin, M.V., "The SPOrt Project: an Experimental Overview," in *3 K Cosmology EC-TMR Conference*, edited by L. Maiani et al., AIP Conference Proceedings 476, American Institute of Physics, New York, 1999a, pp. 186-193

Cortiglioni, S., Cecchini, S., Orsini, M., Boella, G., Gervasi, M., Sironi, G., Fabbri, R., Monari, J., Orfei, A., Ng, K. W., Nicastro, L., Pisani, U., Tascone, R., Popa, L. and Strukov, I.A., "The SPOrt Mission On ISSA," in *Space Technology and Applications International Forum-1999*, edited by Mohamed El-Genk, AIP Conference Proceedings 458, American Institute of Physics, New York, 1999b, pp. 294-298

Cortiglioni, S. and Spoelstra, T.A.Th., "The limitations of cosmic-microwave-background measurements due to linear polarization of galactic radio emission," *Astron. Astrophys.* **302**, 1-8 (1995)

Delabrouille, J., "Analysis of the Accuracy of a Destriping Method for Future Cosmic Microwave Background Mapping with the PLANCK SURVEYOR Satellite," *Astron. Astrophys. Suppl. Ser.* **127**, pp. 555-567 (1998)

Draine B.T., Lazarian, A., "Diffuse Galactic emission from spinning dust grains," *ApJ*, **494**, L19-L22 (1998)

Fabbri, R., Cortiglioni, S., Cecchini, S., Orsini, M., Carretti, E., Boella, G., Sironi, G., Monari, J., Orfei, A., Tascone, R., Pisani, U., Ng, K. W., Nicastro, L., Popa, L., Strukov, I. A. and Sazhin, M. V., "The SPOrt Project: Cosmological and Astrophysical Goals," in *3 K Cosmology EC-TMR Conference*, edited by L. Maiani et al., AIP Conference Proceedings 476, American Institute of Physics, New York, 1999, pp. 194-203

Gutierrez, O., Saez de Adana, F., Gonzalez, I., Catedra, M. F., "Study of the impact of structures on the very sensitive antenna patterns of SPOrt radiometers," *Technical Report* (1999)

Haiman Z., Knox, L., "Reionization of the intergalactic medium and its effect on the CMB," *preprint astro-ph/9902311* (1999)

Janssen, M. A and Gulkis, S., "Mapping the Sky with the COBE Differential Microwave Radiometers," *in The Infrared and Submillimetre Sky after COBE*, edited by M. Signore and C. Dupraz, Kluwer Academic Publishers, the Netherlands, 1992, pp. 391-408

Kogut, A., Smoot, G. F., Bennett, E. L., Wright, E. L., Aymon, J., de Amici, G.,Hinshaw, G., Jackson, P. D., Kaita, E., Keegstra, P., Lineweaver, C., Loewenstein, K., Rokke, L., Tenorio, L., Boggess, N. W., Cheng, E. S., Gulkis, S., Hauser, M. G., Janssen, M. A., Kelsall, T., Mather, J. C., Meyer, S., Moseley, S. H., Murdock, T. L., Shafer, R. A., Silverberg, R. F., Weiss, R., Wilkinson, D. T., "COBE Differential Microwave Radiometers - Preliminary Systematic Error Analysis," *Ap. J.* **401**, p. 1-18

Lopez-Corridoira, M., "A conspicuous increase of Galactic contamination over CMBR anisotropies at large angular scales," *preprint astro-ph/9903460* (1999)

Magueijo, J., Ferreira, P. G., Gorski, K. M., "Where is the COBE maps non-Gaussianity?," *preprint astro-ph/9903051* (1999)

Monari, J., Carretti, E., Orsini, M., Orfei, A., Cortiglioni, S., "SPOrt Polarimeter Output Contamination," *I.Te.S.R.E./CNR Internal Report #234/99, I.R.A./CNR Internal Report #276/99* (1999)

Trampus, P., Stalio, R., Cortiglioni, S., "AMICA, Astro Mapper for Instrument Check of Attitude," *This Conference* (2000)

Treder, A. J., "Space Station GN&C Overview for Payloads," *in Space Technology and Applications International Forum-1999*, edited by Mohamed El-Genk, AIP Conference Proceedings 458, American Institute of Physics, New York, 1999, pp. 49-57

Wright, E. L., "Scanning and Mapping Strategies for CMB Experiments," *preprint astro-ph/9612006*