System-on-Chip Millimeter-wave Radiometers for Space-based Detection of Solar Flares

Final Report Summary - FLARES (System-on-Chip Millimeter-wave Radiometers for Space-based Detection of Solar Flares)

FLARES: final publishable summary report (MAX 2 pages)

The objective of the EU funded (FP7-PEOPLE-2013-IEF Grant No. 625907) Marie Curie intra-European fellowship research project FLARES has been the study, analysis, design, development and experimental characterization of millimeter-wave (mm-waves) system-on-a-chip (SoC) radiometers for spaceborne detection of solar flares. The proposed approach has contributed to reduce significantly the power consumption and weight with respect to the existing instruments for the observation and study of solar flares. The project has been carried out by Dr. Luca Aluigi (research fellow) and Prof. Domenico Zito (scientist-in-charge), at the Marconi Lab, Tyndall National Institute, Cork, Ireland. The project has benefitted of the collaboration with Prof. Federico Alimenti, University of Perugia, Italy, and Prof. Peter Gallagher, Trinity College Dublin, Ireland, as scientific advisors on radiometers and solar physics, respectively. Fig. 1.1 shows the project logo.

Introduction. Conditions and events on the Sun can affect human life by interacting with technological systems on Earth. Solar flares represent one of the major contributors to this interaction. A solar flare is a sudden eruption of a large amount of energy from the Sun's surface. It is important to increase our understanding of solar flares to better cope with such events of dramatic impact on solar system, especially on life and human activities (e.g. modern telecommunication systems) on Earth. This has attracted major scientific interests world-wide, especially in the NASA space programme. The number of solar flares detected at millimeter-wave remains low due to the limitations of current ground-based instruments, so limiting the understanding of phenomena.

The possibility offered by the miniaturization at chip level of radiometric sensors may dramatically improve quantitatively the study of the Sun at mm-waves, by enabling low cost micro-, nano- and pico-satellite missions dedicated to this kind of scientific studies. Even though the integration of radiometers in a single silicon chip is being studied since 2008, the implementation of miniaturized system-on-a-chip (SoC) radiometers at Ka-band for the observation of solar flares has never been proposed before.
The project FLARES has successfully demonstrated the implementation of a radiometer module, integrated on a single silicon chip, for the detection of solar flares from a spaceborne platform.

Description of results. The project objective was broken down into five tasks, which have been sequentially executed and completed. Task 1 was the study of the emission mechanism of solar flares at millimeter-waves. We focused on radio wave component of solar flare spectral emission, and particularly on the mm-wave portion in the Ka-band, which is closely linked to many of the events triggered by flares, such as correlation between γ-ray emissions and 37 GHz flares. Task 2 was the system and circuit specifications identification. The proposed system-on-a-chip radiometer featuring the Dicke architecture is shown in Fig. 1.2. The analog-to-digital (ADC) converter has not been finally integrated since space qualified instruments have been made available on the market and certified by space agencies. The integration of the ADC was not critical, thereby this has not changed the research impact of the project, but has concurred to de-risking the study on the most critical aspects of the project. The most critical building-blocks of the system have been studied in detail at circuit level. A 0.13μm SiGe technology by IHP has been adopted for the implementation on silicon. This technology is under space evaluations, so resulting the most suitable for future space-based applications.

Task 3 was the system and circuit design. In particular, the design of a dual-input pseudo-switch two-stage low-noise cascode amplifier (LNA), a common-emitter (CE) detector and a complete Dicke radiometer has been carried out. Task 4 was the design of the entire microchip module and its subsequent submission for fabrication through the Multi-Project Wafer service by Europractice. Finally, Task 5 consisted of the experimental characterization of test chips.

All the tasks have been completed successfully. The experimental results have confirmed the feasibility, despite a frequency shift has been observed likely as a consequence of the performance exhibited by the provided preliminary inductor library. We designed, fabricated and tested in our laboratory the world-1st system-on-a-chip radiometric receiver for space-borne observations of solar flares, and potentially also for other important phenomena in the Earth atmosphere. Five conference papers have been published, one conference paper has been accepted, two articles have been submitted for journal publication.

Conclusions. The results obtained from our research demonstrate the high potential and innovation for achieving a significant improvement with respect to the state-of-the-art instruments for the observation of solar flares. In particular, the proposed SoC Dicke radiometer can achieve one order of magnitude improvement in terms of resolution, so allowing the detection of solar flares with relatively low intensity, i.e. about 100 times lower than those currently detected by the existing systems, owing to space-borne operations and the microchip-level miniaturization through silicon technology under space qualification. The proposed solution enables a significant reduction of weight, size, and power consumption, strategically important for space applications, especially for micro-, nano- and pico-LEO satellite missions. In perspective, the SoC approach allows a number of innovations, such as on-chip calibration circuitry, on-chip thermal stabilization and on-chip analog-to-digital converter, integrated all together with the receiver circuitry. The results of FLARES, extendable also in other frequency bands, are very promising and provide a good basis for further developments both for 1-, and 2-D observations when combined in focal plane arrays of SoC radiometers.

Socio-economic impact. In line with the H2020 vision, we can break down the contribution of the project FLARES in enhancing European excellence, competitiveness and society, into the three main pillars:
1. Excellent science. FLARES contributed to bridging the gap between basic research and applied research, exploiting the collaboration between three excellent centres, such as the Tyndall National Institute, Cork, Ireland, the Astrophysics group at the Trinity College, Dublin, Ireland, and the University of Perugia, Department of Engineering, Perugia, Italy.
2. Competitive industries. By raising the TRL of the proposed instrument module, the successful completion of the project enables in perspective the realization of innovative products (i.e. SoC mm-wave sensors) exploited by European space industries with a reduced time-to-market.
3. Better society. By enabling a significant improvement in the study of solar flares, the project contributes in deepening our knowledge of the Sun and its effects on the Earth. This will in turn increase the awareness of Space Weather’s effects among scientists, policy makers and the civil society.

Moreover, according to the expected outcomes, the project FLARES has allowed the research fellow, Dr. Luca Aluigi, to strengthen his scientific profile and boost his technical competencies in the area of radio-frequency integrated circuit (RFIC), as in the project objectives. In this perspective, we are pleased to report that at the end of the project Dr. Aluigi has been offered a position in RFIC design from ASK, i.e. a multi-national company in communication headquartered in Italy, with facilities in Europe, Asia, America and Africa. Dr. Aluigi will start next month in his new industry position in Italy, his country of origin. This is a tangible impact in terms of contribution of the project FLARES to the economic competitiveness and societal development in Europe.

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