BEACON: in the next generation ground radars and radio telescopes infrastructures – the SKA project opportunity

Rogério N. Nogueira*[a,c], Vanessa C. Duarte[a,b], João G. Prata[a], Georg Winzer[b], Lars Zimmermann[b], Rob Walker[d], Stephen Clements[d], Marta Filipowicz[e], Marek Napierała[e], Tomasz Nasiłowski[e], Jonathan Crabb[f], Leontios Stampoulidis[f], Javad Anzalchi[g] and Miguel V. Drummond[a]

[a] Instituto de Telecomunicações, 3810-193, Aveiro, Portugal
[b] IHP – Innovations for High Performance Microelectronics, 15236 Frankfurt (Oder), Germany
[c] Watgrid Lda., 3810-193, Aveiro, Portugal
[d] aXenic Ltd., Sedgefield, UK
[e] InPhoTech Sp. z o.o., Warsaw, Poland
[f] Gooch & Housego, Torquay, UK
[g] Airbus Defence & Space, Stevenage, UK
* E-mail: mogueira@av.it.pt

ABSTRACT

The Radio astronomy community is entering a new era with the Square Kilometre Array (SKA), a telescope with 100 times improved sensitivity and a 10.000 fold survey speed compared to existing radio telescopes. For this instrument, new technologies are required for telescope design, data transport, computing and software. In particular, new technologies are being investigated to replace the classic parabolic dish with electronically steered antennas, the so-called phased arrays. Beam forming of these very large arrays, with up to 100 million elements, is an important component of the telescope. Photonic beamforming is of particular interest, due to the potential for miniaturization, high capacity and lower power consumption. The recently closed European funded project BEACON made important state of the art advances regarding photonic beamforming, which are reported on this paper.

Keywords: photonics, beamforming, integrated optics

1 INTRODUCTION

The introduction of photonics in the development of new generation ground radar systems and new generation radiotelescopes is now very close consideration. The application of photonics in such systems is bound to create a new very broad market and unique commercialization opportunity since these systems are extremely volume hungry and will require technologies that combine costoptimized mass manufacturing and compliance with harsh environment operation. The most pronounced example is the SKA (Square Kilometre Array) project, which aims to construct the world's largest radio telescope. The SKA is planned in two construction Phases, with the deployment of different sensor technologies sourcing on new generation phased antenna arrays with thousands of elements and beamforming technologies to demonstrate an aperture of up to a million square meters, built to further the understanding of the most important phenomena in the Universe. The SKA Phase 2 will require performance and technology evaluation through Advanced Instrumentation Programs aiming to guide deployments of cutting edge Aperture Array stations. Photonics is at the heart of AAs and will be critical for a planned cost-effective performance with a low power consumption for such a significant number of elements, either through beamforming or via the optical data circuitry system. This paper reports the recent state of the art advances on photonic beamforming made within the European funded project BEACON.

2 PROJECT BEACON

The BEACON project aimed to disrupt the introduction of photonics into terabit per second payload systems by squeezing current discrete bulk photonic components into compact array modules and generate practical photonics multi-beam systems in a scalable and power efficient way.

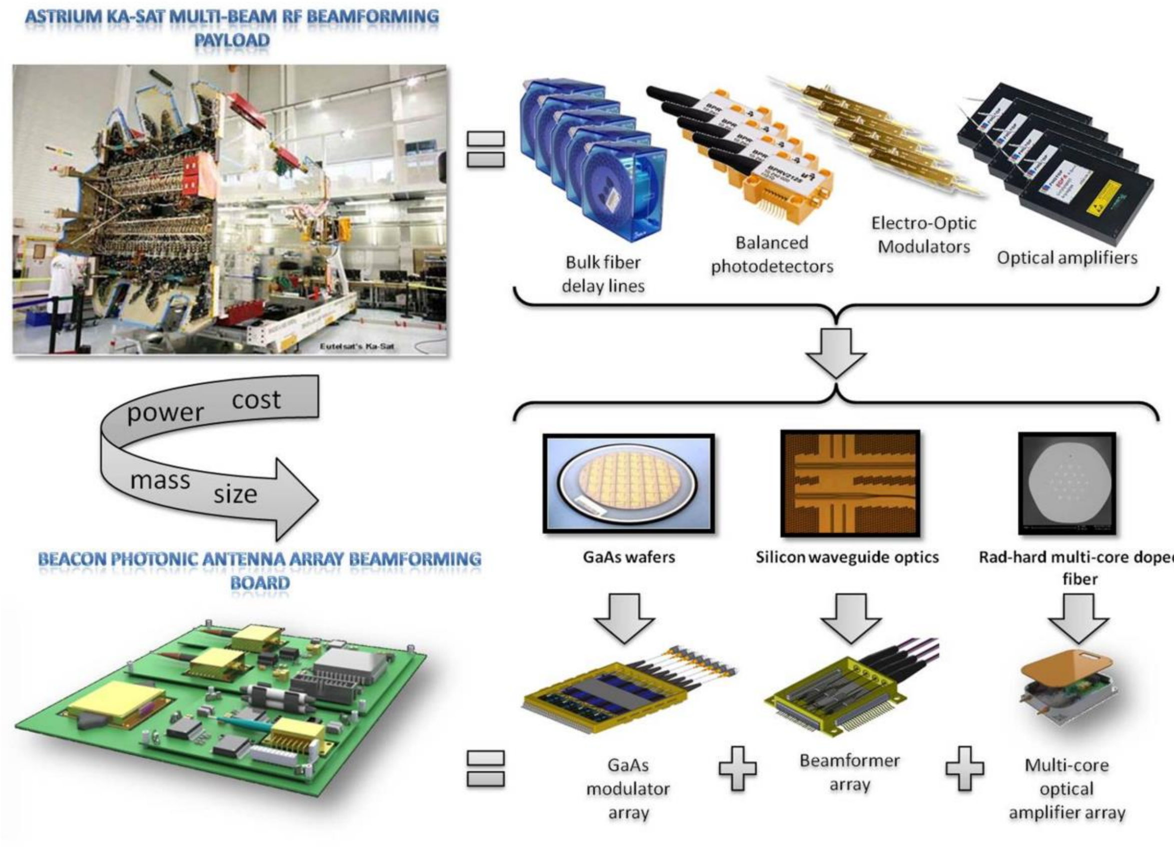

Figure 1. BEACON Project Concept of compact array modules to provide scalable and power efficient photonics for satellite beam array systems

The consortium consisted of:

- Component manufacturers
  - Axenic Limited, United Kingdom,
  - Constelex Technology Enablers, Greece
  - Gooch and Housego Limited (G&H), United Kingdom
  - InPhoTech, Poland
  - Watgrid, Portugal
- End users
  - Airbus Defence and Space (ADS), United Kingdom
- Research Institutions
  - IHP GmbH – Innovations for High Performance Microelectronics, Germany
  - Instituto de Telecomunicações (IT), Portugal

The partners provided a complementary set of skills and experience to match the goals and objectives of the project. The end user in the consortium is Airbus Defence and Space (ADS) who were able to direct and guide the system architecture aspects and set the specification requirements.

The core research activities on the array modules were developed by component partners as follows:

- InPhoTech developed multi-core fiber for optical amplifiers based on their experience from spinning out of leading fiber technology groups in University of Marie Curie-Sklodowska in Lublin.

- Constelex were an innovative technology company and originally the project coordinators in BEACON. Their experience was in fiber amplifier arrays and fiber systems and also in space systems.
- IHP were responsible for the design, development and fabrication of the beamformer elements based on silicon photonic interferometers based on production grade tool-sets for 0.25 and 0.13 micron technologies.
- aXenic developed compact optical modulators and their combination in arrays for efficient low weight, size and power implementations. Their background goes back through to the origins of Gallium Arsenide modulators, high quality fabrication in commercial foundries and assembly technologies.

The construction of integrated modules and their demonstration was mainly focused in the three partners: Gooch & Housego (G&H) who were responsible for the manufacture of the optical amplifiers from the multi-core fiber. Their expertise is based in precision optical components and sub-systems, including fiber components which goes back to 1985. These skills are applied particularly in demanding applications which include space missions with NASA. Watgrid is a technology based company with skills in innovative products and technology transfer services. Their business lies across photonic communication and sensor activities. They were responsible for interfacing on the beamformer and the antenna development for the demonstrator. Finally, Instituto de Telecomunicacões (IT), which is a private, not-for-profit institute co-located at the University of Aveiro with focus on research and education activities. Its expertise in optical communications and networks was deployed in the design test and characterization of the array components and their assembly into a system which included prime responsibility for accomplishing the final demonstrator.

The developments in BEACON sought to address the photonic architecture by addressing technical hurdles in the following:

- **Microwave mixing** using compact integrated electro-optics modulators which are scalable for large arrays. BEACON solution: Gallium arsenide array modulators
- **Optical amplification** which can also manage multiple-optical paths and manage to overcome the sensitivity to radiation of current off-the-shelf amplifiers. BEACON solution: multi-core fiber amplifiers
- **Optical beam-forming** using an integration platform that enables flexible functional and cost-effective integration with fast tuneable beam-forming. BEACON solution: True-time delay Silicon photonics beamformers
- **Photodetection** using co-integration of photo-diodes with the beam formers. BEACON solution: Integration of the photodiodes with the beamformers in silicon photonics
- **Cost and space** reduction using small components, integration for parallel functionality and scalable device technologies. BEACON solution: integrated compact components evaluated for space qualification.

In BEACON, the formidable challenge was not just to achieve these developments but to demonstrate all these advances in a final demonstrator combining the devices in a full working system at Ka band.

These technical activities were supported by several disseminations through exploitation activities, publications and conference presentations.

3 MAIN RESULTS

The BEACON project has achieved the following highlights:

The chief achievement of the project has been the first ever demonstration of a real-time photonic beamformer for processing 4 input Ka band signals (1Gbit/s QPSK at 28GHz carrier), including an array of modulators, a multi-core optical fiber amplifier and a silicon photonic integrated beamformer. The beamformer is based on a self-heterodyne architecture which transforms RF phase shifters into optical phase shifters resulting in a size reduction by a factor of 5000.

The architecture of the demonstration was based on the separate development on the project of the following components:

- The development of a 7-core booster amplifier using radiation resistant multi-core fiber amplifiers. Evaluation for baseline environmental testing for space (Fig. 3).

- The delivery of highly compact modulator arrays which are half the length of conventional modulators, halving the fiber handling space through the use of folded optics and using an expandable array architecture. The devices have performed for Ka band and are capable of much higher frequency operation (Fig. 4).
- The design and fabrication of a set of beamformers fully integrated on CMOS silicon photonics (Fig. 5).

Figure 2. Photograph of the final demonstrator set-up at IT

Figure 3. Fully assembled multi-core array fiber amplifier

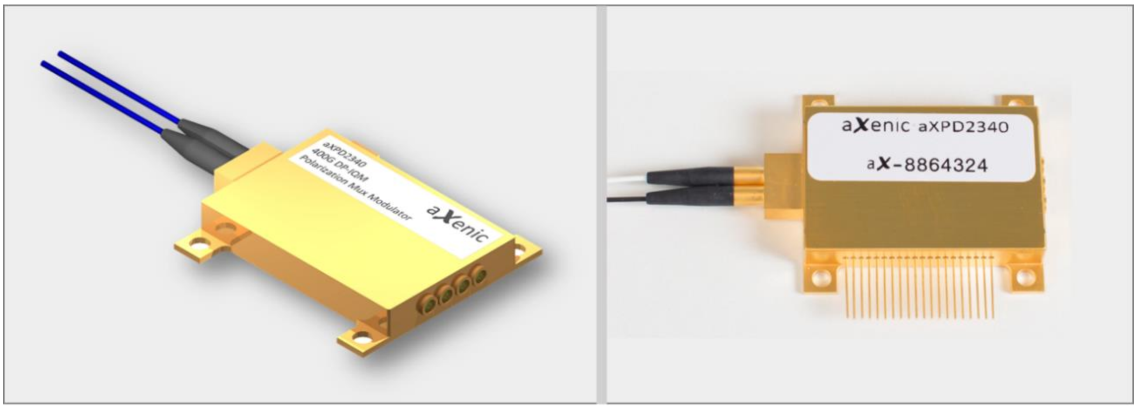

Figure 4. GaAs modulator array package: CAD (left) and photograph (right)

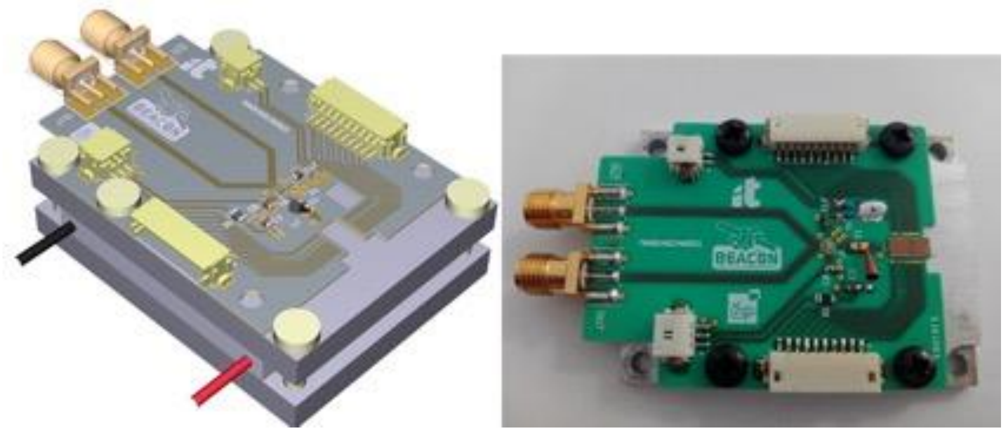

Figure 5. Beamformer (left) PCB design and (right) with all parts placed

4 CONCLUSIONS

Photonic beamforming is considered a key technology for many applications, such as space communications or ultra high capacity radio telescopes. Within the scope of project BEACON, the first ever demonstration of a real-time photonic beamformer for processing 4 input Ka band signals was made. This important milestone was possible due to the development of new architectures and components. These advances pave the way for other applications of photonics beamforming, such as the ones related to aperture arrays on the SKA telescope.

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