Overview of the Swedish – South African (SE-SA) Collaborations under the MIDPREP umbrella

Presented by Marianna Ivashina on behalf of the Chalmers-Stellenbosch team

MIDPREP Chalmers-Stellenbosch team

Ph.D students O. Iupikov and C. Benivenni

Profs. P.-S. Kildal, M.Ivashina, R. Maaskant, Dr. T. Carozzi

Chalmers University of Technology, Sweden

PostDoc A. Young and PhD students D. Prinsloo and T. Beukman

Profs. D. Davidson and P. Meyer

Stellenbosch University, South Africa

1st bi-lateral PhD thesis: Andre Young

SKA AFRICA
SQUARE KILOMETRE ARRAY

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March 2014

In this issue

Three SKA-related PHD's awarded at Maties

In December 2013, doctoral degrees in engineering were awarded to Stellenbosch University (SU) students Dr André Young, Dr Mark Volkmann and Dr Bob Ilgner for their SKA-related research. With the newly capped graduates is Prof David Davidson, holder of the SKA Research Chair at SU.


Photo: Anton Jordaan, Stellenbosch Universit

Dr Young focused on the calibration of radio telescopes. He developed three techniques to provide pattern models that use the least amount of measurement data needed to make an accurate characterisation of the radiation pattern or primary beam of each of the antennas in the SKA array. Dr Volkmann's research looked at the potentia advantages of using superconducting electronics in the digital back end of the SKA array. Dr Il performance and deployment overhead of a parallelized electromagnetic modelling method cal Difference Time Domain (FDTD) on a selection of high performance multiprocessor supercomputers; this method is widely used for modelling RF devices and antennas.

Improving the Direction-Dependent Gain Calibration of Reflector Antenna Radio Telescopes

by

André Young

Dissertation presented for the degree of Doctor of Philosophy in Electronic Engineering in the Faculty of Engineering at Stellenbosch University

Department of Electrical and Electronic Engineering,
University of Stellenbosch,
Private Bag X1, Matieland 7602, South Africa.

Promoters:

Prof. David B. Davidson
Department of Electrical and Electronic Engineering
University of Stellenbosch
Stellenbosch, South Africa

Prof. Rob Maaskant
Department of Signals and Systems
Chalmers University of Technology
Gothenburg, Sweden

Prof. Marianna V. Ivashina
Department of Signals and Systems
Chalmers University of Technology
Gothenburg, Sweden

December 2013

1st bi-lateral PhD thesis: Andre Young

Development of analytical and physics-based functions for efficient modeling of the antenna beams

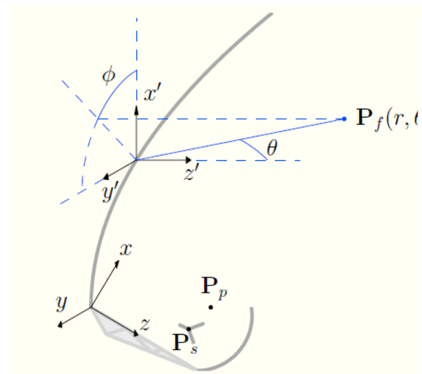
Initial studies in this field:

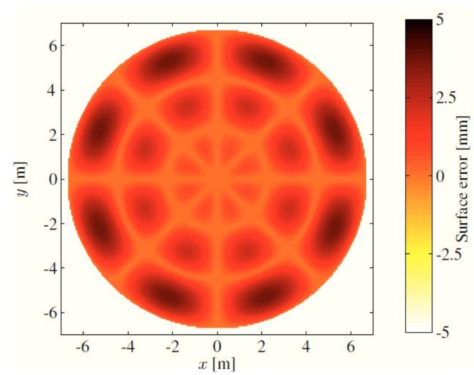
- R. Maaskant, M. V. Ivashina, S. J. Wijnholds, and K. F. Warnick, “Efficient Prediction of Array Element Patterns Using Physics-Based Expansions and a Single Far-Field Measurement,” IEEE Trans. Antennas Propag., vol. 60, no. 8, pp. 3614–3621, Aug. 2012.
- E. de Lera Acedo, N. R.-G. D. Gonzalez-Ovejero, C. Raucy, and C. Craeye, “Low-Order Beam Models for Aperture Arrays,” in AACal, Amsterdam (The Netherlands), Jul. 2012.

2466 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 5, MAY 2013

Accurate Beam Prediction Through Characteristic Basis Function Patterns for the MeerKAT/SKA Radio Telescope Antenna

André Young, Rob Maaskant, *Member, IEEE*, Marianna V. Ivashina, *Member, IEEE*, Dirk I. L. de Villiers, *Member, IEEE*, and David Bruce Davidson, *Fellow, IEEE*





ICEAA2012

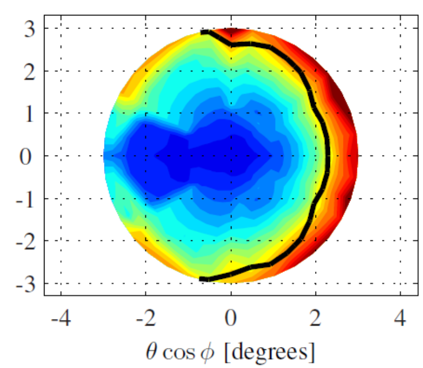
Performance Evaluation of Far Field Paterns for Radio Astronomy Application through the Use of the Jacobi-Bessel Series

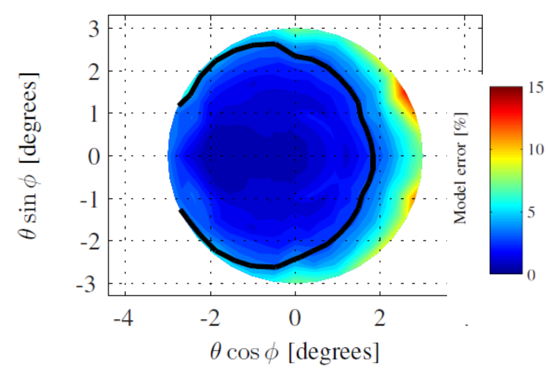
André Young* Rob Maaskant† Marianna V. Ivashina‡ David B. Davidson§

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 5, MAY 2013

Improving the Calibration Efficiency of an Array Fed Reflector Antenna through Constrained Beamforming

André Young, Marianna V. Ivashina, *Member, IEEE*, Rob Maaskant, *Member, IEEE*, Oleg A. Iupikov, and David B. Davidson, *Fellow, IEEE*





Next steps: PostDoc visit of Andre Young

Out goal is to perform experimental verification tests of the proposed beam models through the use of the data from Swedish LOFAR stations (Ref. Tobia Carozzi, OSO)

Next visit of Andre to Chalmers/OSO is in April 2014

Expected PhD thesis at Chalmers, Oleg Iupikov

With contributions of Andre Young (cross-validation with FEKO for small arrays)

Fast and Accurate Analysis of Reflector Antennas with Phased Array Feeds including Multiple Reflections between Feed and Reflector

O. A. Iupikov, R. Maaskant, *Senior Member, IEEE*, M. V. Ivashina, *Senior Member, IEEE*, A. Young, and P. S. Kildal, *Fellow, IEEE*

***Abstract*—Several electrically large Phased Array Feed (PAF) reflector systems are modeled and studied to systematically analyze the mechanism of multiple reflections between parabolic reflectors and low- and high-scattering feeds giving rise to frequency-dependent patterns and impedance ripples. The PAF current is expanded in physics-based macro domain characteristic basis functions (CBFs), while the Physical Optics (PO) equivalent current for the reflector is employed. The reflector-feed coupling is accounted for through a multiscattering Jacobi approach. An FFT expands the reflector radiated field in only a few plane waves, and the reflector PO current is computed rapidly through a near-field interpolation technique. The FEKO software is used for several cross validations, and the convergence properties of the hybrid method are studied for several representative examples showing excellent numerical performance. Finally, it is shown that the measured and simulated results for a 144-element Vivaldi PAF are in very good agreement.**

***Index Terms*—phased array feeds, radio astronomy, method of moments, characteristic basis function method, physical optics.**

This paper will appear in the IEEE Trans. On Antennas and Propagation, 2014

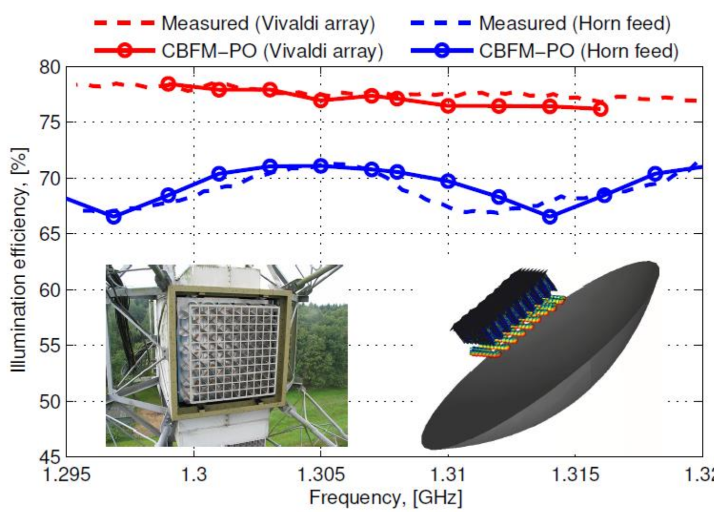


Fig. 12. Illumination efficiencies of the 118λ reflector antenna, either fed by the 121 Vivaldi PAF, or the single-horn feed. The CBFM-PO simulated results are compared to the measured ones for a 25 m reflector antenna of the Westerbork Synthesis Radio Telescope [4]. Bottom of the figure: a photo of the experimental PAF system placed at the focal region of the reflector, and an image of a smaller-scale PAF-reflector model.

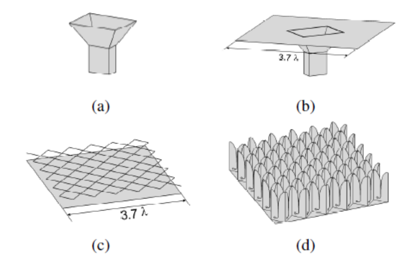
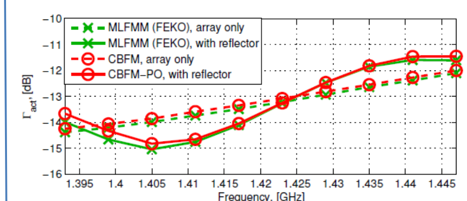
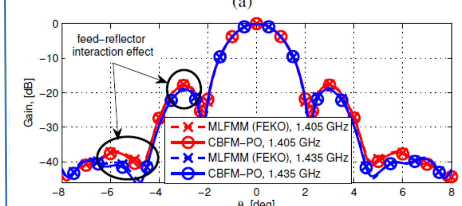


Fig. 5. Considered feed geometries (in addition to the dipole feed with PEC ground plane): (a) a classical pyramidal horn with aperture length ∼1λ; (b) the same horn but with extended ground plane (∼3.7λ), where the ground plane may model the presence of a large feed cabin; (c) an antenna array consisting of 121 0.45λ-dipoles above a ground plane of the same size; (d) the same array, but with the dipoles replaced by wideband tapered slot Vivaldi antennas.



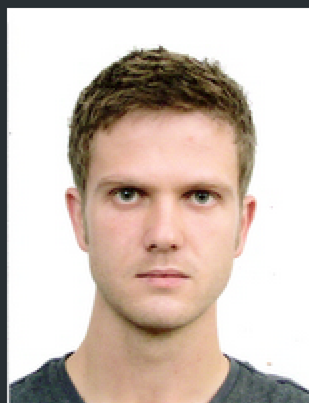
(a)



Cross-validation with FEKO for the array of 121 dipole antenna elements

Measurement data for APERTIF - provided by Wim van Cappellen, ASTRON – many thanks for this!

Expected 2nd bi-lateral PhD thesis



Ph.D. Student : **David Prinsloo**
Project title : **Mixed-Mode Sensitivity Analysis of Active Antennas**

(Stellenbosch University, South Africa, group of Prof. Petrie Meyer)

This project considers antennas fed differentially with differential low noise amplifiers (dLNAs). In dense antenna arrays, such as the aperture arrays (AAs) proposed for the mid-frequency band of the Square Kilometre Array telescope, the AAs and the dLNAs feeding the individual elements cannot be considered separate from one another and neither can the differential and common-modes that propagate between them. In order to quantify the effect both propagation modes have on the system sensitivity a mixed-mode, multi-port signal and noise analysis of the differentially fed active antennas has to be performed. The design and analysis of a new type of dual mode (common + differential mode) antenna having an almost hemispherical field-of-view coverage pattern forms an important part of the project.

Project period: 2011 – 2014

Area of research: imulti-port signal/noise analysis of differentially fed active antennas

Three 2-3 months visit to Chalmers during 2013-2014

See the next talk by David!

Expected 2nd bi-lateral PhD thesis

Mixed-Mode Sensitivity Analysis of a Combined Differential and Common Mode Active Receiving Antenna Providing Near-Hemispherical Field-of-View Coverage

D. S. Prinsloo *Student Member, IEEE*, R. Maaskant *Senior Member, IEEE*, M. V. Ivashina *Senior Member, IEEE*, and P. Meyer *Member, IEEE*

***Abstract*—A theoretical framework for a mixed differential and common mode sensitivity analysis of active receiving antennas is presented, which includes the derivation of a novel set of noise parameters for dual-mode balanced amplifiers. The analysis is applied to an example of a mixed-mode active wire antenna design, consisting of an integrated monopole and dipole structure. Results of numerical simulations and experimental measurements are presented which show that, for a single-polarized design, the judicious usage of both differential and common modes enables the field-of-view coverage to be extended over the entire hemisphere with a ripple in receiving sensitivity less than 3dB in**

differential modes of the antenna. Furthermore, an understanding of how these modes propagate through the entire receiver system is crucial; for instance, it has been observed that CM signals can have a detrimental effect on the DM antenna performance when these undesired CM signals are excited at certain frequencies [6]–[9].

In this paper, we propose a novel dual-mode antenna design intrinsically supporting both the DM and CM signals, thereby creating an additional beamformer degree-of-freedom for im-

This paper has been resubmitted to the IEEE Trans. On Antennas and Propagation after major revisions, 2014

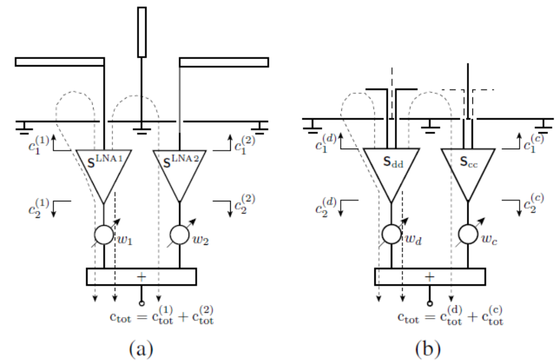


Fig. 3. Propagation paths of the (a) single-ended noise waves and (b) mixed-mode noise waves in the coupled dual-mode active antenna.

M. Ivashina, R. Maaskant, and B. Woestenburg, "Equivalent system representation to model the beam sensitivity of receiving antenna arrays," IEEE Antennas Wireless Propag. Lett., vol. 7, pp. 733–737, October 2008.

1. Name of the innovation

Quad-Mode Antenna for hemispherical FoV coverage and polarisation diversity.

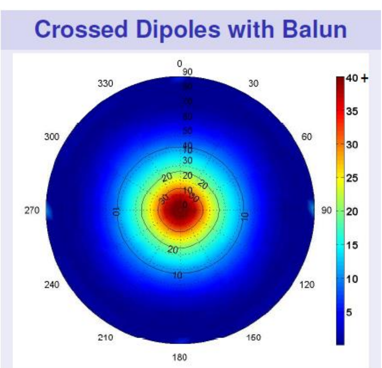
2. Background to the innovation

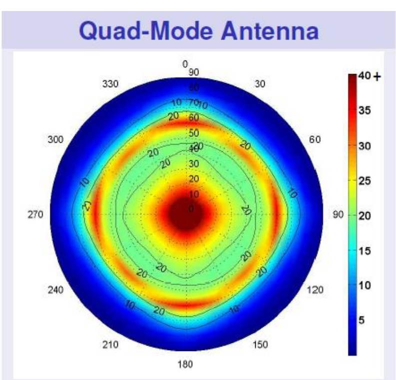
2.1 Which known technology (prior art) related to the innovation already exists?

Patents for antennas with improved polarisation diversity exist that comprise of dipole and monopole antennas, either as stand alone antenna configurations, or that make up unit cells used in array configurations.
In order to realise hemispherical field of view (FoV) coverage with a single antenna element, designs using dual-polarised dipole antennas with reflectors have been patented.

2.2 Of which publications or patents concerning the known technology are you aware? Please att

Antenna with Polarization Diversity - US 7,084,833 B2
Cross-dipole Antenna - WO 2011/017198 A2
Diversity antenna circuit - EP 0 762 542 A2
System for three-dimensional evaluations - WO 03/067710 A1
Dipole for hemispherical coverage antenna - US 8,040,288 B2
Wide scan phased array antenna element - US 8,390,526 B2
Tri-pole antenna element and antenna array - WO 2012/151210 A1





Expected 3d bi-lateral PhD thesis

Ph.D. Student : **Theunis Beukman**
Project title : **Differential Quad-Ridged Horn Antenna and Amplifier Integration**

(Stellenbosch University, South Africa, group of Prof. Petrie Meyer)

This project consists of the investigation and design of microwave networks that allow integration of differential low-noise amplifiers (dLNAs) and single-pixel feeds proposed for the 1–10 GHz band of the Square Kilometre Array (SKA) radio telescope. A new type of reflector antenna feed has been proposed: a differentially excited quad-ridged horn antenna, providing a more constant beamwidth over frequency as well as demonstrates an improved symmetrical beam properties as opposed to more conventional coaxial-probe-excited horn feeds.

The project involves a detailed theoretical analysis of the modal content of the fields in the horn antenna, amplifier-antenna integration aspects, and a sensitivity analysis when used in a reflector antenna system.

Project period: 2011 – 2014

Area of research: integration of ultra wideband antennas and electronics

Two 2-3 months visit to Chalmers during 2013-2014

With contributions of Carlo Bencivenni, Chalmers

MIDPREP Chalmers-Stellenbosch team

Summer 2013, Sweden

Outline:

- Overview of the Swedish – South African (SE-SA) Collaboration under the MIDPREP umbrella *(10 min)*

- Improved design of the Quadruple-Ridged Flared Horn (QRFH) feed for the SKA reflector antennas *(10 min)*

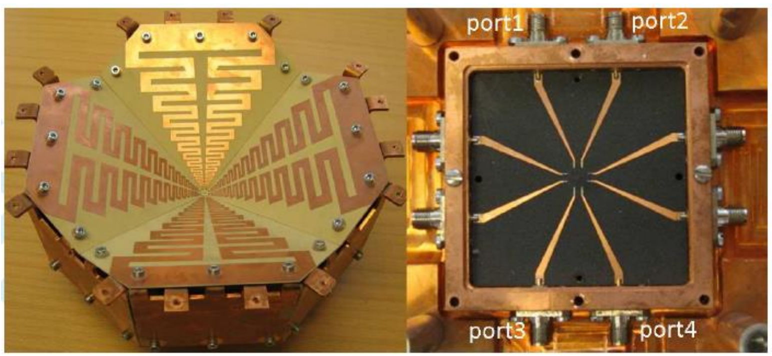
Wideband Single-Pixel Feed Candidates for the SKA reflector antenna systems

Cryogenic 2-13 GHz Eleven Feed for Reflector Antennas in Future Wideband Radio Telescopes

Jian Yang, *Senior Member, IEEE*, Miroslav Pantaleev, Per-Simon Kildal, *Fellow, IEEE*, Benjamin Klein, Yogesh Karandikar, Leif Helldner, Niklas Wadefalk, Christopher Beaudoin

***Abstract*—The paper describes the system design of a cryogenic 2-13 GHz feed with emphasis on its application in future wideband radio telescope systems. The feed is based on the so-called Eleven antenna and the design requires careful integration of various sub-designs in order to realize cryogenic operation. The**

order to reach a figure of merit, A/T (see definition in Section VI), of $5000m^2/K$ [4] (corresponding to an A/T per square meter physical aperture size of $0.02m^2/K$). Achievement of such sensitivity is a primary goal of this work. Therefore,



IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 3, MARCH 2013

Circular Quadruple-Ridged Flared Horn Achieving Near-Constant Beamwidth Over Multioctave Bandwidth: Design and Measurements

Ahmed Akgiray, *Student Member, IEEE*, Sander Weinreb, *Life Fellow, IEEE*, William A. Imbriale, *Life Fellow, IEEE*, and Christopher Beaudoin, *Member, IEEE*

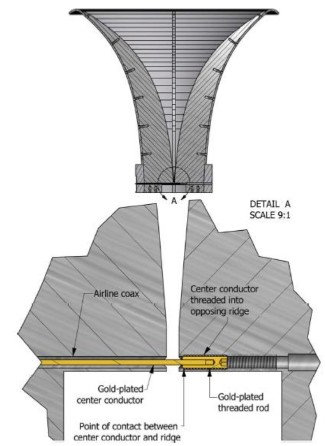


Fig. 7. Detailed view of input coax center conductor connection with opposing ridge. The other two ridges and sidewall are not shown in Detail A for clarity.

QRFH: Pros and Cons for the SKA

Pros:

- Good impedance match to a single-ended 50-100 Ohm LNA (per polarization).
- Almost constant beamwidth in E- and D-planes.
- Possibility to control the beamwidth to optimally illuminate reflectors with sub. angles from 40 to 120°.

Cons:

- Beamwidth variation in H-plane is a factor ~3.5 over the 6:1 frequency band.
- Relative cross-polarisation level can be as high as -7.2dB.

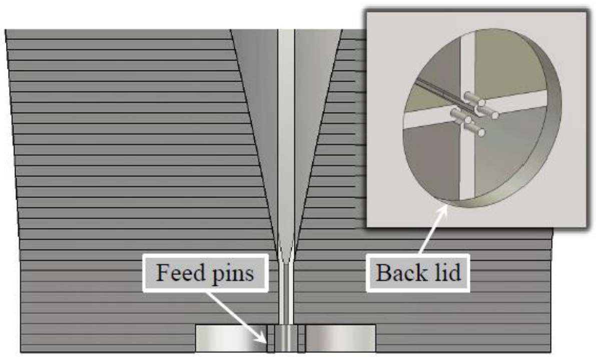
On-going work towards the improved QRFH

Accepted to EuCAP2014

A Quadraxial Feed for Ultra-Wide Bandwidth Quadruple-Ridged Flared Horn Antennas

Theunis S. Beukman[1], Marianna V. Ivashina[2], Rob Maaskant[2], Petrie Meyer[1], Carlo Bencivenni[2]

[1]Department of Electrical and Electronic Engineering, Stellenbosch University, Stellenbosch, South Africa
Email: theunis.beukman@gmail.com; pmeyer@sun.ac.za
[2]Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden
Email: marianna.ivashina@chalmers.se; rob.maaskant@chalmers.se; carlo.bencivenni@chalmers.se



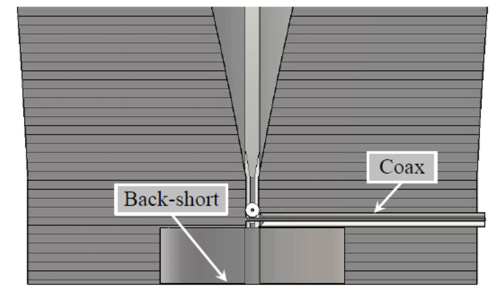
Our simulations have demonstrated:

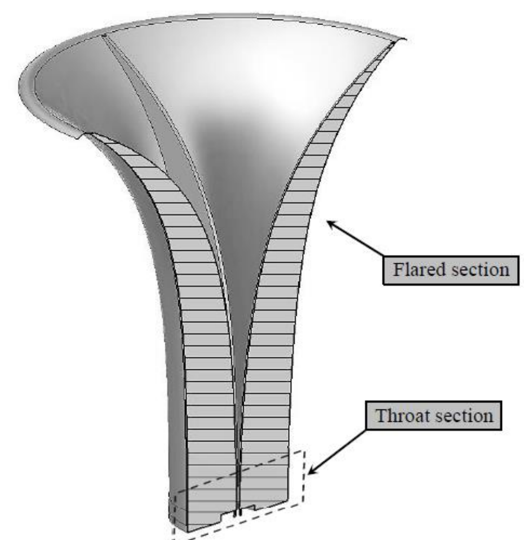
- Improved overall shape of the radiation patterns and their frequency behaviour;
- Improved co-pol pattern symmetry in the elevation planes;
- Reduced cross-polarisation levels in comparison with the coaxial feed.
- ~10% reduced length of the horn

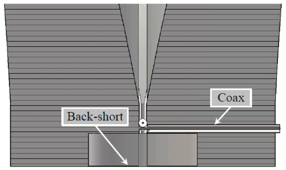
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 61, NO. 3, MARCH 2013 1099

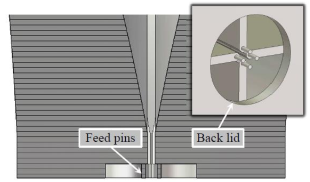
Circular Quadruple-Ridged Flared Horn Achieving Near-Constant Beamwidth Over Multioctave Bandwidth: Design and Measurements

Ahmed Akgiray, *Student Member, IEEE*, Sander Weinreb, *Life Fellow, IEEE*, William A. Imbriale, *Life Fellow, IEEE*, and Christopher Beaudoin, *Member, IEEE*









A Quadraxial Feed for Ultra-Wide Bandwidth Quadruple-Ridged Flared Horn Antennas

Theunis S. Beukman[1], Marianna V. Ivashina[2], Rob Maaskant[2], Petrie Meyer[1], Carlo Bencivenni[2]

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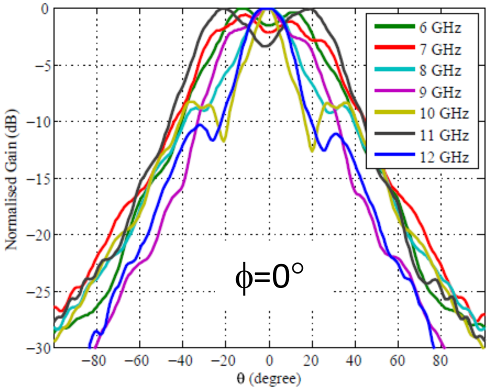
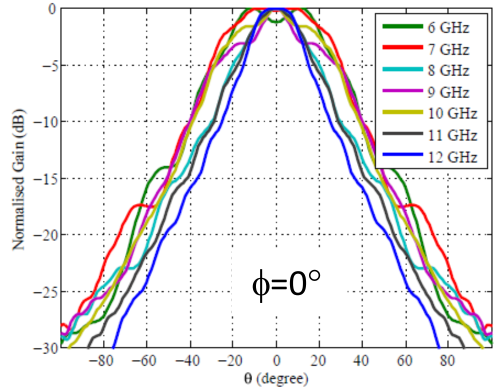
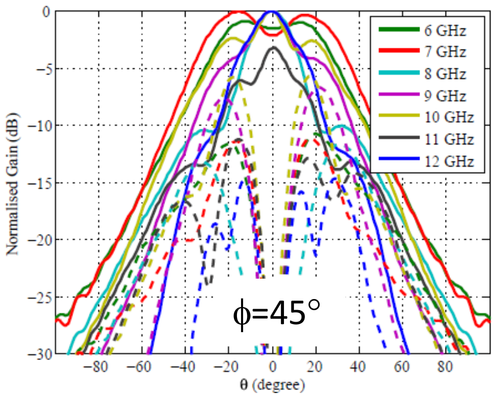
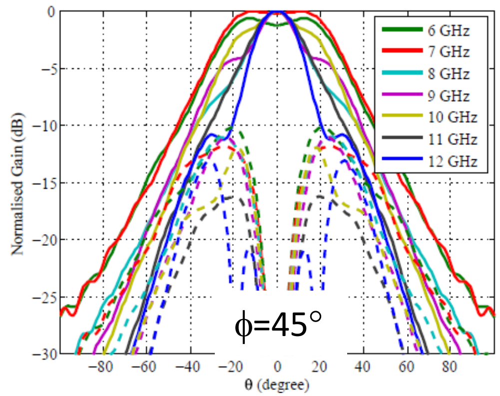
Email: marianna.ivashina@chalmers.se; rob.maaskant@chalmers.se; carlo.bencivenni@chalmers.se

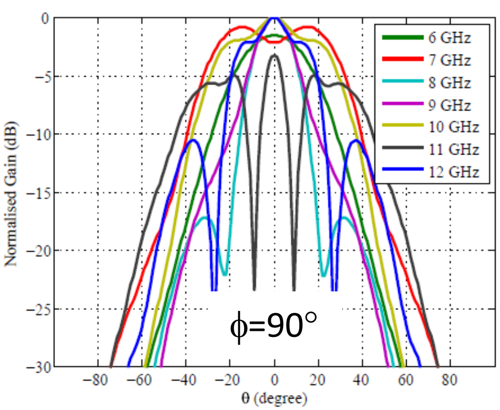
Accepted to EuCAP2014

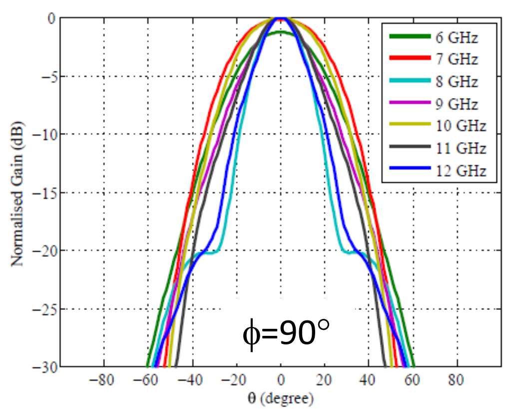




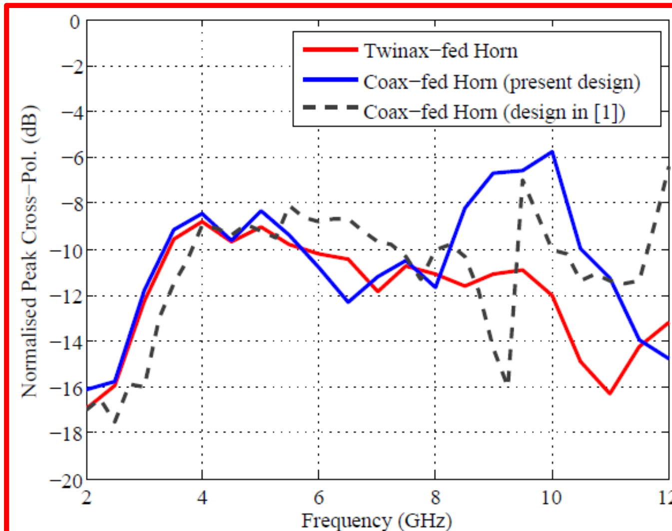




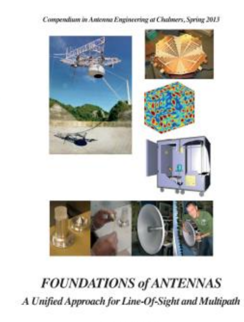




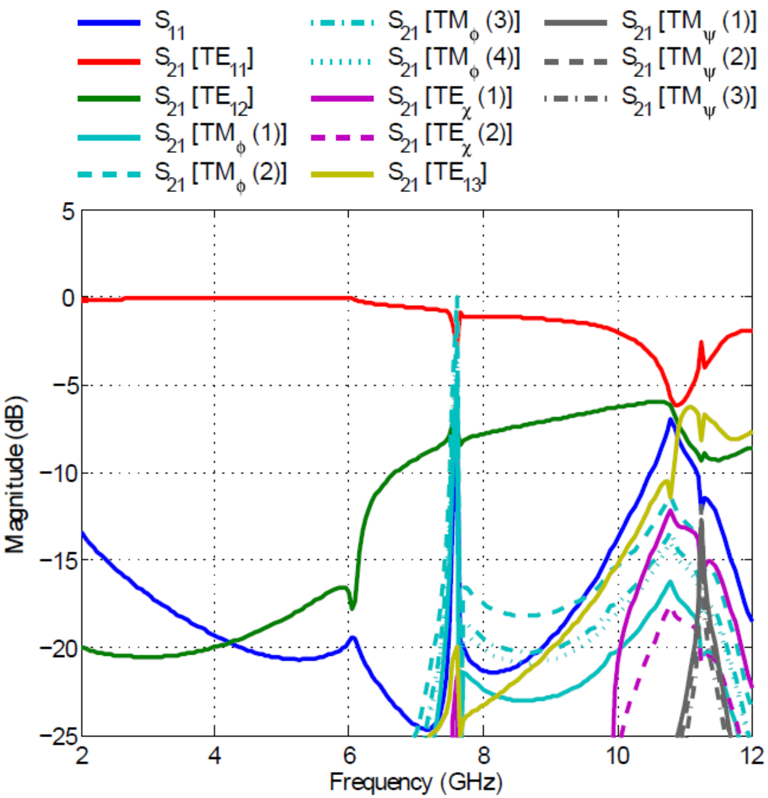
Note: this design has not been optimized for the SKA dish yet

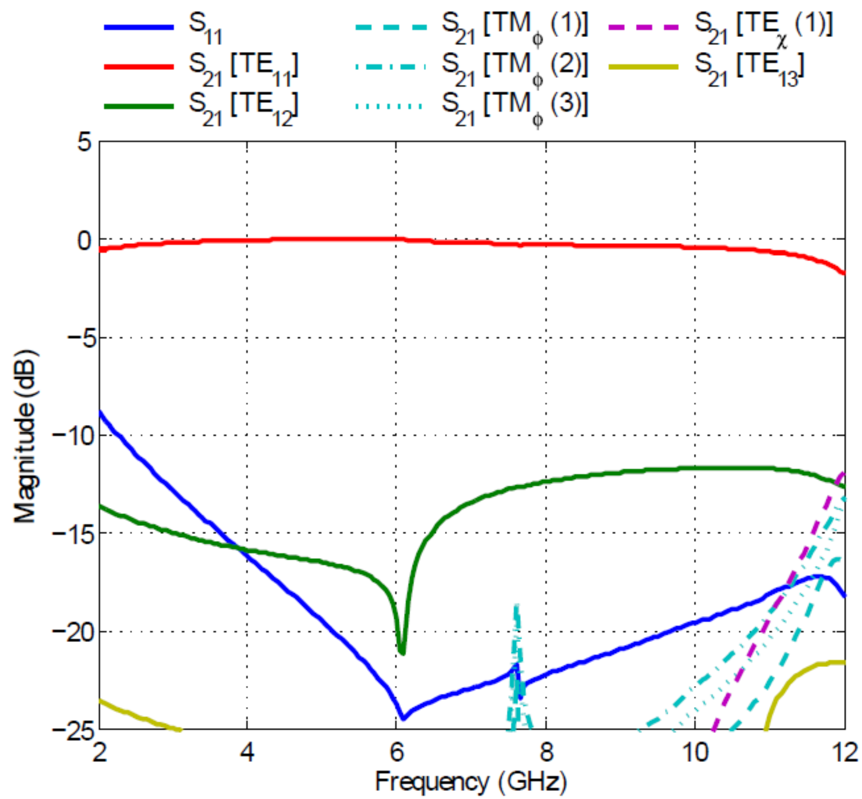


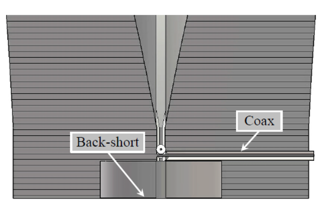
$$(XP)_{dB} = 10\log\left|\frac{E_{xp}}{E_{co}}\right|^2 \text{ dB}$$

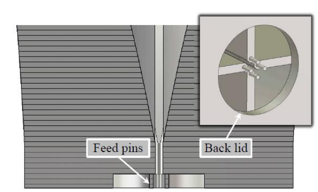


Modal content analysis









Acknowledgements

MIDPREP

Square Kilometre Array Project South Africa

National Research Foundation South Africa

Vinnova (Sweden)

Swedish Research Council