PAF WORKSHOP 2016

PHASED ARRAY FEED WORKSHOP
AUGUST 24-26, 2016 - CAGLIARI, ITALY

Cefalù 06
Cefalù & Astronomy

OAC Osservatorio Astronomico di Cagliari

INAF ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Scope:

- engineering feedback from commissioning and early science observations;
- element and array design with ultra-wide bandwidth;
- analog and mixed-signal electronics;
- traditional beamforming and innovative solutions;
- beamformer calibration;
- array characterization and testing;
- sensitivity and field of view limits;
- cryogenic PAFs;
- systems integration;
- telescope optics for PAFs;
- imaging, and lessons learned from early PAF deployments;

Web page: http://paf2016.oa-cagliari.inaf.it/
Email: PAF2016@oa-cagliari.inaf.it
Venue: Hotel Regina Margherita, viale Regina Margherita 44, Cagliari, Italy

Organizers

The PAF2016 Workshop is organized by the Italian National Institute for Astrophysics (INAF)-Astronomical Observatory of Cagliari (OAC) in collaboration with the Association Cefalù & Astronomy.

Organizing Committees

Local Organizing Committee (INAF-OAC):

Alessandro Navarrini, Tiziana Coiana, Andrea Saba

Scientific Organizing Committee:

Alessandro Navarrini (*INAF*, Italy), Mark Bowen (*CSIRO*, Australia), Lisa Locke (*NRC-DAO*, Canada), Bruce Veidt (*NRC-DRAO*, Canada), Wim van Cappellen (*ASTRON*, The Netherlands)

INAF Radio Astronomy

The INAF-OAC (Astronomical Observatory of Cagliari) based in Cagliari, and the INAF-IRA (Institute for Radio Astronomy), based in Bologna, are in charge of the scientific and technical development of the main radio astronomy facilities in Italy, the 64-m diameter Sardinia Radio Telescope (SRT) and the two 32-m diameter telescopes in Medicina and Noto. The two institutes maintain highly valued partnerships with national and international organizations and play a crucial role in international radio astronomy projects such as SKA and ALMA. In particular, the INAF radio astronomy community works across a wide range of radio astronomy science, including the development of new instrumentation and operation of the SRT, located 35 km North of Cagliari.

In addition to INAF-OAC and INAF-IRA, radio astronomy activities are also conducted at INAF-OACT (Catania Astrophysical Observatory), INAF-OA (Arcetri Astrophysical Observatory, Florence), and INAF-OATS (Astronomical Observatory of Trieste). A high degree of coordination is provided for radio astronomy projects through a dedicated section of the INAF Science Directorate, based in Rome.

Fig. 1. The three main INAF radiostronomy facilities: SRT, Medicina and Noto radio observatories.

Welcome to

Web page: http://paf2016.oa-cagliari.inaf.it/

Email: PAF2016@oa-cagliari.inaf.it

The INAF-Astronomical Observatory of Cagliari and the Association Cefalù&Astronomy welcome you to the Phased Array Feed Workshop PAF2016, Aug.24-26, 2016, Cagliari, Italy.

Scope:

- engineering feedback from commissioning and early science observations;
- element and array design with ultra-wide bandwidth;
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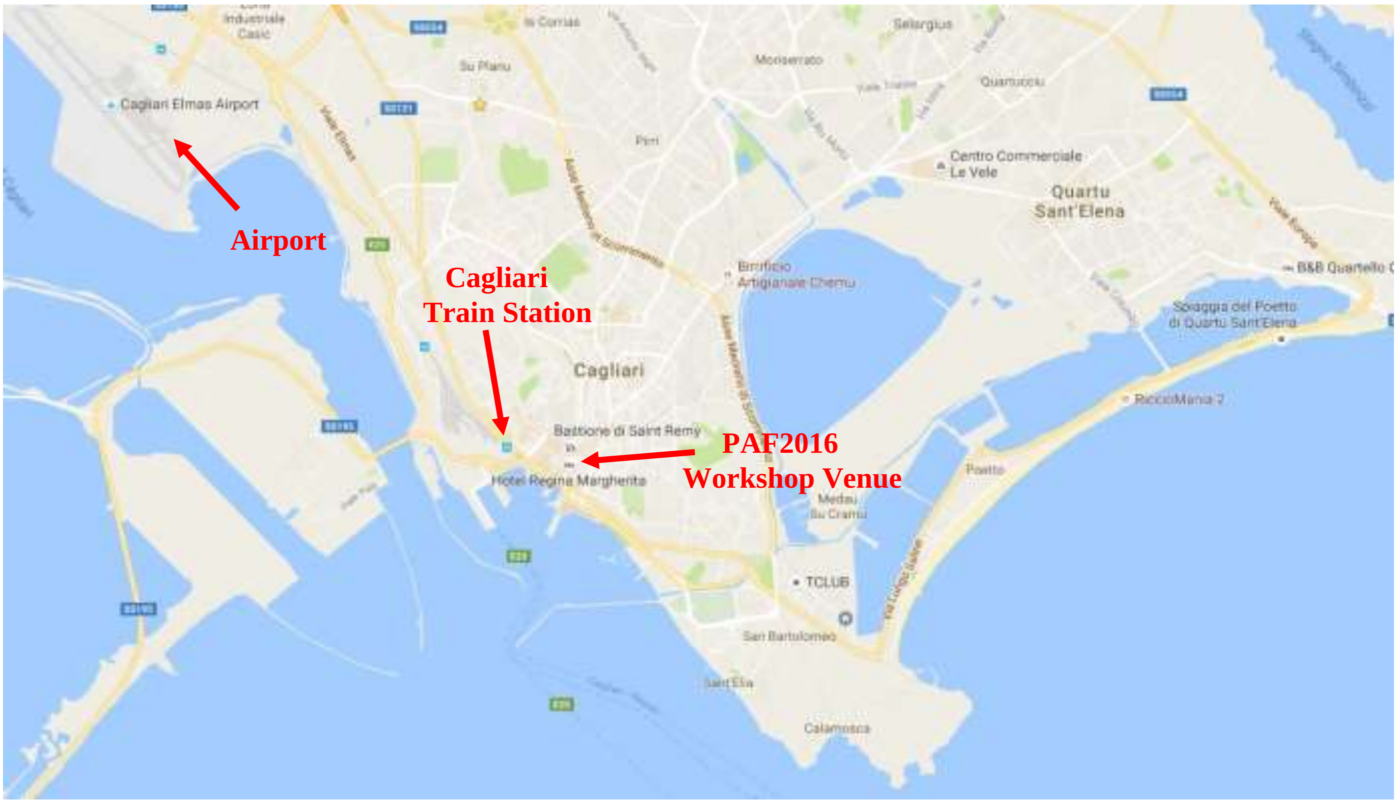
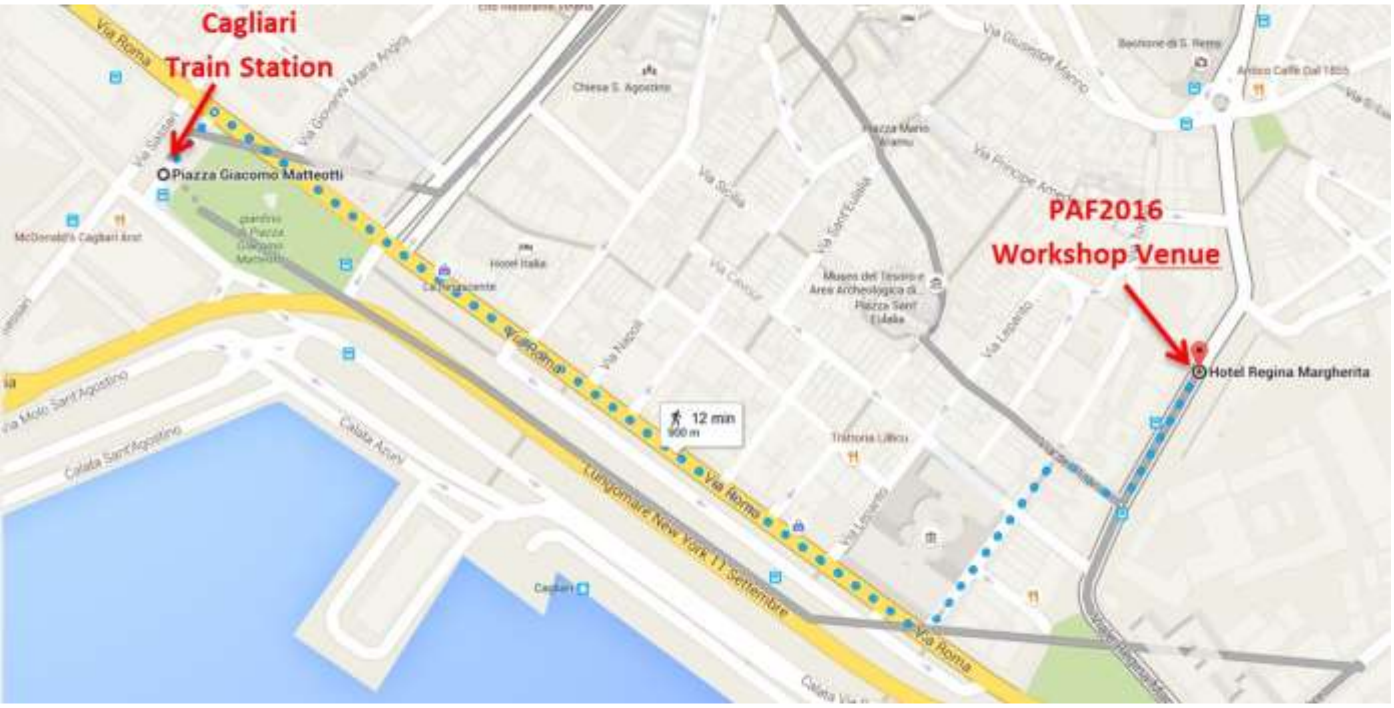
- systems integration;
- telescope optics for PAFs;
- imaging, and lessons learned from early PAF deployments;

Cagliari city maps

PAF2016 Workshop Venue: Sala Villanova, Hotel Regina Margherita, viale Regina Margherita 44, Cagliari





Registration & Welcome Reception

A welcome reception will be held at the Hotel Regina Margherita (viale Regina Margherita 44, Cagliari) on Tuesday evening Aug. 23rd, between 18h00 and 20h00. Appetizers, light refreshments, and beverages will be available. You will also be able to pick up your registration packages at the welcome reception.

Those who have not yet registered or paid can do so at the registration desk which will be available also on Wednesday morning Aug. 24th, between 8h00 and 9h00.

The registration fee includes:

- Access to all workshop sessions;
- Registration materials, conference guide, and giveaway items;
- Welcome Reception on Tuesday Aug. 23rd 2016;
- Coffee, snacks, lunches during the three days of the workshop (Aug. 24-26, 2016);
- Transfer and visit to the Sardinia Radio Telescope (including lunch) on Thursday Aug. 25th 2016;
- All taxes and VAT;

The workshop fee does not include the dinners during the three days of the workshop (Aug 24-26, 2016).

Conference Room & Internet Access

The conference room is the Sala Villanova located near the entrance hall of the Hotel Regina Margherita.

A free wifi connection will be available inside the hotel. WiFi SSID: *HRM*. Internet connection requires to login with social credentials (like Google+, Facebook, Twitter, Instagram, etc.). The local organizing committee is available for assistance.

Electricity & Power sockets

The standard voltage in Italy is 230 Volts, 50 Hz. The photo shows a power socket that will be available in the hotel conference room.

SRT Visit

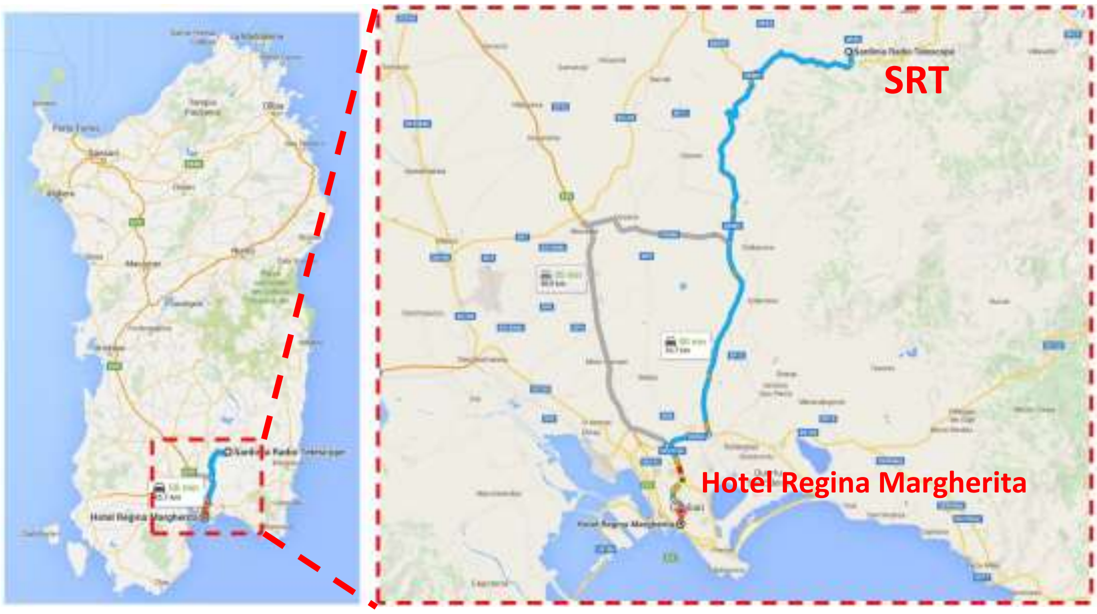
A visit to the Sardinia Radio Telescope (SRT, http://www.srt.inaf.it/) is scheduled the second day of the workshop, August 25th, 2016. The SRT site, approximately 35 km North of Cagliari, will be reached by bus (travel time will be approximately 50 minutes). The bus leaves from the Hotel Regina Margherita at 8h30am (meeting in front of the hotel at 8h20am). The PAF2016 workshop group photo will be taken upon arrival at the SRT site.

Various parts of the SRT telescope and associated infrastructures will be accessible. Videos on the SRT construction and some refreshments will be available in the tensile structure next to the telescope. Participants will be divided in four groups (Group A to D).

Important: For safety reasons, participants wishing to tour the telescope are required to wear suitable shoes with anti-sleep outsole, possibly with safety grooves to improve grip (do not wear open-toed shoes, sandals, or leather-soled shoes). Please, be aware that a vertical ladder will have to be climbed to access the upper parts of the telescope.

Because of exposure to the Sun and the Summer season we recommend the use of sunscreen and sunglasses.

The bus leaves from the SRT site at 12h00. A lunch will be served in a countryside restaurant on the way back to the conference venue in Cagliari.



Program of SRT visit of Aug. 25th 2016 - PAF2016 Workshop

08h30: *Bus departure from Hotel Regina Margherita;* **09h20:** *Bus arrival at SRT***; 09h25:** *Group photo;* **09h30:** *Distribution of safety helmets;* **09h35:** *Start of visit of the four Groups (A, B, C and D):*

Location	Speaker	Schedule	
SRT basement	*Ignazio Porceddu*	Group A	09h45-10h00
		Group B	10h00-10h15
		Group C	10h15-10h30
		Group D	10h30-10h45
SRT ALidade Equipment Room (ALER)	*Sergio Poppi*	Group A	10h00-10h10
		Group B	10h15-10h25
		Group C	10h30-10h40
		Group D	10h45-10h55
SRT Elevation Equipment Room (EER)	*Carlo Migoni*	Group A	10h10-10h20
		Group B	10h25-10h35
		Group C	10h40-10h50
		Group D	10h55-11h05
SRT Beam Waveguide Room (BWG)	*Giuseppe Valente*	Group A	10h20-10h30
		Group B	10h35-10h45
		Group C	10h50-11h00
		Group D	11h05-11h15
SRT Gregorian Room	*Alessandro Navarrini*	Group A	10h30-10h40
		Group B	10h45-10h55
		Group C	11h00-11h10
		Group D	11h15-11h25
SRT Control Room (CR)	*Elise Egron*	Group A	11h20-11h30
		Group B	09h35-09h45
		Group C	11h30-11h40
		Group D	09h45-09h55
SRT Box AP (Backends)	*Andrea Melis*	Group A	11h10-11h20
		Group B	11h25-11h35
		Group C	09h35-09h45
		Group D	09h55-10h05
Mobile RFI station	*Giampaolo Serra*	Group A	11h00-11h10
		Group B	11h15-11h25
		Group C	09h45-09h55
		Group D	09h35-09h45
Tensile structure (refreshments & SRT videos)	*Tiziana Coiana*	Group A	11h30-11h50
		Group B	11h35-11h50
		Group C	11h40-11h50
		Group D	11h45-11h50

Group A	Touring: Pasqualino Marongiu	Basement → ALER → EER → BWG→ Gregorian → → Mob. RFI station →Box AP → CR→ Tensile structure
Group B	Touring: Adelaide Ladu	CR →Basement →ALER → EER → BWG→ Gregorian → → Mob. RFI station → Box AP → Tensile structure
Group C	Touring: Andrea Saba	Box AP → Mob. RFI station → Basement →ALER → EER → → BWG→ Gregorian → CR → Tensile structure
Group D	Touring: Paolo Soletta	Mob. RFI station → CR →Box AP → Basement→ALER → → EER → BWG→ Gregorian → Tensile structure

Bus leaves from SRT at 12h00

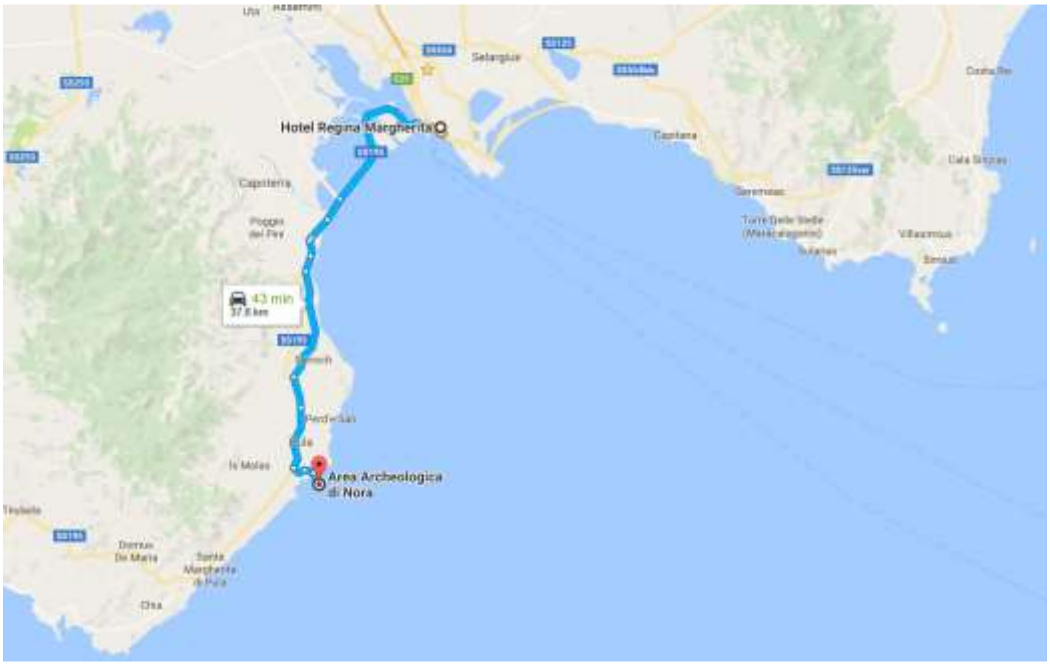
Social events

Workshop dinner on Aug. 24th

The workshop social dinner is going to be held in a seaside restaurant in Nora (approximately 40 km from Cagliari). The dinner will follow a 45 min visit to the Nora archeological site. The bus transfer from/to Cagliari and the guided tour of the archeological site are free. The dinner is not included in the registration fee and is subject to an extra cost of 40 Euros per person. Free evening in Cagliari is an option. Accompanying guests are welcome to join the welcome reception (on Aug. 23^{rd}) and the Workshop Dinner (on Aug. 24^{th}).

Bus transfer from the Hotel Regina Margherita to Nora leaves at 17h50. Meeting point at the Hotel at 17h40. The bus transfer back to the hotel in Cagliari is scheduled to leave from Nora around 22h30 (arrival at 23h30).

If you wish to participate to the free visit of the archeological site and the associated social dinner, please inform the organizers during the workshop registration days (August 23th and 24th, 2016).



Guided walking tour of Cagliari city center on Aug. 25th

A free guided walking tour of the Cagliari city center is organized on the evening of Aug. 25th between 19h00 and 20h30. Meeting point at the Hotel Regina Margherita at 18h50.

If you wish to participate to the free guided walking tour, please inform the workshop organizers before Aug. 24^{th}, end of the day.

Cagliari is not a single city, but so many cities in one. The itinerary proposes an evocative walk through squares, monuments and ruins that date back to Roman and medieval eras, going through Contemporary Age. We'll walk through the narrow streets of the city centre, and run across the stone buildings, hear the distant echoes of the merchants, the horse soldiers and the crowd gathered in front of the main buildings, emblem of political and religious power. But there is more… the strategic position of the city centre, called "quartiere Castello" provides several breathtaking views of the city.

Instructions for speakers

The number of registered participants is 55. A total of 24 abstracts were received, including one invited contribution. All contributions are allocated oral presentation.

Most presentations have been allocated a total time of 30 min, including 5 min for questions and discussion (25 min+5 min). Please refer to our acceptance notification email and to the workshop program (further down) for details on allocated time.

Please provide electronic presentation materials during the registration sessions or the coffee break before your session. A laptop with Windows operating system will be available to support .ppt and .pdf file formats. Note that Macintosh platform will not be provided (if you are a Mac user, please convert your presentation to the above indicate formats).

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Tuesday Aug. 23rd, 2016:

18h00-20h00	Welcome Reception, Registration and Payment at Hotel Regina Margherita (no sessions)

Wednesday Aug. 24th, 2016:

08h00-09h00	Registration and Payment	
09h00-09h05	Welcome address from hosting Institution	
09h05-09h15	Logistic information	
09h15-09h30	PAFs and the future of radio astronomy, *S. Tingay (INAF, Italy)*	**Session 1** Chair: E. Carretti
09h30-10h15	Introductory Talk: Mutual coupling analysis of line-feeds devoted to cylindrical reflectors, *C. Craye (Univ. Louvain, Belgium)*	
10h15-10h45	High-Performance PAFs with CMOS LNAs, *B. Veidt (NRC, Canada)*	
10h45-11h05	Coffee break	
11h05-11h35	Early commissioning results from the Focal-plane L-band Array feed for the Green Bank Telescope (FLAG), *B. Jeffs (Brigham Young Univ., USA)*	**Session 2** Chair: M. Bowen
11h35-12h05	Focal L-band array for the GBT: Instrumentation Upgrades and Performance Results, *Anish Roshi (NRAO, USA)* - *Videoconf*	
12h05-12h35	An update on APERITIF and future PAF activities at ASTRON, *W.A. van Cappellen (ASTRON, The Netherlands)*	
12h35-13h05	Online Calibration Scheme for APERITIF, *B. Hut (ASTRON, The Netherlands)*	
13h05-14h00	Lunch break	
14h00-14h30	Development of the L-band Phased Array Feed for the Five-hundred-meter Aperture Spherical radio Telescope, *Y. Wu (NAO, China)*	**Session 3** Chair: L. Locke
14h30-15h00	Measuring PAFs at CSIRO, *A. P. Chippendale (CSIRO, Australia)*	
15h00-15h30	First astronomy with a modified Mark II ASKAP PAF on the 64 m Parkes radio telescope, *A. P. Chippendale (CSIRO, Australia)*	
15h30-15h50	Coffee break	
15h50-16h20	The development of a CSIRO MKIII wideband phased array feed, *A. Dunning (CSIRO, Australia)*	**Session 4** Chair: A. Navarrini
16h20-16h50	High Polarisation Isolation Crossed-Ring Antenna Array for SKA-MFAA, *Y. Zhang (University of Manchester, UK)*	
16h50-17h20	A 160 channel Cryo Phased Array Camera for Radio Astronomy, *G. Cortes-Medellin (Cornell University, USA)*	
17h50-18h50	Bus transfer from Hotel Regina Margherita to Nora (free evening in Cagliari is an option)	
19h00-19h45	Visit of Nora archeological site (guided tour for free)	
20h00-22h30	Social dinner in a seaside restaurant (cost 40 € per person, accompanying persons are welcome)	
22h30-23h30	Bus transfer from Nora to Hotel Regina Margherita	

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Thursday Aug. 25th, 2016:

08h30-09h20	Bus transfer from Hotel Regina Margherita to Sardinia Radio Telescope site	
09h20-12h00	Visit of the Sardinia Radio Telescope and group photo	
12h00-12h30	Bus transfer from Sardinia Radio Telescope to restaurant	
12h30-14h10	Lunch in a countryside restaurant	
14h10-14h40	Bus transfer to Hotel Regina Margherita	
14h50-15h20	CryoPAF4 – a cryogenic phased array feed design, *L. Locke (NRC, Canada)*	**Session 5**
15h20-15h50	Variable Dielectric Delay Lines in Liquid Crystals for Phased Array Feed, *L. Liu, (University of Manchester, UK)*	Chair:
15h50-16h05	Cryo-mechanical solutions for a cryostat equipped with large window: The PHAROS case, *S. Mariotti (INAF, Italy)*	W. van Cappellen
16h05-16h30	Coffee break	
16h30-17h00	PAF Aperture Array Tests: Analog and Digital Beamforming Compared, *D. B. Hayman (CSIRO, Australia)*	**Session 6**
17h00-17h30	The ASKAP Phased Array Feed Digital Beamformer: Design Overview and Performance Characteristics, *J. Tuthill (CSIRO, Australia)*	Chair:
17h30-18h00	A[nother] beamforming strategy – an information theoretic look at beamforming with PAFs, *G. Hellbourg (CSIRO, Australia) - Videoconf*	B. Veidt
18h00-18h30	Spatial RFI mitigation with Phased Array Feeds, *G. Hellbourg (CSIRO, Australia) – Videoconf*	
19h00-20h30	Free evening. Possibility of guided walking tour of Cagliari city center: meeting point at the Hotel Regina Margherita at 18h50.	

Friday Aug. 26th, 2016:

09h00-09h30	Fast Numerical Method for the Simulation of Hexagonal Focal Plane Array, *R. Sarkis (Antonine Univ., Lebanon)*	
09h30-10h00	SKA as Piggyback on Solar Power Towers?, *A. Roy (MPIfR, Germany)*	**Session 7**
10h00-10h30	PAFs for imperfect optics, *O. Wucknitz (MPIfR, Germany)*	Chair:
10h30-10h50	First astronomy results from PAFs, *P. Serra (CSIRO, Australia)*	K. Grainge
10h50-11h10	The CSIRO Astronomy and Space Science Phased Array Feed Development Program, *M. A. Bowen (CSIRO, Australia)*	
11h10-11h30	Coffee break	
11h30-12h30	Workshop summary	**Session 8**
12h30-13h00	Next workshop	All
13h00-14h30	Lunch break	
	END of PAF2016 Workshop	
14h30-16h00	Kick-off meeting of PAF SKA Advanced Instrumentation Program – Part 1 (closed session)	
16h00-16h30	Coffee break	
16h30-18h00	Kick-off meeting of PAF SKA Advanced Instrumentation Program – Part 2 (closed session)	

Mutual coupling analysis of line-feeds devoted to cylindrical reflectors

C. Craeye[1*], R. Sarkis[2]
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[2]*Antonine University, Hadat, Lebanon*
* Contact: Christophe.craeye@uclouvain.be

Abstract— This communication attempts to provide a picture of mutual coupling in dense arrays in simple and intuitive ways, while keeping the descriptions as rigorous as possible. Line feed receives a special attention.
The first third of the presentation will focus on a reminder of coupling-related figures of merit for arrays made of any number of radiating elements in any configuration, each of which is simply defined by its associated "port". Here, the embedded element pattern corresponds to the key quantity of interest and it will be shown how the introduction of mutual coupling actually solves a number of power-budget paradoxes. Representations allowing the decoupling of the terminations and radiating structures will be favored. Noise coupling will be included using as few concepts and formulas as possible. The role of (partial or complete) decorrelation between noise sources in the formation of the array sensitivity will be emphasized.

The second part of the talk will deal with line-feed arrays devoted to cylindrical reflectors: their applications, their advantages and drawbacks, their different possible implementations. It is important to notice here that each periodic unit cell of the array can contain multiple antennas, which can be of various shapes and orientations to implement polarization diversity. In other words, the actual feed can be much more than just a "line-feed". Based on fundamental electromagnetic concepts, a simple but not-so-intuitive result will be described regarding the receiving cross-section of an antenna located in such an array, with or without a reflector. This includes the "azimuthal" directivity of the antenna and its link with the embedded element pattern. Here too, it will be shown how mutual coupling balances the power budget of the array on transmit and which is the consequence of coupling on receive.

The last part of the talk will emphasize the importance of numerical methods in the evaluation of the effects of mutual coupling. In particular, it will be shown how the full-wave study of focal lines feeding cylinders benefits from integral-equation approaches. In a nutshell, such methods aim at the determination of currents on the interfaces only, through the use of analytical results regarding the link between source currents and radiated fields. This leads to a strongly limited number of unknowns compared to other EM analysis techniques, while preserving a rigorous study of coupling among elements, as well as between line feed and reflector. Physical interpretations will be given in terms of cylindrical Floquet waves. Examples illustrating the concepts reviewed in the previous two parts of the talk will be given.

References:

[1] M.V. Ivashina, M.N. Kehn, P-S. Kildal, R. Maaskant, "Decoupling efficiency of a wideband Vivaldi focal plane array feeding a reflector antenna," *IEEE Trans. Antennas Propag.*, Vol. 57, pp. 373-382, Feb. 2009.

[2] J. Diao, K.F. Warnick, "On the bandwidth gap between the array-feed and cluster-feed regimes for broadband multifeed systems," *IEEE Trans. Antennas Propag.*, Vol. 64, pp. 2207-2216, June 2016.

[3] M. Deng, D. Campbell-Wilson, "The cloverleaf antenna: A compact wide-bandwidth dual-polarization feed for CHIME," *ANTEM 2014 Symp.*, Victoria, July 2014.

[4] G. Virone, R. Sarkis, C. Craeye, G. Addamo, O. Perevini, "Gridded Vivaldi antenna feed system for the Northern Cross radio telescope," *Special Issue of the IEEE Trans. Antennas Propagat. on Next-generation radio telescopes*, Vol. 59, pp. 1963 – 1971, June 2011.

[5] C. Craeye and D. Gonzalez-Ovejero, "A review on array mutual coupling analysis", *Radio Science*, 46, RS2012, April 2011.

[6] C. Craeye and M. Arts, "On the receiving cross-section of an antenna in infinite linear and planar arrays," *Radio Science*, April 2004.

High-Performance PAFs with CMOS LNAs

B. Veidt[1*], L. Belostotski[2], T. Burgess[1], A. Beaulieu[2], Y. and J. W. Haslett[2]
[1]*NRC Herzberg Astronomy and Astrophysics, Penticton, BC, Canada*
[2]*University of Calgary, Calgary, AB, Canada*
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Abstract— The Advanced Focal Array Demonstrator (AFAD) project is exploring the potential of phased-array feeds (PAFs) at 0.7 to 1.5 GHz as a wide-field survey instrument providing multiple low-noise beams. Initially we constructed a small 41-element dual-polarized array using thick Vivaldi elements with embedded low-noise amplifiers (LNAs) to reduce loss [1]. We then replaced 9 central co-polarized elements with elements using custom high-performance ambient-temperature CMOS LNAs, achieving in a very low receiver temperature of ~20–30K [2]. Given these encouraging results we are expanding this array to 96 elements (both polarizations), all equipped with CMOS LNAs. This enhanced AFAD will feed a real-time digital beamformer. Initial testing will be done in aperture-array mode using the sky as a cold load and a large panel of microwave absorber as a hot load. The array will then be deployed on the DVA-1 offset Gregorian reflector antenna [3], allowing us, for the first time, to evaluate a PAF on an offset dual reflector telescope similar to what will be used for SKA-MID. This presentation will give a status report on this project.

References:

[1] B. Veidt, T. Burgess, K. Yeung, S. Claude, I. Wevers, M. Halman, P. Niranjanan, C. Yao, A. Jew, A. Willis "Noise Performance of a Phased-Array Feed Composed of Thick Vivaldi Elements with Embedded Low-Noise Amplifiers," *9th European Conference on Antennas and Propagation (EuCAP)*, 2015.

[2] A. Beaulieu, L. Belostotski, T. Burgess, B. Veidt, J. Haslett , "Noise Performance of a Phased-Array Feed with CMOS Low-Noise Amplifiers," *IEEE Antennas and Wireless Propagation Letters*, 2016.

[3] G. Hovey, L. Baker, G. Cortes, D. DeBoer, M. Fleming, W. Imbriale, G. Lacy, B. Veidt, P. Byrnes, J. Fitzsimmons, L. Knee, M. Kesteven, "Dish Verification Antenna 1: A Next Generation Antenna for cm-Wave Radio Astronomy," *URSI AT-RASC*, 2015.

Early commissioning results from the Focal-plane L-band Array feed for the Green Bank Telescope (FLAG)

B. D. Jeffs[1*], R. A. Black[1], K. F. Warnick[1], R. M. Prestage[2], J. Ford[2], S. White[2], B. Simon[2], W. Shillue[3], A. Roshi[3], D. J. Pisano[4], D. Lorimer[4]

[1]*Brigham Young University, Provo UT, USA*

[2]*Green Bank Observatory, Green Bank WV, USA*

[3]*National Radio Astronomy Observatory (NRAO) CDL, Charlottesville VA, USA*

[4]*West Virginia University, Morgantown WV, USA*

* Contact: bjeffs@ee.byu.edu

Abstract— West Virginia University, the National Radio Astronomy Observatory (NRAO), and Brigham Young University have been collaborating over the past three years to develop the first, permanent cryogenically cooled L-band phased array feed (PAF) for a major single dish radio telescope. This new instrument for the Green Bank Telescope underwent initial commissioning tests in July and August 2016. The presentation will highlight results and performance data from these tests, including first light observations, beamformer calibration methods, field of view sensitivity calculations, radio camera snapshot imaging, and beampattern measurements. The design approach and system architecture for the PAF array sensor, analog front end and signal transport, frequency channelization, and back end real-time digital beamformer/correlator/spectrometer will be presented.

This first commissioning run utilized a preliminary single unit digital back end (one of five planned units.) This limited observing to 30 MHz of aggregate instantaneous bandwidth as separated subband blocks spanning the instrument's designed total bandwidth of 150 MHz. A second commissioning run will take place in 2017 with the full complement of back end units and full bandwidth coverage. The recent commissioning tests have served as thorough engineering evaluations to confirm operational integrity and performance baselines.

With its large filed of view, FLAG will increase telescope survey speed relative to existing single-pixel instruments by a factor of 3-5. This will enable significant new science, including searching for pulsar-black hole binary systems for use in testing gravitational physics in the limit, using pulsars to probe the equation of state of matter at high densities, and a census of diffuse HI around galaxies to answer open questions about galaxy formation, gas accretion, and star formation. FLAG will open up a new parameter space region for studies of the transient radio sky, particularly for bright but low rate transients.

Several technical innovations were introduced in the FLAG design. These include: 1) numerically optimized array element design and spacing for maximum sensitivity over the field of view, 2) the first fully operational cryogenically cooled L-band PAF, using room temperature antenna elements and cryogenically cooled LNAs, 3) a unique digital fiber signal transport system between the PAF array analog front end in the receiver cabin and the digital polyphase filterbank frequency channelizer in the Jansky Lab, and 4) a real-time array correlator which runs concurrently with the real time digital beamformer. This enables real-time adaptive beamforming RFI mitigation, commensal transient searches and fine frequency resolution HI observations, and post-correlation beamforming.

With this unique post correlation beamforming capability, short-term integrated array covariance matrices are stored for each frequency channel as the final data product rather than beamformed spectra. This enables the observation data set to be revisited at a later time using any desired set of beamformer weights for post-correlation beamforming. With this approach one can, "after the fact," address data defects (such as RFI) and study possible resolution enhancements or weak source detection improvements with any desired test beampattern.

We acknowledge the work of the extended project team, including many additional technical staff and graduate students.

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Focal L-band Array for the GBT: Instrumentation Upgrades and Performance Results

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Abstract— A new low-noise cryogenic phased array feed (PAF) optimized for the Green Bank Telescope (GBT) optics has been developed as part of the focal L-band array for the GBT (FLAG) project. The feed consists of near-half-wave elements tuned to operate near 1.4 GHz. The elements are shaped to optimize for active impedance matching to cooled low noise amplifiers (LNAs). Custom designed, sideband-separating, digital downconverters digitize 150 MHz of bandwidth with 8 bit Analog-to-digital converters (ADCs) and transport the data through fiber optic links. The data are received and channelized using poly-phase filter banks (PFB), implemented in Casper's ROACH II based FPGA system. A streaming data acquisition system is used to record one of the PFB channels to disk for initial tests. The data are then processed offline. We present preliminary results from our recent test observation campaign with the GBT.

An update on APERTIF and future PAF activities at ASTRON

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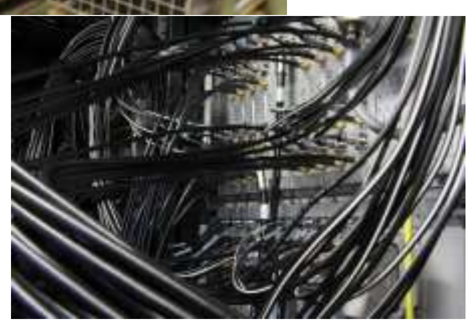
Abstract— As part of the APERTIF project, Phased Array Feeds (PAFs) have been installed in the reflector antennas of the Westerbork Synthesis Radio Telescope (WSRT) in 2015 and early 2016. These PAF systems can simultaneously form 37 beams on the sky at an instantaneous bandwidth of 300 MHz. The multi-beaming capability of the PAFs greatly improves the survey speed of the WSRT, enabling new astronomical science. The upgrade is combined with major maintenance of the telescope structures: The telescopes have been repainted and motor drives, position encoders and end-switches have been replaced. In October 2015, first light was obtained with the first three dishes. At the time of writing, practically all hardware has been installed in all APERTIF dishes and commissioning is in full swing. ARTS, the APERTIF Radio Transient System, extends the wide-field APERTIF imaging system to high time resolution, enabling unique searches for millisecond transients, as well as nanosecond neutron-star timing. ARTS also allows for a wholly new approach to Very Long Baseline Interferometry (VLBI) that produces sensitive, wide-area images at milliarcsecond angular resolution. ARTS passed its CDR with flying colors in March 2016 and is currently being implemented.

A feasibility study has been performed towards a 4-12 GHz PAF. In particular, the potential performance of such PAF operating at room temperature and a cryogenically cooled version has been compared. Conceptual designs for both version have been made and key components have been identified. It has been concluded that, with an approximate system noise temperature below 25 K, a factor of 4 and 3 better than for present and future room temperature PAFs, the choice for a cryogenically cooled PAF is an obvious one.

In my contribution I will present a brief overview of the APERTIF and ARTS systems and provide a status update of the rollout and commissioning work. I will also present the results of the feasibility study towards a high frequency PAF and ASTRON's future plans.



Online Calibration Scheme for APERTIF

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Abstract— The APERTIF (APERture Tile In Focus) project aims to install Phased Array Feeds (PAFs) in the reflector antennas of the Westerbork Synthesis Radio Telescope (WSRT). These PAF systems can simultaneously form 37 compound beams on the sky and will replace the single beam horn feeds. The survey speed of the WSRT will be improved significantly, bringing down the time to execute a deep wide-field astronomical survey by a factor 17. The design phase is completed and samples of final hardware have been tested. Twelve WSRT dishes will have a PAF system, which are already equipped with final hardware. These 12 dishes are now used to characterize and fine-tune the system in detail.

In this contribution, we report on the online calibration system. Within a PAF system, electronic gain drift between receiver chains can occur. These drifts are introduced by various causes, for example a varying temperature gradient over the 121 coaxial cables. Such a variation may be introduced by the Sun starting to radiate on a selected number of coaxial cables, whereas the others are not exposed to sunlight directly. The drift between receiver chains affect the compound beamshapes. To satisfy the beam stability requirements, the beamformer weights should be known to an accuracy of 0.3 dB in amplitude and 2 degree in phase. In order to compensate for the electronic gain variations between receiver chains, the weights will be updated during an astronomical observation, i.e. online. This online calibration is a 6-step scheme. First, the data in the regular data path is flagged as invalid, then an antenna on the reflector surface will radiate broadband noise to the PAF. The complex inter PAF element correlation matrix is recorded for the case that the noise source is turned on and off (see Figure 1). These two matrices are input to an algorithm that returns corrections to the beamformer weights. The corrections are applied in the beamformer and as a final step the 'invalid data' flag is cancelled to continue the observation. The time required for online calibration and how often it should be executed are two items that are part of the experiments scheduled for the upcoming months. Experiments also include a path from the noise diode directly into the calibration correlator (see Figure 2). This enables recording the direct correlation between PAF elements and the noise diode. There is a possibility that this can reduce the required time for online calibration or make it more accurate.

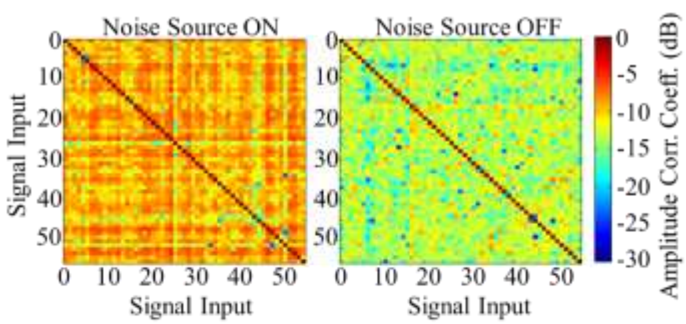

Figure 1: Absolute part of inter element correlation matrices. The noise source is turned (left) on and (right) off.

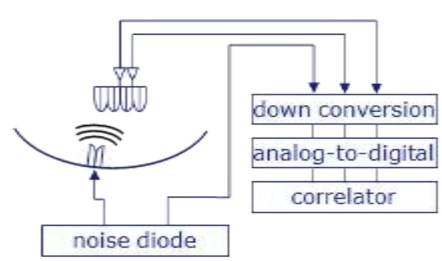

Figure 2: Block diagram of the calibration system.

Development of the L-band Phased Array Feed for the Five-hundred-meter Aperture Spherical radio Telescope

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Abstract—Phased array feed (PAF) is an emerging technology which can greatly improve the survey speed of telescopes. As a world-class radio telescope, the Five-hundred-meter Aperture Spherical radio Telescope (FAST) is also trying to enhance its observation capability and open up new scientific studies at several frequency bands by PAFs. At the first part of this paper, the blue print of the FAST PAFs development and corresponding scientific goals are introduced, as well as the progress has been made in these PAFs.

Among these multi-beam receivers, the L-band FAST PAF is of the greatest importance and most developed. It is expected to have more than 100 digital formed beams, with cryogenic low noise amplifier, and even cooled feeding array to achieve possible highest sensitivity. Cavity-backed dipoles are adopted to cover the frequency from 1.05 to1.45GHz, for the merits of wide bandwidth and lower mutual coupling between elements. This paper presents the details of the L-band PAF design, estimated system performance, and some test results of the first prototype components.

Compared with traditional single pixel feeds, another advantage of PAF is adaptive beam-former, which can be employed to compensate the vibration of feed cabin. This will largely reduce the burden of the mechanical positioning system, and improve the pointing accuracy at higher frequencies. Some results of this study will be presented also.

Measuring PAFs at CSIRO

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Abstract— This presentation will summarise work to measure and understand the antenna properties of phased array feeds (PAFs) at CSIRO.

CSIRO has made numerous measurements of PAF receiver noise temperature in aperture array mode [1–3] and PAF system-temperature-over-efficiency as installed at the focus of a paraboloidal reflector [4, 5]. We have also applied calibrations, using on-reflector noise sources and near-field antenna range measurements, to make aperture array measurements with beam weights that match the focal field of specific reflector geometries, allowing estimations of on-antenna performance without installing the PAFs on antennas [6].

Recently, we used different approaches to isolate the system noise temperature and aperture efficiency on a PAF installed on a telescope. From drift-scan measurements of the sky, we have fitted the received power to models of the radio sky and jointly solve for system temperature and aperture efficiency [4, 6]. On the same system, we have measured system-temperature-on-efficiency on a celestial source and then, with the PAF still installed on the telescope, immediately measured system temperature by inserting microwave absorber in front of the PAF [7]. Aperture efficiency was estimated by dividing the system-temperature-on-efficiency and the system temperature; both were measured with the same beamformer weights and the same reference sky measurement to ensure common external contributions such as spillover.

This presentation will compare the results of the above techniques and highlight the extent to which they give consistent results. The prognosis is good and we are starting to achieve some consistent measurements of noise temperature and aperture efficiency via different approaches. Also, we have made the first quantifications of spillover for our installed PAF systems.

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First astronomy with a modified Mark II ASKAP PAF on the 64 m Parkes radio telescope

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Abstract— We will present the first astronomical observations made with a modified Mk. II ASKAP phased array feed (PAF) on the 64 m Parkes radio telescope [1]. We have successfully observed pulsars, hydrogen absorption in a young radio galaxy at redshift z=0.44, and hydrogen emission from our own galaxy. We will also summarise efforts to calibrate and characterise PAF beams.

The Max Planck Institute for Radio Astronomy (MPIfR) is collaborating with CSIRO to begin astronomy with the PAF on the Parkes 64 m radio telescope. After a 6-month commissioning and observing program at Parkes, this PAF will be installed on the 100 m telescope at Effelsberg.

A key application for this PAF will be to search for fast radio bursts (FRBs).

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The Max-Plank Institute for Radio Astronomy financed the PAF discussed in this abstract and its modification for a less radio-quiet site. The Parkes radio telescope is part of the Australia Telescope National Facility which is funded by the Australian Government for operation as a National Facility managed by CSIRO.

The development of a CSIRO MKIII wideband phased array feed

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Abstract— At the 2015 phased array feed workshop in Penticton we presented a preliminary investigation of a wideband phased array feed design. This design, the CSIRO MKIII PAF, is based around a body of revolution element which resembles a rocket. At that time we were able to report on the performance of the LNA and the simulated performance of an infinite array based upon the array unit cell. Here we present further developments in the design, simulation, manufacture and testing of this PAF.

We have manufactured a prototype 40 channel array employing the 'rocket' elements and the accompanying edge elements. The array is operated at room temperature and is populated with six RF modules containing the LNA, post LNA amplification, filtering and RF over fibre transmitters. Each RF module contains eight channels.

In order to more accurately predict the performance of the 40 channel prototype we have undertaken a full 3D finite element simulation of the array including edge elements. We combine this simulation with the simulated S-parameters and noise parameters of the LNA to estimate the noise temperature of the array with various weighting schemes. We also calculate the beam parameters including the aperture efficiency of the array when illuminating a parabolic dish such as the Parkes Radio Telescope.

As a simple test of the noise performance of the PAF we have made a Y-factor measurement using an analogue summing network. This measurement used the sky as a cold load and room temperature absorber as the hot load. The results from simple analogue beamformer are in good agreement with simulation and confirm the simulated minimum noise temperature of 15K.

In order to evaluate the noise performance of the array with a port weighting close to the weights that might be expected when in use on a parabolic reflector we have performed a Y-factor measurement using the ASKAP BETA digital receiver. The digital receiver allows for the measurement of the full noise covariance matrix enabling the noise temperature to be evaluated with arbitrary sets of weights. We have also performed Y-factor measurements using absorber cooled by liquid nitrogen as an alternative approach to using the sky as a cold reference. We will discuss the merits and limitations of this approach.

Lastly, we present measurements of the system noise temperature and Tsys/Efficiency with the array on the Parkes Radio Telescope. These initial measurements do not agree well with simulation. We speculate that the usefulness of these measurements is limited by several factors, most notably by an increased noise floor due to intermodulation products caused by high levels of RFI at the Parkes site.

Figure 1. The 40 channel prototype array during testing at the Parkes aperture array test facility.

High Polarisation Isolation Crossed-Ring Antenna Array for SKA-MFAA

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Abstract— The Octagonal Ring Antenna (ORA) array has been developed by the University of Manchester for possible use for Mid-Frequency Aperture Array in SKA phase 2 [1] [2]. ORA is a printed structure incorporating capacitively coupled radiating elements. The benefits that ORA can bring include: a) broad bandwidth with a frequency ratio of about 4:1; b) a planar structure with a low profile; c) ease of manufacture, using low cost printed circuit techniques; d) good scalability: for example 300MHz – 1GHz or 3GHz -10GHz and beyond; Therefore the concepts of the ORA could be extended into other useful frequency ranges.

The "Mid-Frequency Aperture Array" (MFAA) is a part of the SKA programme. The SKA Mid-Frequency Aperture Array (SKA-MFAA) is proposed to operate in the frequency range from 450MHz to 1450MHz. Front-end design is crucial part of the aperture array as the system noise performance will be dependent on the front-end design solution. For SKA use, the antenna array needs to integrate the low noise amplifier to minimize the noise temperature. In this paper, a modified crossed-ring antenna array, representing the latest generation of ORA, is presented. Compared to the initial design of ORA, this crossed-ring antenna array has improved polarisation isolation and integrated low noise amplifier. The crossed-ring antenna array can be fed with a differential or single-ended (LNA) + balun. The differential front-end design is discussed in this paper as this removes the need for the Balun. The LNAs have been developed by researchers at the Observatoire de Paris, Nançay Observatory. The LNA is integrated with the crossed-ring element in close proximity and this reduces the feed line losses thus generates a lower noise temperature.

To verify the proposed design, a 10 x 10 dual-polarised finite crossed-ring antenna array has been prototyped. The working frequency is between 400MHz and 1450MHz. The separation between the antenna elements is 125mm. The array has a low profile with a thickness of less than 10cm. Only the central 64 elements are excited, while the 36 elements on the edges are terminated with the matched loads. Each excited element has integrated 2 low noise amplifiers for its dual polarisation. The simulation results verify the broad bandwidth and low noise temperature performance of the proposed differential front-end solution. Measurements have also been carried out to test the prototyped antenna array's characteristics and its performance.

Figure: Crossed-ring antenna array working at 450MHz-1450MHz with the improved polarisation isolation and integrated LNAs

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A 160 channel Cryo Phased Array Camera for Radio Astronomy

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Abstract— Beam-formed phased array feeds enable full and continuous access to the instantaneous field of view (FoV) available at the focal plane of a radio telescope's optics, this combined with fully cryogenic antenna elements and low noise amplifiers to lower the beam-formed system temperature results in survey speed improvements of several orders of magnitude compared with single pixel systems. We are presenting the current concept design for an 80-element (160-channel) Cryo-PAF camera the Arecibo radio telescope.

The instrument's front-end camera is designed to cover the frequency band form 1.280 GHz to 1.720 GHz. The antenna elements are dual-polarized sleeve dipoles and LNA assembly cryogenically cooled to 15 K. The camera will be capable of producing in real-time 40 dual-polarized digitally formed beams, in the FoV of the telescope, with a system temperature goal of < 30 K. The input receiver bandwidth per channel is 312.5 MHz (tunable within the front-end frequency band), yielding a total instantaneous processing bandwidth of 50 GHz. The camera's back-end will provide 800 coarse channels with a bandwidth of 390.625 kHz and 26,600 fine channels with a resolution of 12.2 kHz.

We will present the current design concept for this cryo-phased array instrument, including the electromagnetic and cryo-mechanical design of the front-end camera, data transport, digital beam-former and back-end systems.

CryoPAF4 – a cryogenic phased array feed design

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Abstract— For earth- and space-based astronomical telescopes, the microwave (1-10 GHz) and millimeter-wave (10-300 GHz) frequency ranges contribute a wealth of information inaccessible at optical frequencies. There is a drive for wider bandwidths and larger fields of view without compromising the stringent sensitivity required to detect farther and fainter sources, pushing antenna and receiver technology to extreme limits.

Currently microwave/millimeter telescopes with mature cryogenic single pixel receivers have been upgraded to multi-pixel receivers and phased array feeds (PAFs) to increase effective field of view and in turn, imaging speeds. The Square Kilometer Array (SKA) has fostered early research and development of room temperature L-band (1-2 GHz) PAFs at DRAO (Canada), ASKAP (Australia) and at ASTRON (Netherlands) with system temperatures in the 40-70K range. However to attain superlative performance as compared to a single pixel feed, cryogenically cooling part or all of the front end is essential to match the high level of sensitivity possible with large reflector diameters and very low system temperatures. Cryogenic PAF research at L-band with AOPAF (Cornell U.-Arecibo) and NRAO/BYU's warm dipole and cooled LNA system have achieved 36K and 45K system temperatures respectively.

We propose a 2.8 – 5.18 GHz dual polarization coherent PAF receiver with cryogenically cooled antennas and amplifiers, to demonstrate the feasibility of sub-20K system temperatures to compete similar noise levels of single pixel receivers but at a higher frequency than current cryogenic PAFs. The resulting increase in field of view and survey speed is a factor of ~8 compared to a single pixel receiver through the production of multiple farfield beams in the beamformer.

The PAF receiver architecture is composed of a cryostat with a 50 cm diameter composite laminate radome window/aperture. Internal to the cryostat are layers of RF transparent heat shields reflecting the infrared radiation through the radome, attenuating the thermal transfer from ambient onto the large metal antenna array elements. This antenna array is composed of 140 dual-linear Vivaldi blades configured on a square grid. The 3.5 K noise temperature amplifiers and the Vivaldi blades and feeds are all cooled to 16 K. Concentric thin metal cylinders provide necessary thermal insulation to the low noise amplifiers and coaxial cables leading out of the dewar. External to the cryostat for each of the 96 active receiver chains is a bandpass filter followed by a 35 dB amplifier and a digital beamformer performing direct digital 8-bit sampling, frequency band selection, beamforming and array covariance matrix calculation. The 96 input RF signals form 18 dual-polarization beams; 36 in total. The expected total receiver temperature is 11 K.

Planned tests on DVA-1, an offset Gregorian 15 m dual-reflector telescope located at DRAO Penticton. The half opening angle at the focus to secondary is 55 degrees with a -16 dB feed edge taper. Physical and geometrical optics modelling analysis of the focal plane array will be shown including focal plane beam placement and resulting farfield beams, overlap, and aberrations off axis.

Variable Dielectric Delay Lines in Liquid Crystals for Phased Array Feeds

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Abstract— In this project we seek to exploit a novel liquid crystal (LC) technology, which allows a controllable true time delay (TTD) to be applied to an RF signal of frequencies up to tens of Giga-Hertz. The basic technology has already been demonstrated and has a wide variety of applications. We now intend to use this technology to construct a real astronomical demonstration system for delay lines and show that these can be integrated into the beam-forming module of an existing Phased Array Feed (PAF) instrument, dramatically improving its capabilities.

PAFs are an essential next step for radio astronomy. They offer the possibility of increasing a telescope's Field-of-View (FoV), of improved calibration and of allowing operation up to high frequency. PAFs have been implemented in instruments such as PHased Arrays for Reflector Observing Systems (PHAROS) and can achieve these goals, but over a narrow bandwidth due to the use of phase shifters in the beam-former hardware. In this project we seek to implement a TTD beam-former, which will allow the whole available bandwidth to be used. This will make use of novel technology — LC stripline whose dielectric constant can be varied by application of an AC voltage. We propose a two year programme during which we will produce a PAF module using a set of TTD units that will be tested within the PHAROS receiver, which is available for use on this project and will make an ideal test-bed. Our focus is on demonstrating the Technology Readiness Level (TRL) of these delay lines in the context of a prototype instrument, thereby addressing integration issues as well as pure technology development.

The objective of this project is to realise the potential of a TTD signal module implemented by a controllable dielectric constant LC through construction of the hardware for a PAF. Achieving this will develop this promising LC technology from TRL 4 to TRL 7. To this end, in this project we will: develop a unit and its associated control hardware which can apply a true time delay to a 4–8 GHz signal; produce a set of 13 (plus 2 spares) of these units; and demonstrate that these units when incorporated into one module of the PHAROS receiver can be used to form a single steerable broad-band beam.

Cryo-mechanical solutions for a cryostat equipped with a large window: The PHAROS case.

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Abstract— PHAROS, is the acronyms of a PHased Array for Reflector Observing System. It is basically a low-noise, phased receiver array to be installed on primary focus of wide radio-telescopes. It has been financed by a JRA *RadioNet* trough FP6.

In this talk, the adopted solutions for the cryo-mechanical realization is presented.

The challenging problem related to the required vacuum window, as large as 60 cm, and the huge shield system are shown in details. The heat flowing through the window has been determined experimentally; the measurement is presented as well the practical solutions adopted to reduce such heat flux.

Finally, are given some considerations on cooling power when the receiver will be installed on antenna like SRT.

PAF Aperture Array Tests: Analog and Digital Beamforming Compared

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Abstract— Over the years of PAF testing we have sought to increase our confidence in our measurement systems. This has become increasingly important as the equivalent noise temperatures of our arrays has dropped from over 100K to under 20K. One recent step is the use of an analogue beamformer as an adjunct to the main digital systems we use.

We have predominantly performed the beamforming digitally, largely because we have had the systems available as part of the ASKAP development. The data is stored in a way that has allowed weights to be determined and applied in the post processing stage. This flexibility allows a range of investigations not available in the analogue approach, including applying weightings that match those that will be used in the focus of a dish [1].

Our digital beamforming systems do have disadvantages stemming from their complexity and that they are designed to be part of an operating radio telescope rather than a measurement instrument. These issues increase the difficulty in a number of areas:

- calibrating the ‘backend’ contribution
- dealing with RFI
- identifying uncertainties the measurements
- identifying errors in the post processing.

As a check of the data quality, we have used simple equal weight analogue beamformers (signal combiners) to provide a comparison this one beam weighting. We will present the results of this comparison and discuss the uncertainties in both digital and analogue beamformers. Other advantages have been extending the frequency coverage beyond the digital backend band and the speed of the measurement process.

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The ASKAP Phased Array Feed Digital Beamformer: Design Overview and Performance Characteristics

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Abstract— We present an architectural overview, design details and performance bounds of the digital beamformer developed for the new Phased Array Feed (PAF) system that forms the heart of the Australian Square Kilometer Array Pathfinder (ASKAP). ASKAP is a 36-antenna aperture synthesis radio telescope array. The ASKAP back-end Digital Signal Processor (DSP) is based on the *FX* correlator architecture [1] where division into narrow frequency bands (*F*) is done prior cross-correlation (*X*). In the ASKAP DSP, the frequency channelization is done in two stages: a coarse channelization stage and a fine channelization stage. A digital beamformer is implemented between these two stages [2] so that coarse channelization is done on PAF port voltages while fine channelization is performed on beam voltages. The entire ASKAP back-end DSP is implemented using Field Programmable Gate Array (FPGA) technology with the digital beamformer capable of simultaneously forming 36 dual-polarized beams in real-time from 188 PAF receiver element voltage signals across a total bandwidth of 384MHz.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been using the ASKAP digital beamformer almost continuously since mid-2014 for both engineering characterization trials of the PAF system and for early astronomy science observations. As such, CSIRO Engineering and Science teams have acquired substantial knowledge and experience surrounding the operation, performance characteristics and limitations of the ASKAP beamformer architecture [3-6]. In this presentation we provide an overview of the complete ASKAP signal path for the back-end DSP; from the PAF "checkerboard" element array samplers through to the correlator and we highlight the location of the digital beamformer and its associated modules within this structure. We focus on the digital beamformer implementation and how it is operated and controlled in combination with its partner computational module, the Array Covariance Matrix (ACM).

We review some of the key operational parameters of the ACM and digital beamformer including computational load, ACM data dump rates, beamformer weight upload rates and beamformer output dynamic range monitoring and control. The computational load and data transfer rates, in particular, are the determining factors for the dynamic beam update rate.

Finally we will provide a brief overview of the latest development for the DSP firmware, namely a 10GE beamformer interface for streaming beam voltage data directly from a single PAF system to a network switch and post-processor (such as a GPU cluster). This work was done primarily for the single-dish PAF system to be installed on the Effelsberg 100m diameter radio telescope in the North Rhine-Westphalia region of Germany for the Max Planck Institute for Radio Astronomy.

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A[nother] beamforming strategy
An information theoretic look at beamforming with PAFs

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Abstract— Phased array feeds (PAFs) enable the customization of the response of a dish antenna in order to meet the technical requirements of an experiment (e.g. increasing its Field-of-View (FoV) or offering multiple independent steering directions).

The beam design strategy suggested in the literature for astronomical PAFs consists in forming a set of narrow-band beams maximizing the sensitivity of the instrument in independent steering directions. Uniformly-sensitive FoV can then be approximated with selecting the appropriate number of beams and their separation for instance.

This strategy relies on a very physical interpretation of beamforming, and induces a redundancy of information collected by the instrument due to beam-to-beam correlation.

We suggest in this work a different look at beam formation with PAFs based on the minimization of the mutual information brought by multi-beamforming systems. We set up a practical framework allowing the information-efficiency evaluation and, in a near future, the design of optimum PAF multi-beamformers.

Spatial RFI mitigation with Phased Array Feeds

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Abstract— Active Radio Frequency Interference (RFI) mitigation is becoming a necessity for radio astronomy due to the increasing instrumentation sensitivity coupled with a rapidly filling spectrum occupancy. Even Radio Quiet Zones and frequency allocations are reaching their protection limits due to strong and / or moving transmitters (e.g. satellites, airplanes, atmospheric ducting events…).

The current and popular approach to perform RFI mitigation consists in automatically or manually monitoring various statistics of the received signals and excise potentially corrupted time and frequency data slots. This method is efficient up to a selected Probability of Detection, but more generally suffers from a possibly significant loss of data – impacting therefore the instrument efficiency.

Phased array feeds combine the flexibility of phased array technologies as well as the sensitivity of single dishes telescopes. Among various advantages, the possibility to perform RFI mitigation in the spatial domain is of high interest to radio astronomy as it allows the recovery of uncorrupted time and frequency data.

Spatial filters are either constructed blindly - using nothing more than the data provided by the array, e.g. multivariate time series or covariance matrices - or supported by prior information regarding the interferer, e.g. location, trajectory, statistics... The latter scheme shows superior RFI rejection and astronomical information recovery levels, but early results for both implementation strategies show outstanding performances.

After modeling the data received by a phased array feed, we are going to address in this talk the problem of RFI detection and mitigation. In particular, we are going to evaluate the optimum performances expected by such system in terms of astronomical information retrieval in a corrupted scenario, and compare standard filtering algorithms performances to these bounds. We will also present various examples of simulated and implemented spatial filters.

Fast Numerical Method for the Simulation of Hexagonal Focal Plane Array

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Abstract— this communication extends the ASM-MBF fast numerical method to the simulation of triangular lattice array for focal plane applications. The ASM-MBF method reduces the needed memory and time for the simulation of antenna arrays by compressing the MoM matrix using infinite array solution and small finite array. The current of each antenna element will be expressed as a linear combination of the pre-calculated set of current distribution. In order to numerically validate the implementation of the ASM-MBF as an effective method for the simulation of large hexagonal lattice arrays, we simulated an array of flat Vivaldi antennas, then we compared the obtained results with the brute force solution. The comparison in term of port current shows an error below −40 dB when we used 2 × 2 ASM simulations combined with the current distribution from the solution of a finite array of 12-elements (see Figure 2).

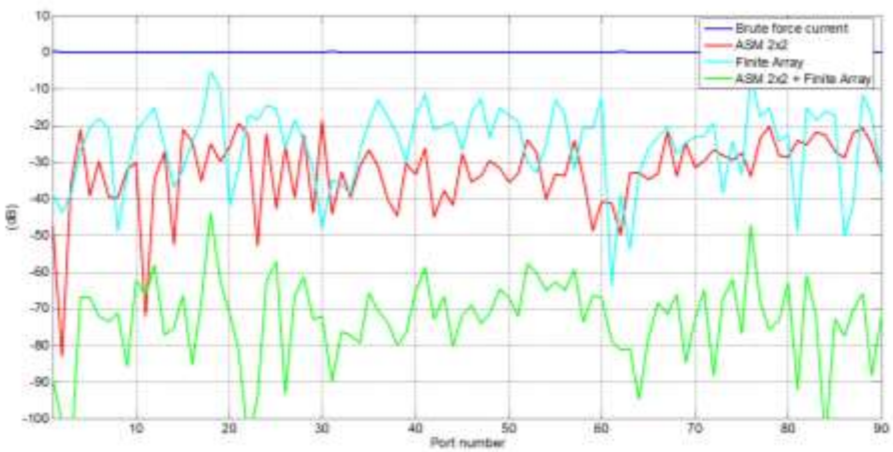

Figure 2: Comparison of the brute force port current and the error of ASM-MBF simulated currents.

Finally, we present the design of metallic 3D Vivaldi antenna and we simulate its performance in a large hexagonal array of 91 antenna elements (see *Figure 3*). Simulation results will be compared in terms of gain, beam width and scanning resolution to the performance of a planar dual polarized array of 61 antenna elements occupying the same surface (see *Figure 4*).

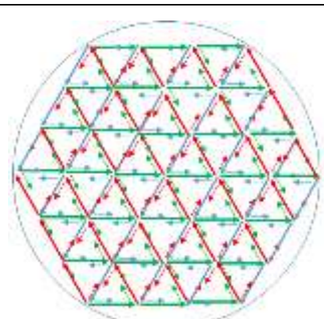

Figure 3: Hexagonal array of 91 TSA elements.

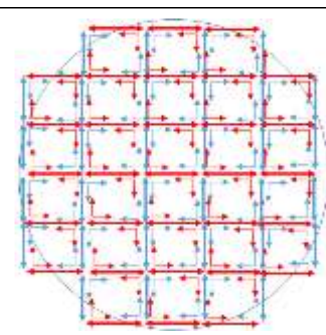

Figure 4: Dual polarized planar antenna array of 61 TSA elements.

SKA as Piggyback on Solar Power Towers?

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Abstract— The growing global investment in renewable energy has lead to the construction of enormous areas of solar concentrators, all of which lie idle at night. They have surface accuracies sufficient for efficient operation at gigahertz frequencies and so far four square kilometres of collecting area are operating in the form of solar power towers, which form a point focus convenient for installing a radio receiver. We have been thinking how one might combine signals from the mirror field to form a single dish or interferometric array with equivalent diameter of eg 620 m in the case of Gemasolar in Spain. However, the mirror field does not lie on a parabola and so the signals sum incoherently in the focal plane to produce a speckle pattern. To form a coherent sum and gain the full sensitivity of the aperture calls for a focal-plane array with the number of elements similar to the number of mirrors in the field. One would form phased-array beams directed at each mirror and apply a digital delay for each beam according to the path length to be compensated to each mirror before summing. I will introduce the concept and possible array configurations that we have considered so far.

PAFs for imperfect optics

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Abstract— In this contribution we study how PAFs can recover SNR in the case of optics that do not produce an optimal focal image. This is motivated by the idea to use Solar Power Tower arrays for radio astronomy (see talk by Alan Roy). These arrays cannot combine radiation coherently, so that standard receivers would not utilise the huge collecting areas. PAFs can solve this problem by collecting all the received radiation and realigning it to form a coherent sum. Preliminary calculations are very promising and we are currently investigating options for tests with real Solar arrays. An application of the same idea that is closer to standard astronomical equipment is to use PAFs to correct for optical aberrations caused by imperfect optics, e.g. in parabolic reflectors beyond their design frequency. In this way it is potentially possible to use the largest dishes at much higher frequencies than currently possible.

Time permitting I will also present the status of the "PAF for Effelsberg" project.

First astronomy results from PAFs

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Abstract— I will give an overview of recent astronomy results obtained using PAF-equipped radio telescopes. I will focus in particular on astronomy papers published during the last two years using data from ASKAP/BETA. These are the first successes of PAFs as radio astronomy intruments. They include the study of the variable radio sky, the imaging of very large fields in radio continuum, and the imaging of radio spectral lines both in emission and absorption. These studies provide a glimpse of the large surveys to come, and I will give a broad overview of the main scientific goals of those surveys.

I will discuss some aspects of data processing, e.g., how standard calibration procedures scale when a telescope is equipped with PAFs, and how our science is affected beam forming and beam stability. Finally, I will show the scientific relevance of the ongoing effort to decrease PAFs' system temperature as well as develop active RFI mitigation techniques.

The CSIRO Astronomy and Space Science Phased Array Feed Development Program

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Abstract— CSIRO is currently undertaking a number of complementary projects focused on the developing of PAF systems for radio astronomy. These projects include development of the Australian SKA Pathfinder (ASKAP); installation of a modified ASKAP Mk II PAF on the Parkes radio telescope, in partnership with MPIfR; development of the next generation of PAF feed elements and Low Noise Amplifiers (LNAs); and demonstration of a range of concepts which are relevant to the future of PAFs on the SKA.

The largest element of the CSIRO program ASKAP, is now entering the final stage of construction and the emphasis of the project is moving away from construction to commissioning and early science. This presents both challenges and opportunities for CSIRO Astronomy and Space Science (CASS), as the engineering team which has primarily devoted to production and installation of PAF systems on ASKAP now moves back to the development of future systems. We will describe the challenges associated with the evolution of the CASS engineering program, outline the various elements of the current PAF program, describe how these elements may combine to progress work in key areas and discuss areas where additional development activity may be relevant.

One of the other significant components of the CASS PAF development is associated with the SKA. The SKA re-baselining process resulted in the deferral of SKA_Survey and consequently the deployment of phased array feeds as part of SKA1. Prior to re-baselining, the SKA dish consortium developed a single dish design for SKA_Mid and SKA_Survey which was compatible with the installation of PAFs. CSIRO and the other SKA partners involved in PAF development have continued their engagement in the SKA Dish consortium with the aim of ensuring that the SKA_Mid dish will continue to support the deployment of PAFs at some point in the future. The SKA office has recognised that PAFs remain an important technology for the future of radio astronomy and have taken steps toward continuing SKA related PAF development as part of the SKA Advanced Instrumentation Program (AIP). An update on progress towards establishment of this program as part of SKA pre-construction will also be presented.

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Objective questions from last year workshop

(PAF2015 Workshop, NRC-DRAO, Penticton, Canada):

- what are the optimal beamformer weights for astronomy (not just max-SNR) and how do we get them?
- standing waves – do PAFs suppress them or not?
- why haven't cryogenically-cooled PAFs provided ultra-low noise temperatures?
- how to perform parallactic-angle de-rotation, mechanically or electronically?
- how often do beamformer weights have to be updated?
- do we need a local signal (e.g. source on dish surface)?
- how can we come up with a set of terms for the different levels of calibration (beamformer, phase/gain tracking, flux scale, self-cal)?
- What is the maximum/minimum number of formed beams and overlap amount?