CEOI 5th and 6th Open Calls
Final Review

High-Level System Integration of UK Receiver Technology for STEAM-R & MWS

RAL Space, STAR-Dundee Ltd

BMA House, Tavistock Square, London

20 March 2013

Outline

- Project Background
- Aims of Current Project
- Review of UK Support to STEAM-R
  - Introduction to STEAM-R
  - Previous development work related to current project
- Technical Report on Current Project
- Achievements v Goals, Issues & Problems Encountered, Positioning Achieved
- Roadmap / Future Activities

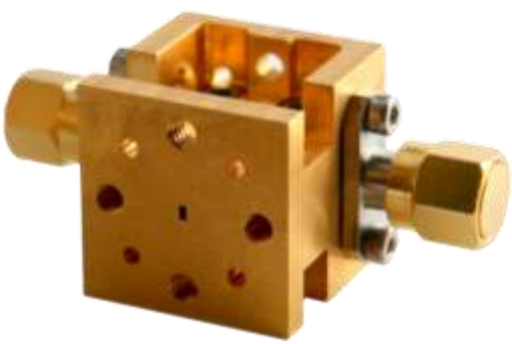
Project Background

- UK invited to support Swedish-led development of STEAM-R (2003)
  - Follow-on to ODIN mission
  - Millimetre-wave payload of PREMIER mission (EE7)
- Core UK support funded through CEOI (from Phase 1)
  - Science support (Remote Sensing Group, RAL Space)
  - Critical hardware development (MMT Group, RAL Space; Astrium Ltd; STAR-Dundee Ltd)
- Related activities
  - Deployment of MARSCHALS in PREMIER-Ex & ESSENCE science campaigns (ESA/NCEO/STFC)
  - Development of wideband spectrometer (ESA/STAR-Dundee Ltd/Astrium Ltd)
  - MARSCHALS Upgrade (STFC/UKSA)
- EE7 User Consultation Meeting (this month)
  - Awaiting official decision (expected in May)
  - In event of PREMIER de-selection by PBEO, STEAM-R likely to become Swedish national mission

Aims of Current Project

- System-level integration & characterisation of UK receiver technology
  - Development of Wideband Spectrometer v2 (WBS II) [STAR-Dundee Ltd]
  - Breadboarding & characterisation of total-power radiometer comprising 340 GHz sideband-separating receiver with high-resolution back-end (SHIRM + WBS II) [RAL Space]
  - Preliminary assessment of integration of SHIRM + WBS II receiver into MARSCHALS [RAL Space]

- Risk mitigation in preparation for full upgrade of MARSCHALS



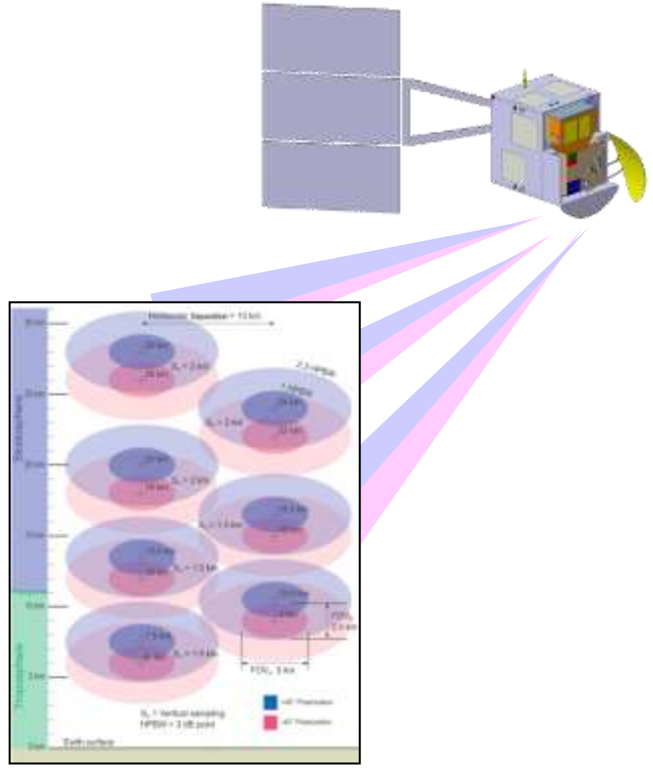
Sub-Harmonic Image-Rejection Mixer (SHIRM)

Wideband Spectrometer II

MARSCHALS on Geophysica

Review of UK Support to STEAM-R

- Purpose of PREMIER
  - Provide better understanding of link between composition of UTLS and climate change
  - STEAM-R provides observations in presence of cloud (H_2O, O_3, N_2O, CO, HCN, …)
- Spectral coverage: 315 – 355 GHz
- Heterodyne receiver array providing 14 simultaneous views through the UTLS
  - DSB (baseline)
  - 2SB (high priority option for lowest views)
- High resolution spectrometer back-end
  - 168 GHz instantaneous BW (min.)
  - Incumbent technology is Digital Autocorrelation Spectrometer (DAS) from Omnisys Instruments



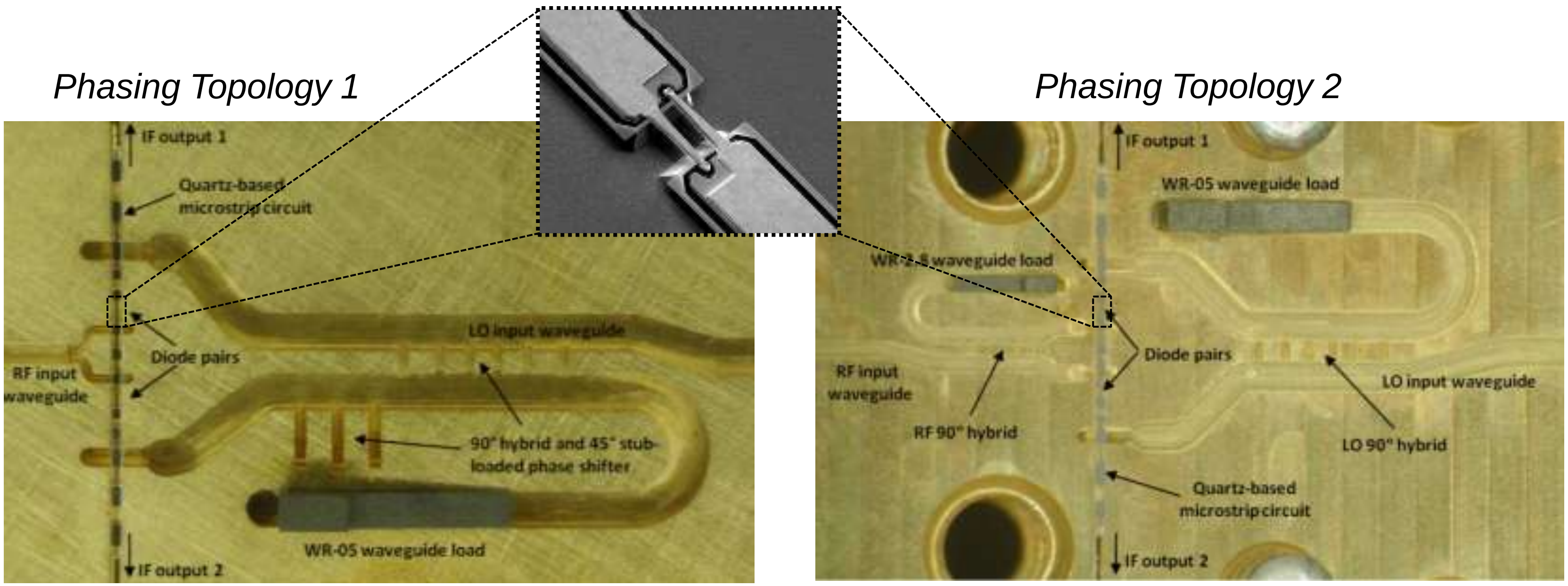
STEAM-R viewing geometry: 14 simultaneous views in UTLS region. Receivers split into two 7-element arrays observing in orthogonal polarisations

Review of UK Support to STEAM-R

Development Review: Sub-Harmonic Image-Rejection Mixer

- SHIRM Optimised performance
  - Sideband rejection: 15 dB min. (>20 dB nom.), IF BW = 2-14 GHz
  - SSB receiver noise temperature: ~3000 K

- Devices employ planar Schottky diode technology from RAL Space

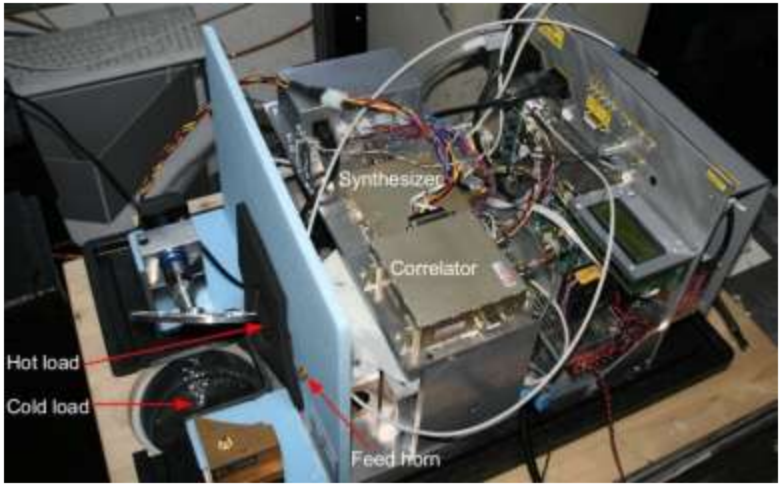


Review of UK Support to STEAM-R

Development Review: Sub-Harmonic Image-Rejection Mixer

- SHIRM receiver deployed at High Altitude Research Station Jungfraujoch in Feb 2012
  - Collaboration with Institute of Applied Physics, University of Bern
  - IAP contracted by Omnisys to undertake atmospheric measurements of their DSB receiver for STEAM-R

Sphinx Observatory: 3480m a.m.s.l

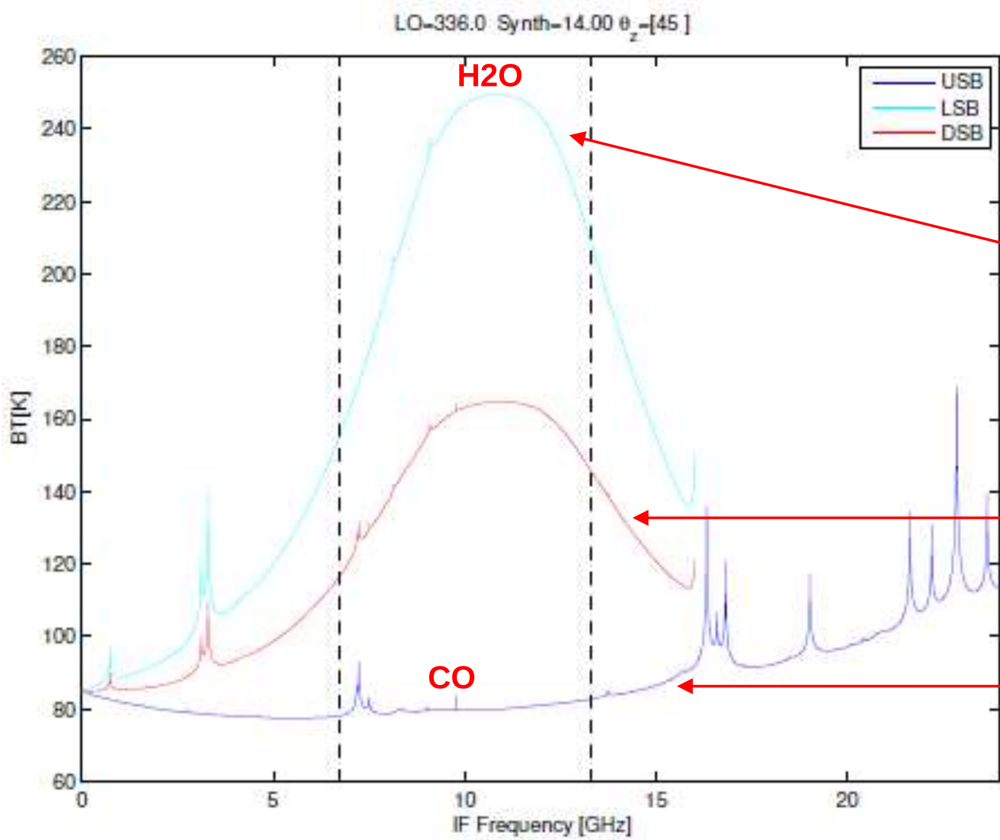


Test-bed comprising:
- UK SHIRM receiver or Swedish DSB receiver
- Omnisys digital autocorrelation spectrometer

Review of UK Support to STEAM-R

Development Review: Sub-Harmonic Image-Rejection Mixer

- Demonstrating SHIRM performance through atmospheric observation



LSB = 323-329 GHz
USB = 343-349 GHz

LSB dominated by H2O line @ 325.15 GHz

Average of LSB & USB would be output from DSB receiver

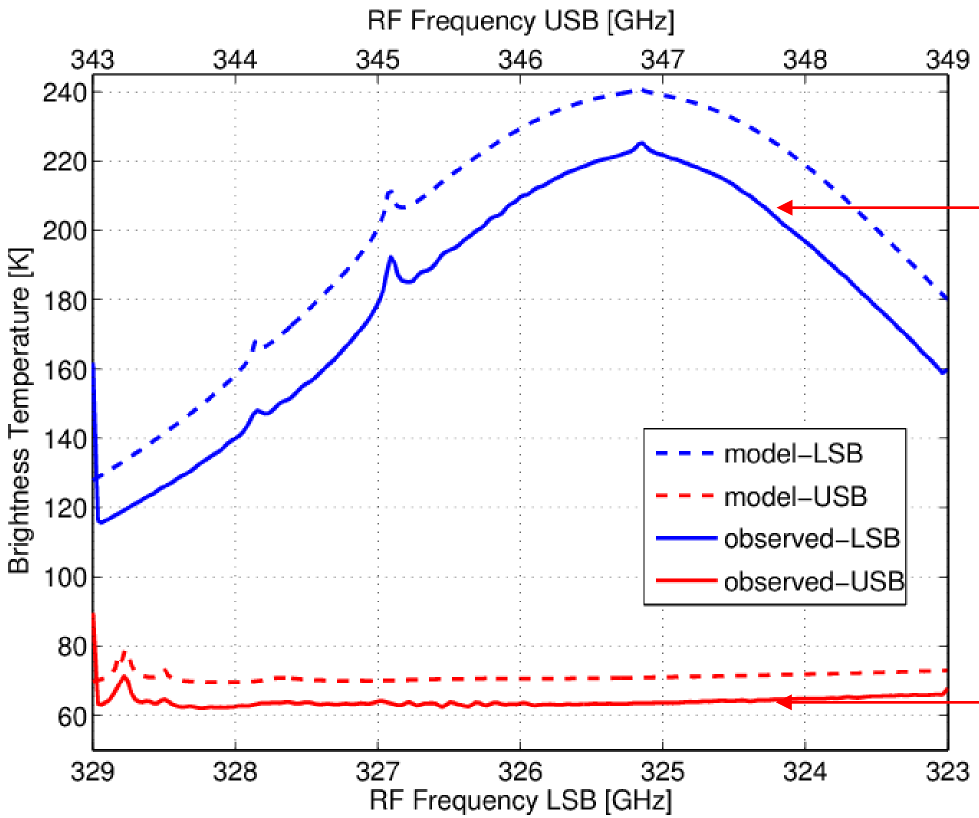
USB mainly continuum emission with weak CO line at 344.9 GHz

Simple atmospheric simulation at mid-latitudes

Review of UK Support to STEAM-R

Development Review: Sub-Harmonic Image-Rejection Mixer

- Successful demonstration of sideband separation receiver
  - Sideband separation of 24 dB inferred from atmospheric data



H2O line observed in LSB

No breakthrough of H2O line in USB (indicates high level of sideband separation)

Review of UK Support to STEAM-R

Development Review: Wideband Spectrometer

- Prototype Wideband Spectrometer (WBS) developed by STAR-Dundee Ltd / Astrium Ltd (ESA Wideband Spectrometer Study)
  - Digital FFT-based, real sampling @ 3 Gsamples/s max
  - Bandwidth 1 GHz, Resolution 1 MHz

- Additional work funded in CEOI 4th call project
  - Characterisation with mm-wave front-end (MARSCHALS)
  - Options for increasing bandwidth and route to space implementation
  - Recommendations for WBS v2

Prototype WBS

WBS Characterisation at RAL

Technical Report on Current Project

Project Status

- WBS II Development
  - WBS II undergoing final testing at STAR-Dundee Ltd
  - Two units being assembled for delivery to RAL
- SHIRM-WBS II Instrument Breadboard
  - Instrument integration at an advanced stage
  - Test of sub-systems partially completed
  - Awaiting WBS II units
- MARSCHALS Upgrade Study
  - SHIRM front-end integration study complete
  - Awaiting final WBS II performance / budgets as inputs to backend integration study
- Target completion date: End June 2013

Technical Report on Current Project

Wideband Spectrometer II Development

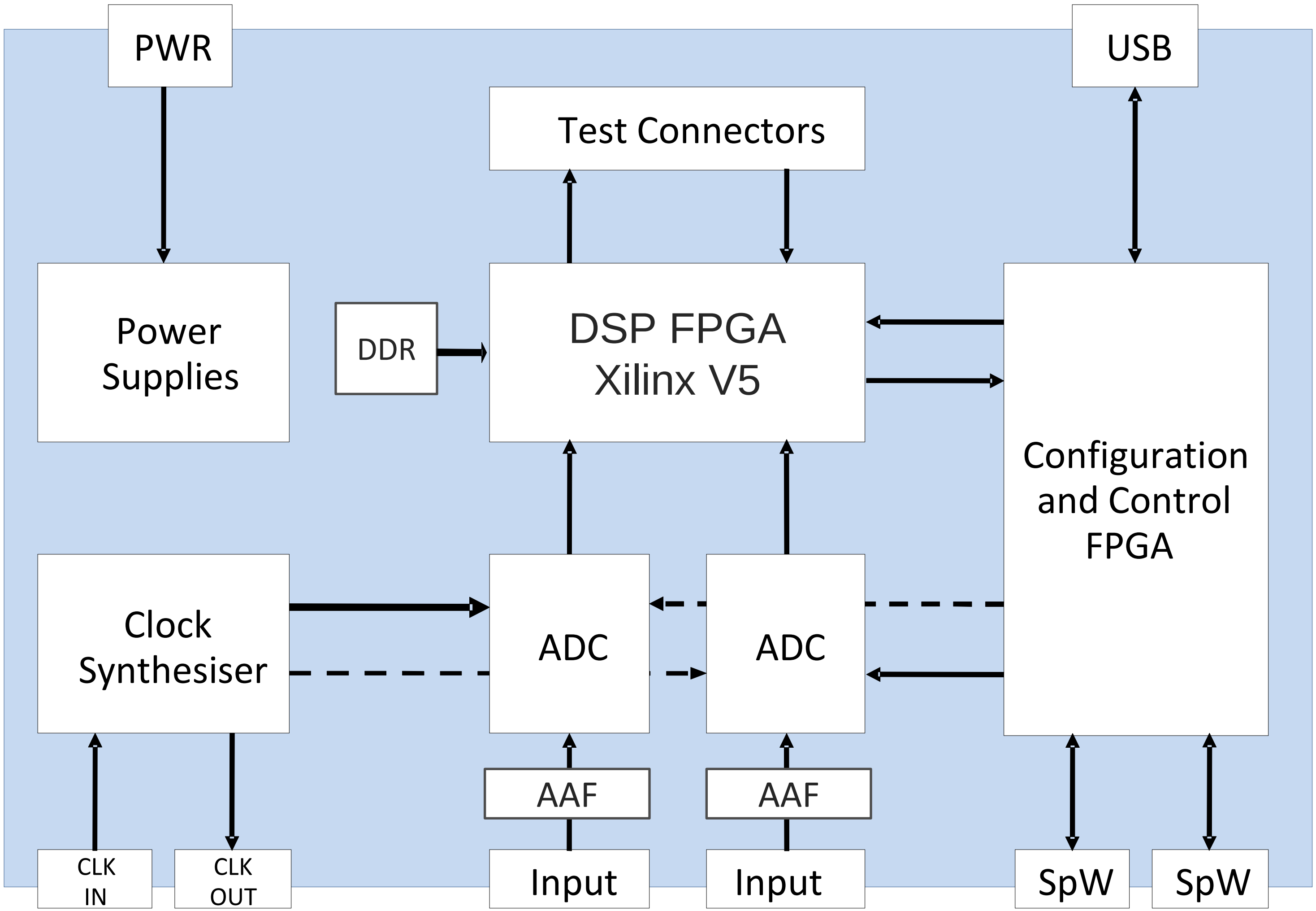
- Two ADCs sampling at 3 Gsamples/s
  - I & Q sampling
  - Resulting signal bandwidth > 2 GHz

- Custom Fast Fourier Transform (FFT) chip design
  - Windowing
  - 2048 point complex FFT at 3 Gsamples/s
    ~ 1.5 MHz resolution
  - Power detection and accumulation
  - Zero dead-time between data acquisitions

- Hardware triggering interface
  - Start/stop individual acquisitions
  - Start/stop groups of acquisitions of predetermined duration

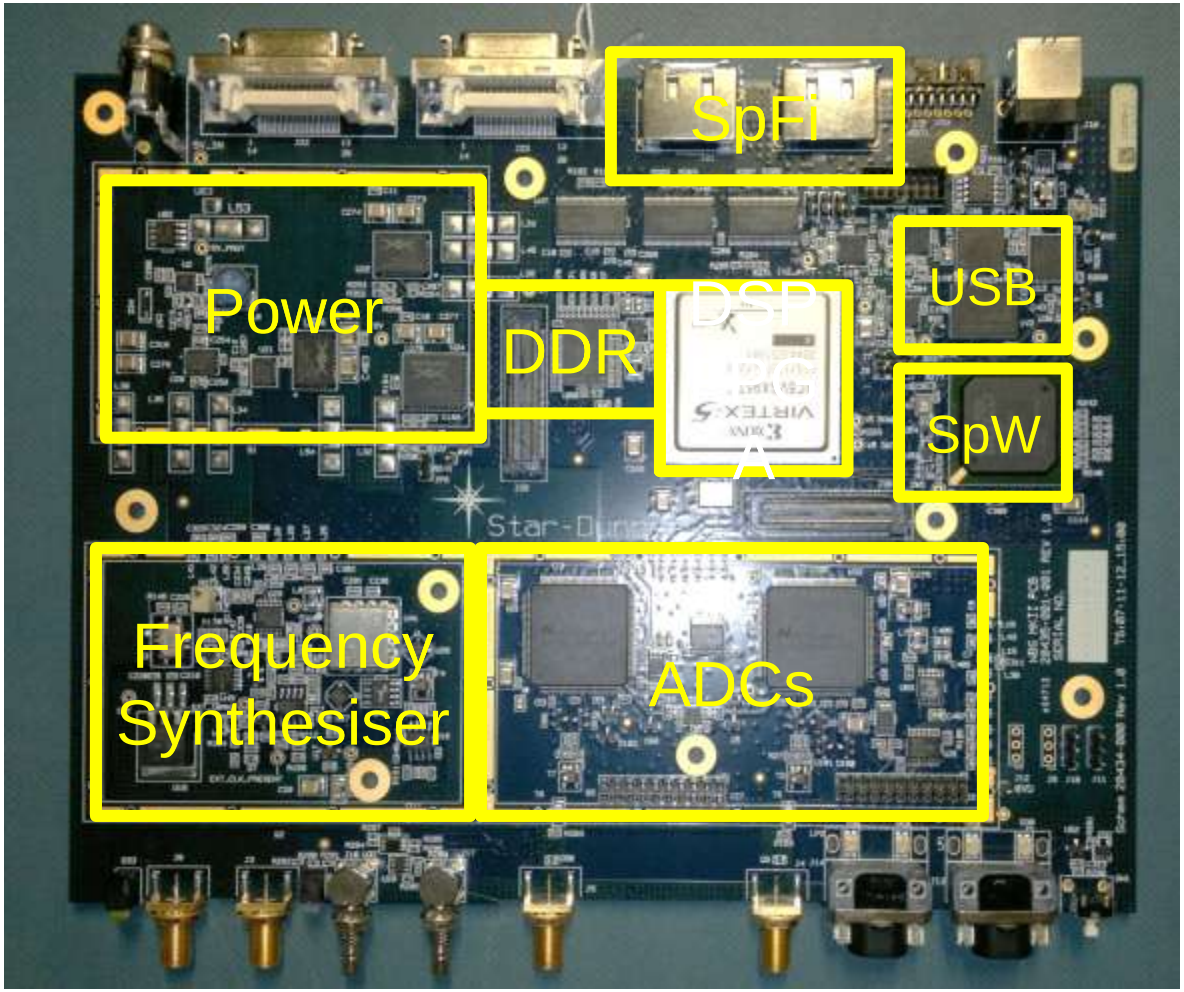
Technical Report on Current Project

Wideband Spectrometer II Development



Technical Report on Current Project

Wideband Spectrometer II Development



Technical Report on Current Project

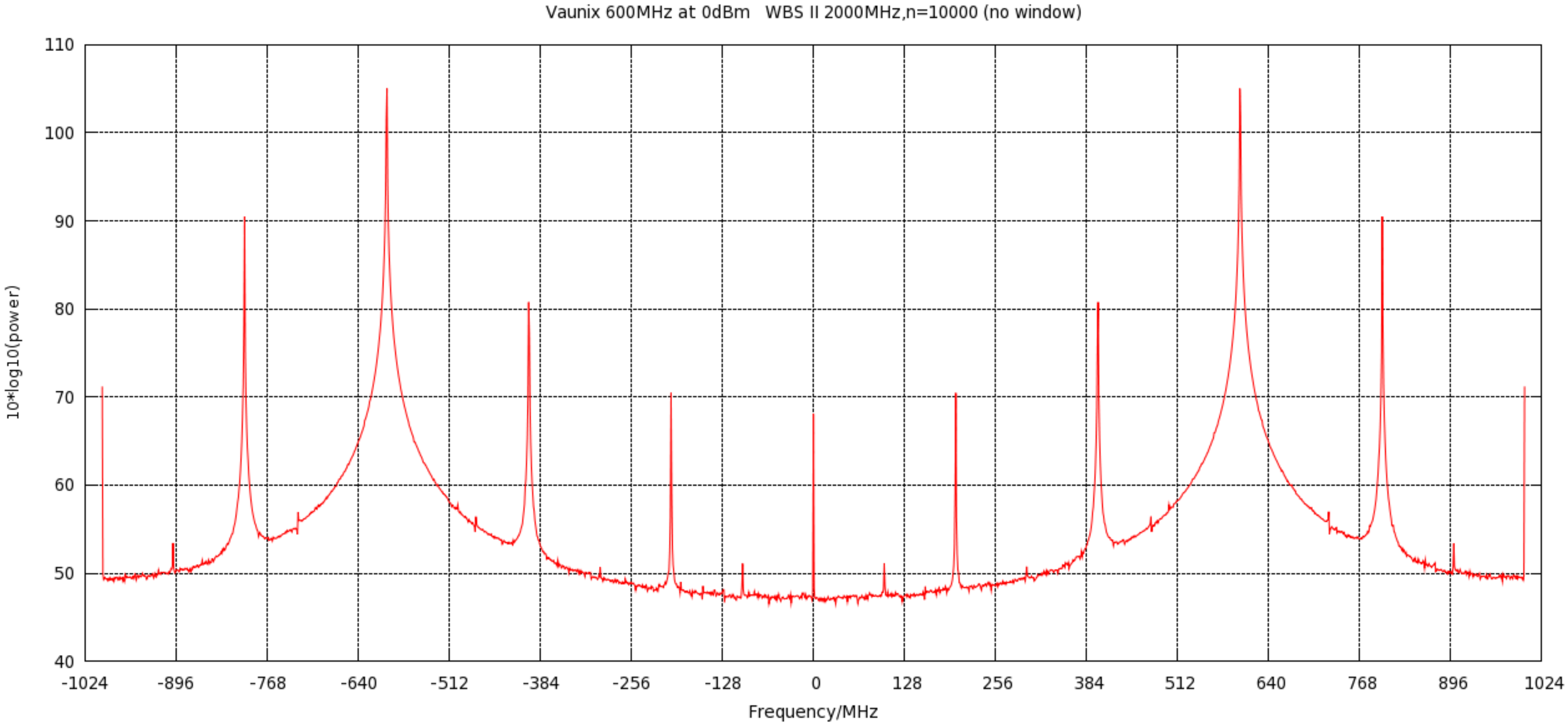
Wideband Spectrometer II Development

Dimensions
L= 165 mm
W= 220 mm
H= 30 mm

Technical Report on Current Project

Wideband Spectrometer II Development

Preliminary Test Results: FFT running in hardware



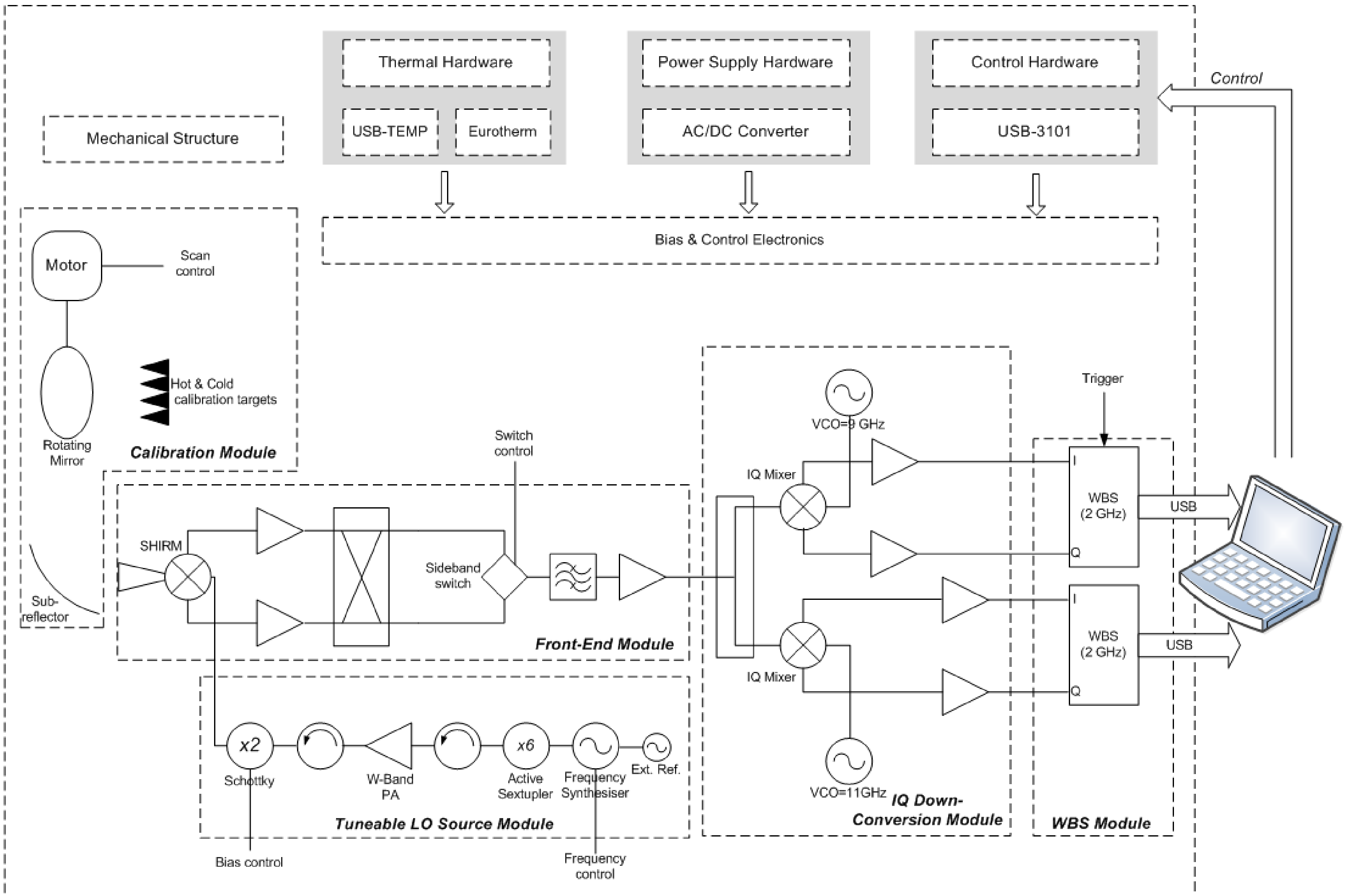
Signal fed into I input, Q input = 0
Averaged for 10,000 spectra
Primary signal at 600 MHz (spurs at ~200, 400 & 800)
Clock breakthrough is low (@ 100 MHz)

Technical Report on Current Project

SHIRM-WBS II Breadboard Development

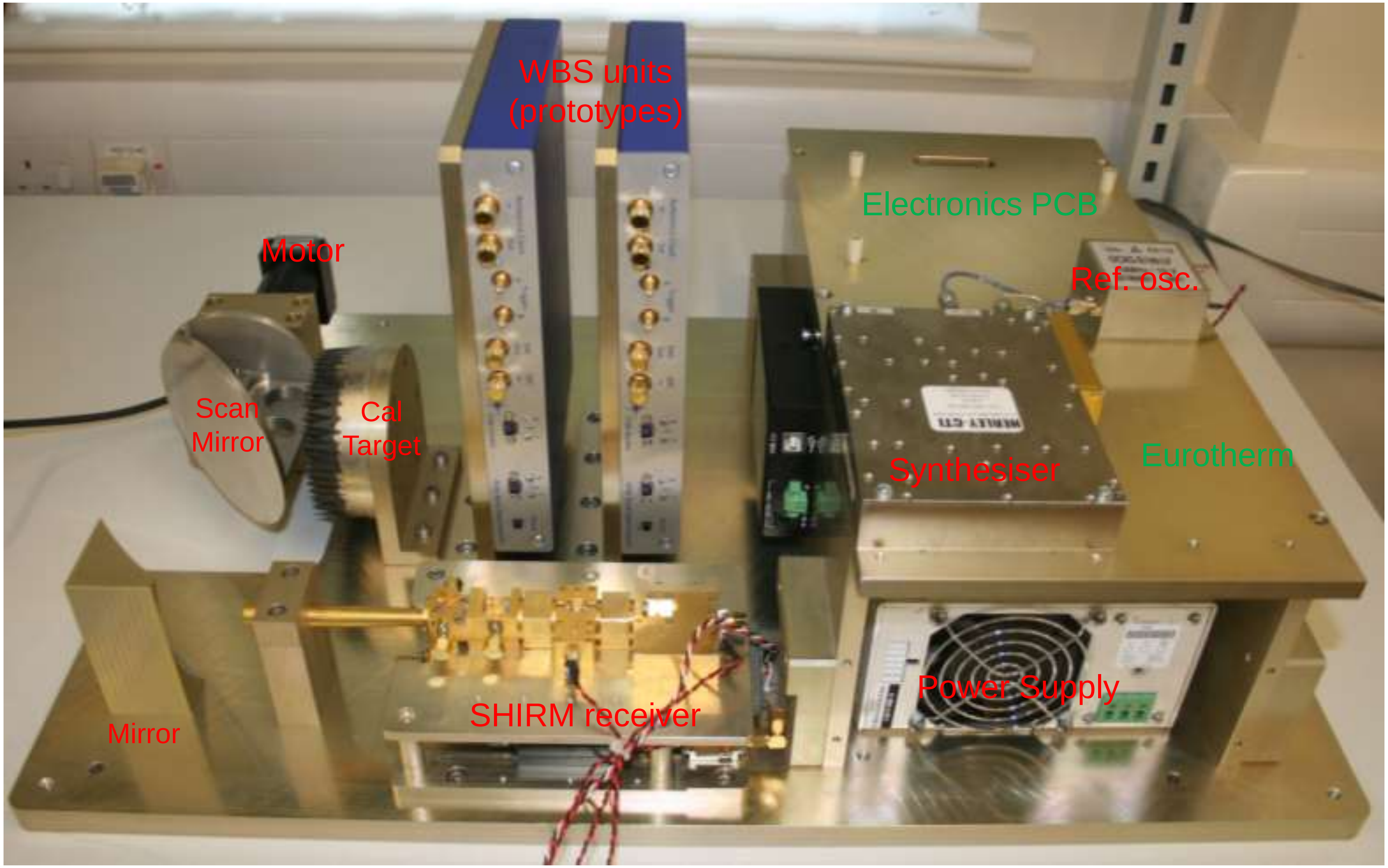
- Development of total-power radiometer comprising
  - 340 GHz sideband-separating receiver
  - 2x WBS II units providing 4 GHz bandwidth
- Characterisation of receiver
  - Noise temperature, sideband separation, stability, spectral response
  - Knowledge & understanding of system-induced artefacts
  - Risk mitigation in preparation for MARSCHALS upgrade
- Potential for future deployment at ground-based observatory
  - Return to Jungfraujoch

SHIRM-WBS II Breadboard Development

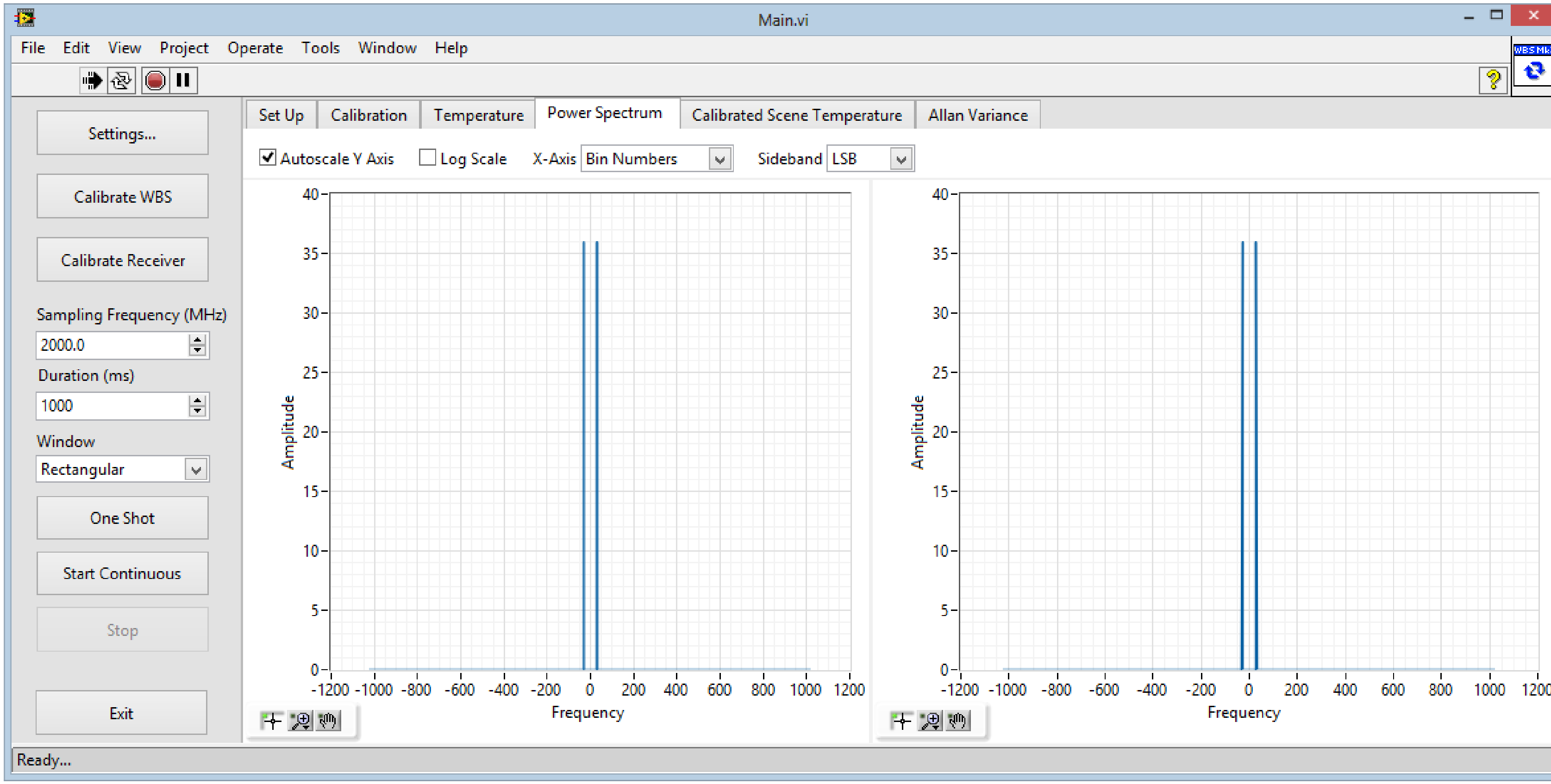


Technical Report on Current Project

SHIRM-WBS II Breadboard Development



SHIRM-WBS II Breadboard Development



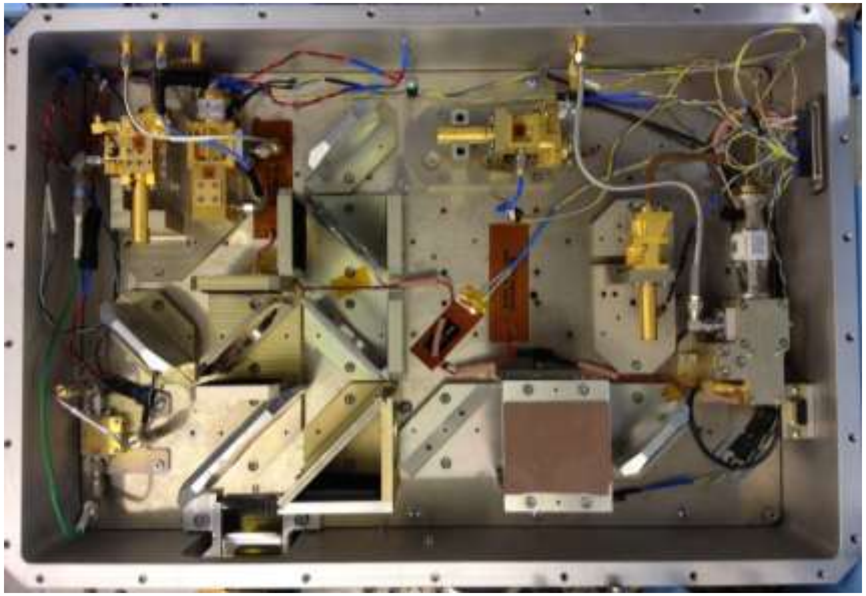
Screenshot of software showing two spectra from two WBS units.
Tabs indicate different views of the data.
Configuration and calibration buttons down on the left hand side.

Technical Report on Current Project

MARSCHALS Upgrade Study

- Preliminary assessment for integration of
  - 340 GHz sideband-separating receiver
  - 6x WBS II units providing 12 GHz bandwidth

- Front-End assessment conclusions
  - Existing receivers in MARSCHALS
    - Band B (294-305.5 GHz)
    - Band C (316.5-325.5 GHz)
    - Band D (342.2-348.8 GHz)
  - Replace Band D with SHIRM receiver
  - New QO diplexer required



MARSCHALS QO Layout

Technical Report on Current Project

MARSCHALS Upgrade Study

- Preliminary assessment for integration of
  - 340 GHz sideband-separating receiver
  - 6x WBS II units providing 12 GHz bandwidth

- Back-End assessment on-going
  - Expect to retain original filterbank spectrometers (12 GHz @ 200 MHz res.)
    - well characterised and flight-proven
  - Must find additional space for WBS II units (space identified on MARSCHALS)

Identified space for high-res spectrometer

Achievements against Goals

- Project not completed, however significant hardware development undertaken in short timeframe

- Development of WBS II
  - Xilinx FFT core too slow
  - Custom FFT FPGA core had to be designed

- Development of SHIRM-WBS II breadboard instrument
  - System design of complete instrument
    - mm-wave receiver
    - Mechanical design
    - Power supply
    - Thermal control
    - Bias/control electronics
    - Instrument control software
    - Scan control
    - Calibration

Issues and problems encountered

- WBS II
  - New FFT core design was challenging – difficult to fit logic into FPGA
  - Synchronisation of data from ADCs was problematic

- SHIRM-WBS Instrument Breadboard
  - No major issues yet (although development has taken longer than expected)
  - Instrument characterisation has not started yet – issues to be expected

Positioning Achieved

- Leverage achieved
  - STFC/UKSA funding for UK support to STEAM-R through FYs 12/13, 13/14: £500,000 for upgrade of MARSCHALS

- Collaborations forged
  - Work performed by RAL Space, Astrium Ltd and STAR-Dundee Ltd
  - Support from IAP, University of Bern
  - Support from International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HJSJG)

Other Achievements

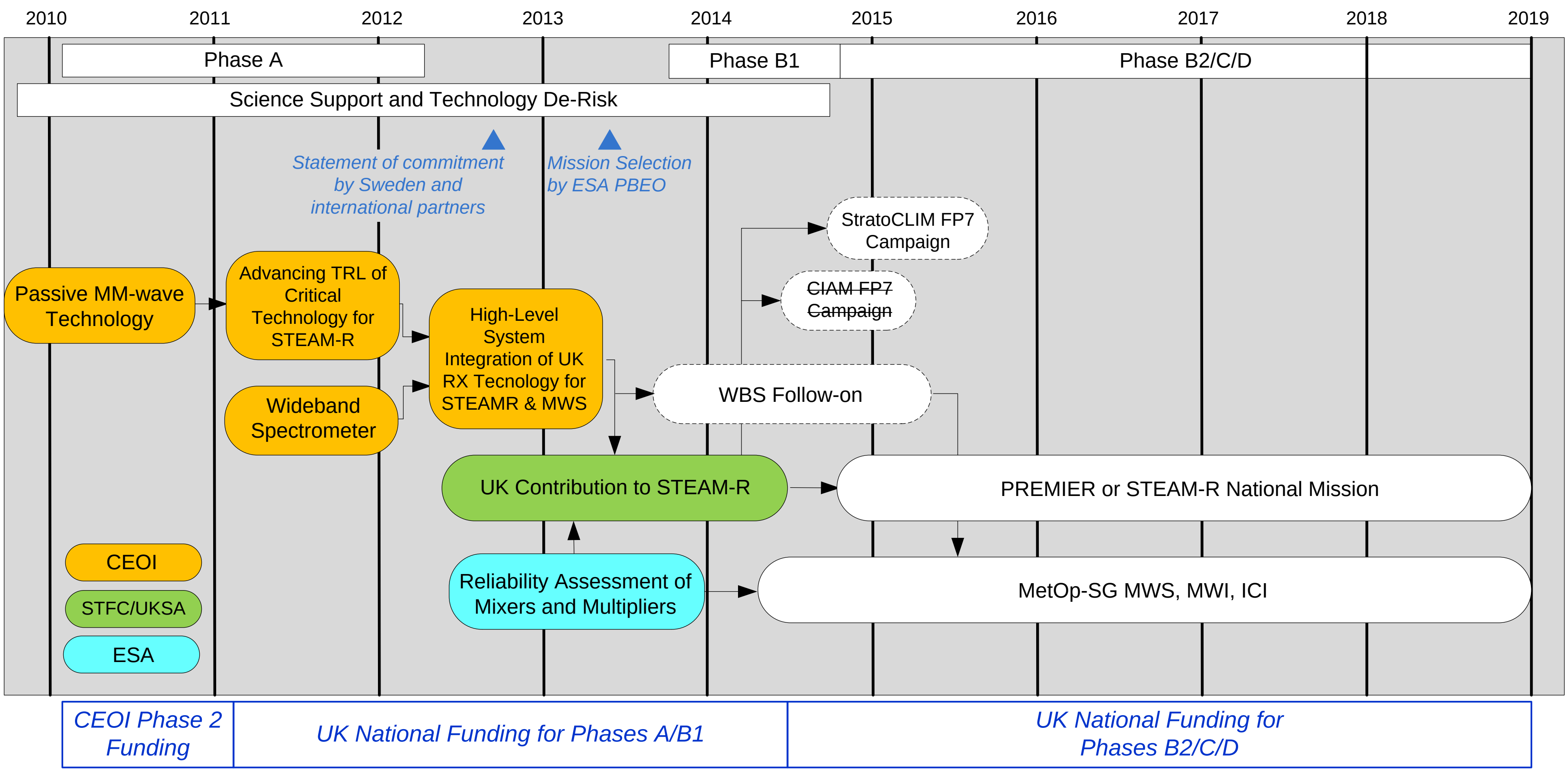
- Training and knowledge exchange
  - Sandwich Placement Student at RAL Space: Sean Woodley (University of Bath)
  - Supporting development of SHIRM-WBS II breadboard

- UK Capability enhancement
  - Development of digital spectrometer with wide range of applications
    - Passive radiometers
    - Synthetic aperture radar
    - Image processing
    - On-board data processing

  - Demonstration of end-to-end performance of sideband-separating receiver with high-resolution backend using UK technology

    → strengthens case for inclusion of SHIRM receiver in STEAM-R

Roadmap


2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Phase A
Phase B1
Phase B2/C/D
Science Support and Technology De-Risk
Statement of commitment by Sweden and international partners
Mission Selection by ESA PBEO
StratoCLIM FP7 Campaign
~~CIAM FP7 Campaign~~
Passive MM-wave Technology
Advancing TRL of Critical Technology for STEAM-R
High-Level System Integration of UK RX Tecnology for STEAMR & MWS
Wideband Spectrometer
WBS Follow-on
UK Contribution to STEAM-R
PREMIER or STEAM-R National Mission
Reliability Assessment of Mixers and Multipliers
MetOp-SG MWS, MWI, ICI
CEOI
STFC/UKSA
ESA
CEOI Phase 2 Funding
UK National Funding for Phases A/B1
UK National Funding for Phases B2/C/D

Future Activities

- Future steps
  - Await final decision on EE7
  - Engage with Swedish partners in event of PREMIER de-selection

- Continue with current funded projects
  - CEOI 5th Call
  - UK Support to STEAM-R (STFC/UKSA)

- WBS follow-on project (dependent on target mission)
  - Increase bandwidth further (higher speed ADCs)
  - Implement IQ imbalance correction
  - Develop flight-representative unit (radiation tolerant FPGA or ASIC)