The Radio Astronomy Technology (RAT) Centre
at the
Durban University of Technology

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STRUCTURE OF THE PRESENTATION

1. Overview.
2. So what are we trying to detect?
3. Single dish vs interferometer
4. Indlebe Radio Telescope.
5. Indlebe Enkulu Radio Telescope.
6. Phased Experimental Demonstrator (PED-2)
7. Multi Frequency Interferometer Telescope for Radio Astronomy (MITRA).
8. The SKA.

Overview

- In 2006 a decision was made to build a small radio telescope that could provide a real world platform for student project work.

- An objective was to be part of IYA 2009 and the result was the Indlebe Radio Telescope that saw first light on 28 July 2008.

- Contact with the SKA SA Project Office followed and this resulted in students starting their work integrated learning at HartRAO in 2009.

- The centre now has four radio telescope instruments at various stages of completion.

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So what are we trying to detect?

EM radiation from a source can be produced by thermal or non-thermal mechanisms.

Thermal -:

- A continuous spectrum (noise) related to the temperature of the object (blackbody radiation)
- Discrete absorption or emission spectra (e.g. hydrogen at 1420 MHz, λ = 21 cm)

Non-thermal-:

- Synchrotron radiation (high energy particles spiralling through a magnetic field)

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Blackbody radiation (thermal noise)

- A blackbody with a temperature higher than 0 K emits some energy at all wavelengths.
- A blackbody at higher temperature emits more energy at all wavelengths than a cooler one.
- The higher the temperature, the higher the frequency at which the maximum energy is emitted.

$$P_n = kT \Delta v$$

Boltzmann's constant (k)

Temperature (T)

Bandwidth (Δv)

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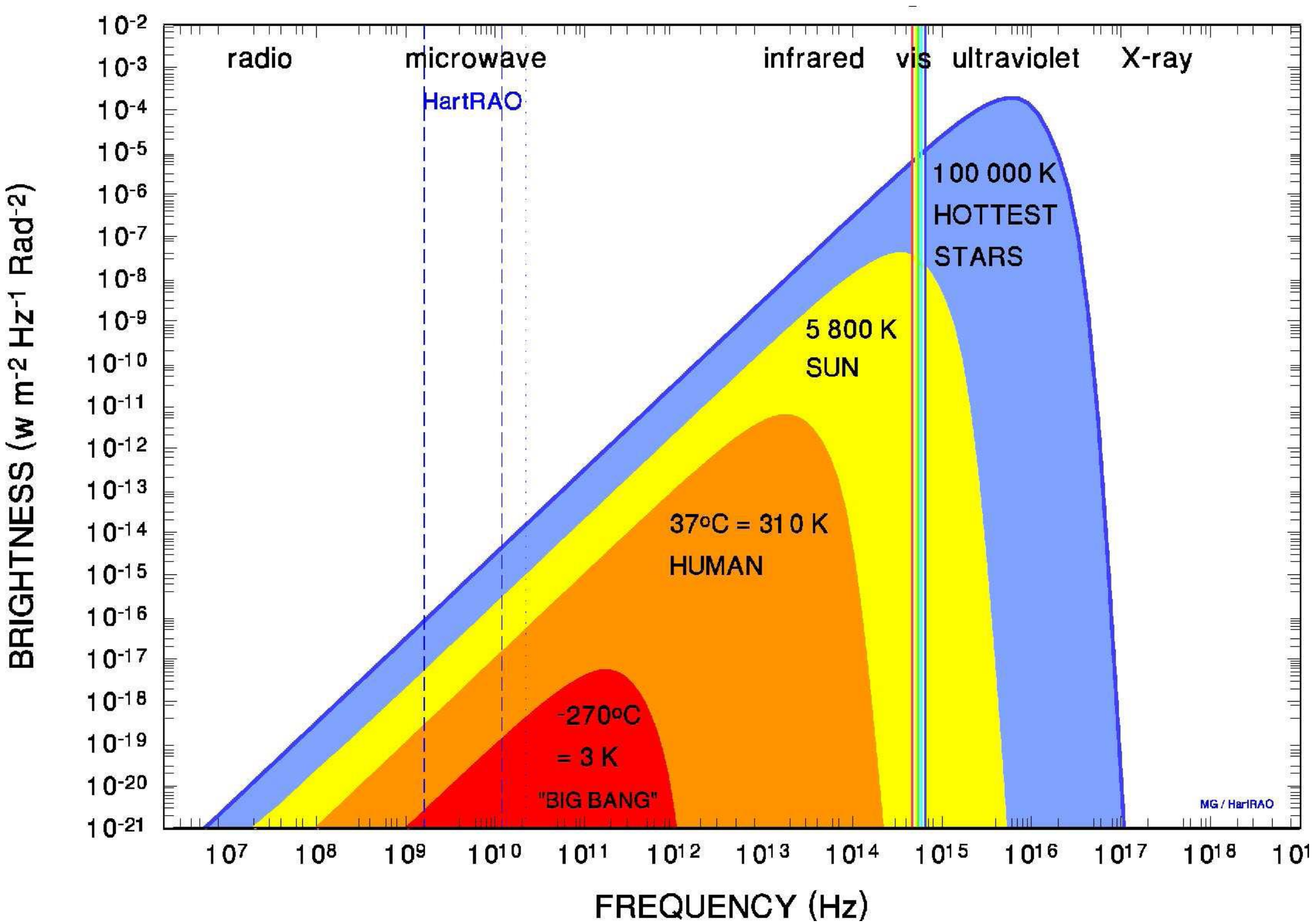
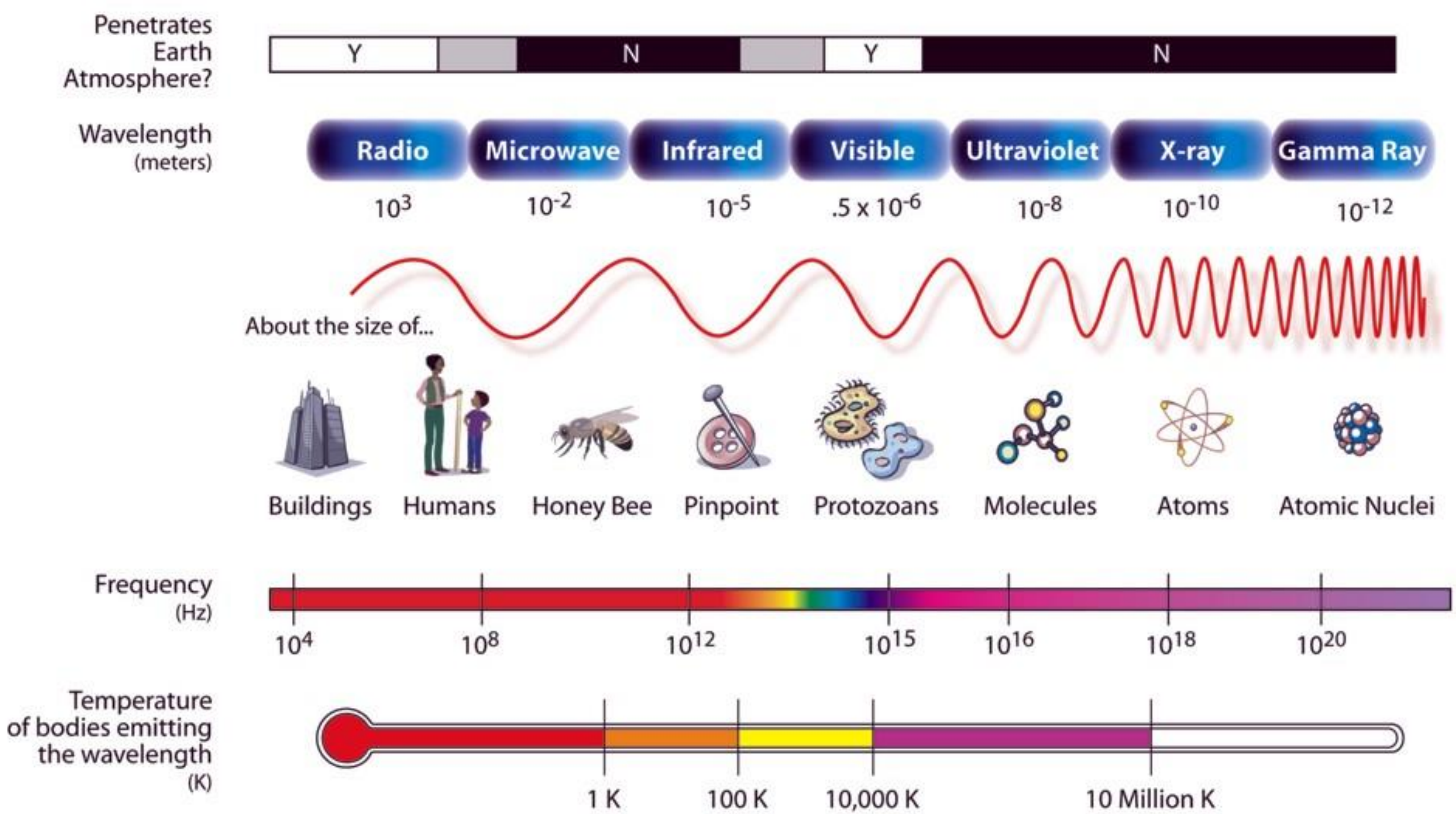
Planck's radiation curve



- *As temp increases, energy (Brightness) increases*
- *As temp increases, frequency of radiation peak increases*

THE ELECTROMAGNETIC SPECTRUM



(Humans ≈ 310 K   Sun ≈ 5800 K)

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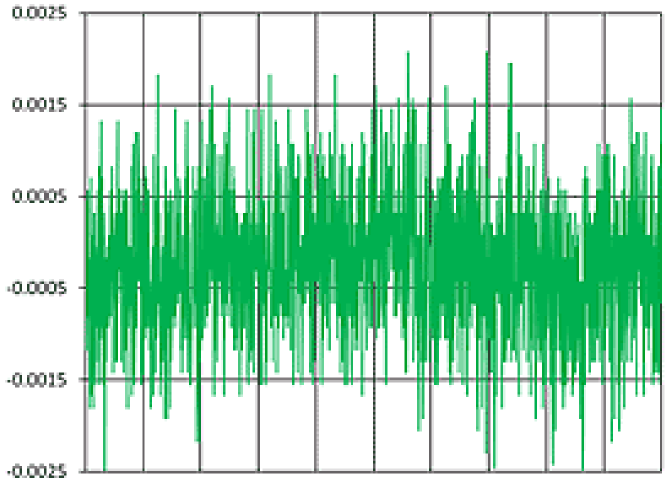
Concept of equivalent noise temperature

Components and systems that generate noise (as long as it is random) can be characterised by saying they have an equivalent noise temperature T_e where

$$T_e = \frac{P_n}{k\Delta v}$$



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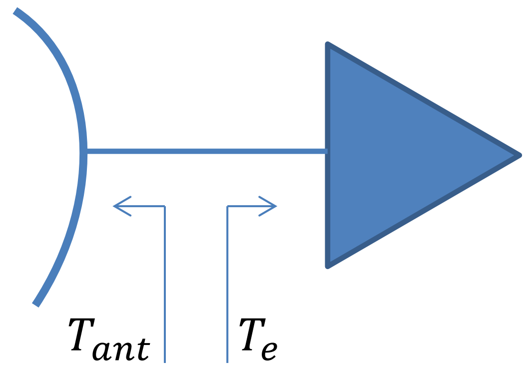
System thermal noise

$T_{ant} = T_{cmb} + T_{atm} + T_{wv} + T_{gr} + T_{src}$

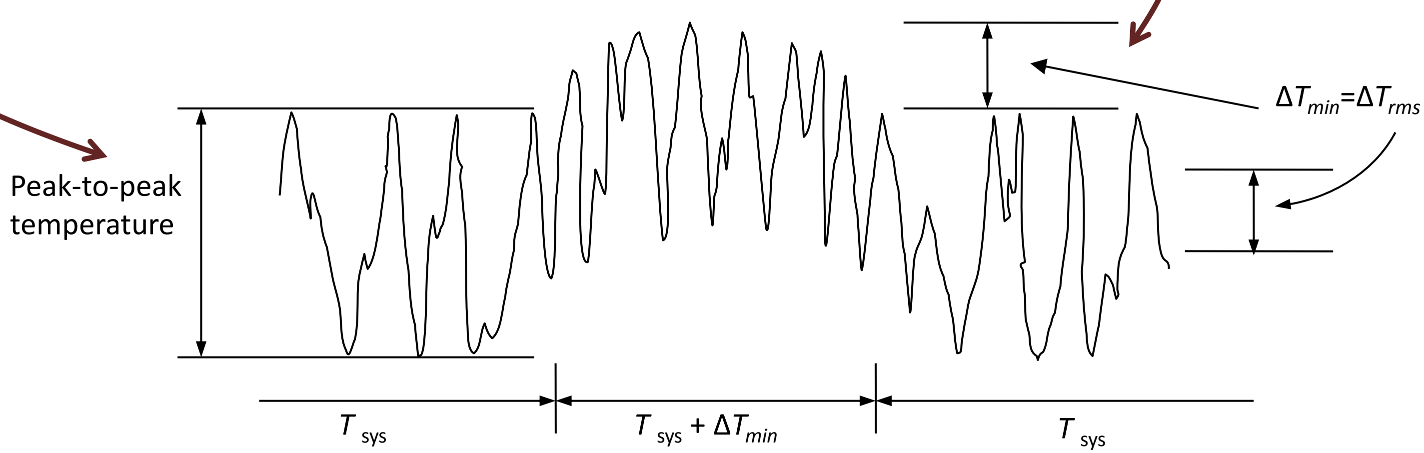
$T_{sys} = T_{ant} + T_e$

$P_n = kT_{sys}\Delta v$



$$\Delta T_{min} = \frac{T_{sys}}{\sqrt{\Delta v t n}}$$

The source equivalent brightness temperature ΔT is added to T_{sys}



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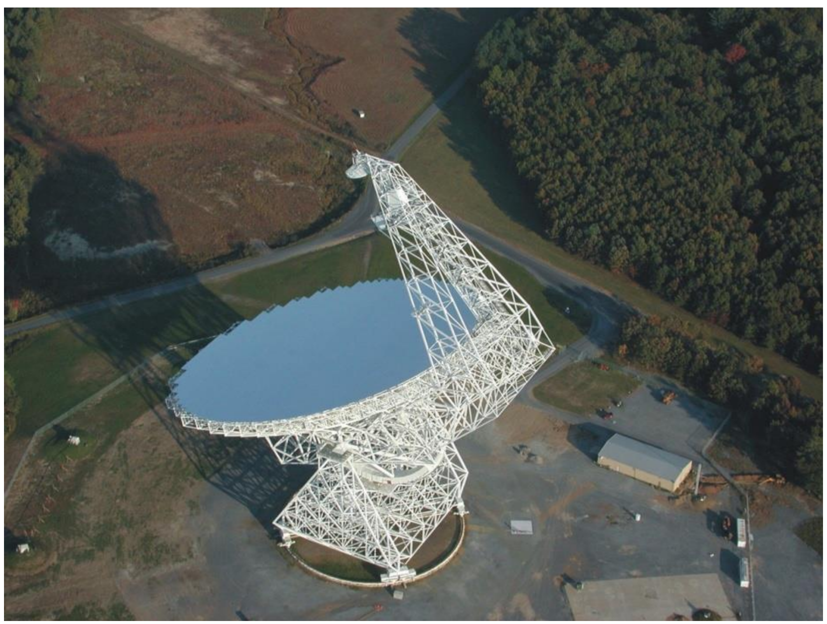
Single dish vs Interferometer

It's all about sensitivity and resolution
(size does count!)

GBT, West Virginia USA
100 m diameter
0,1-116 GHz



Jodie Foster (Contact)

VLA, New Mexico USA
27×25 m diameter
75-50 GHz

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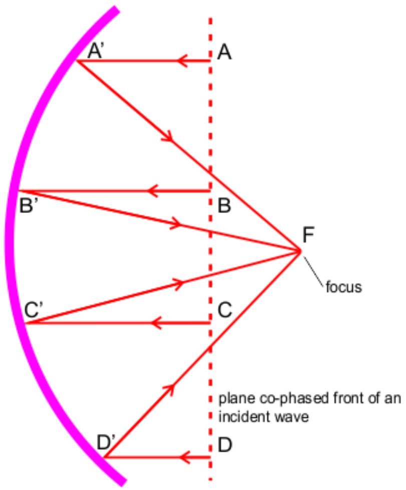
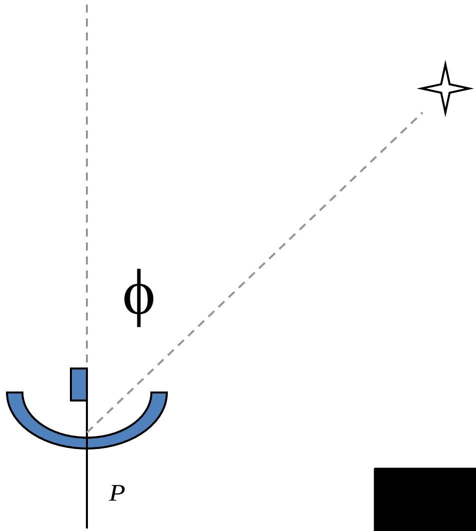
Point Source and a Single Dish

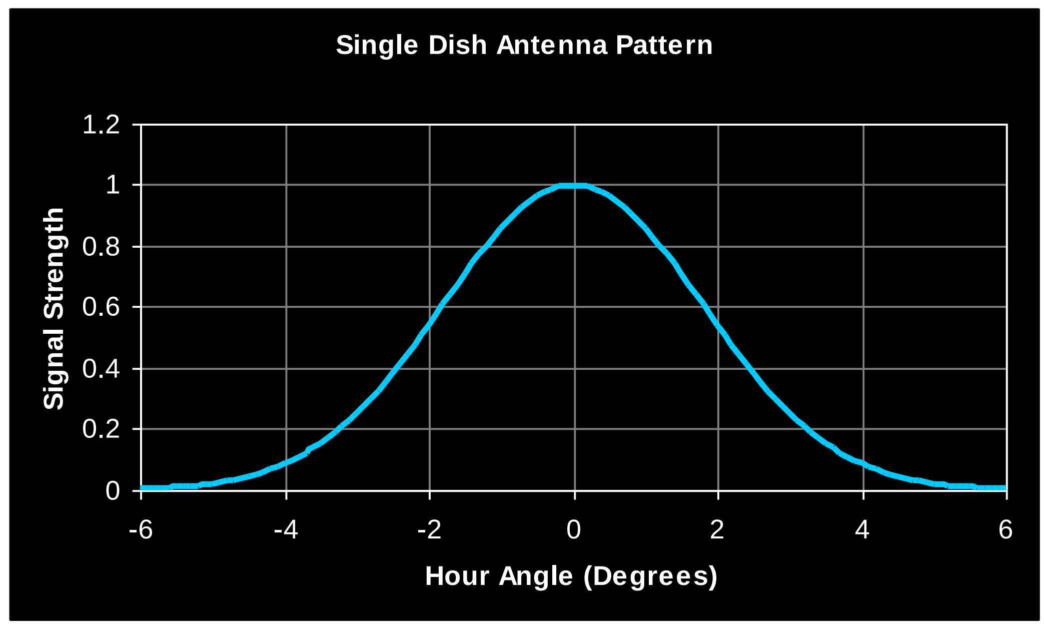




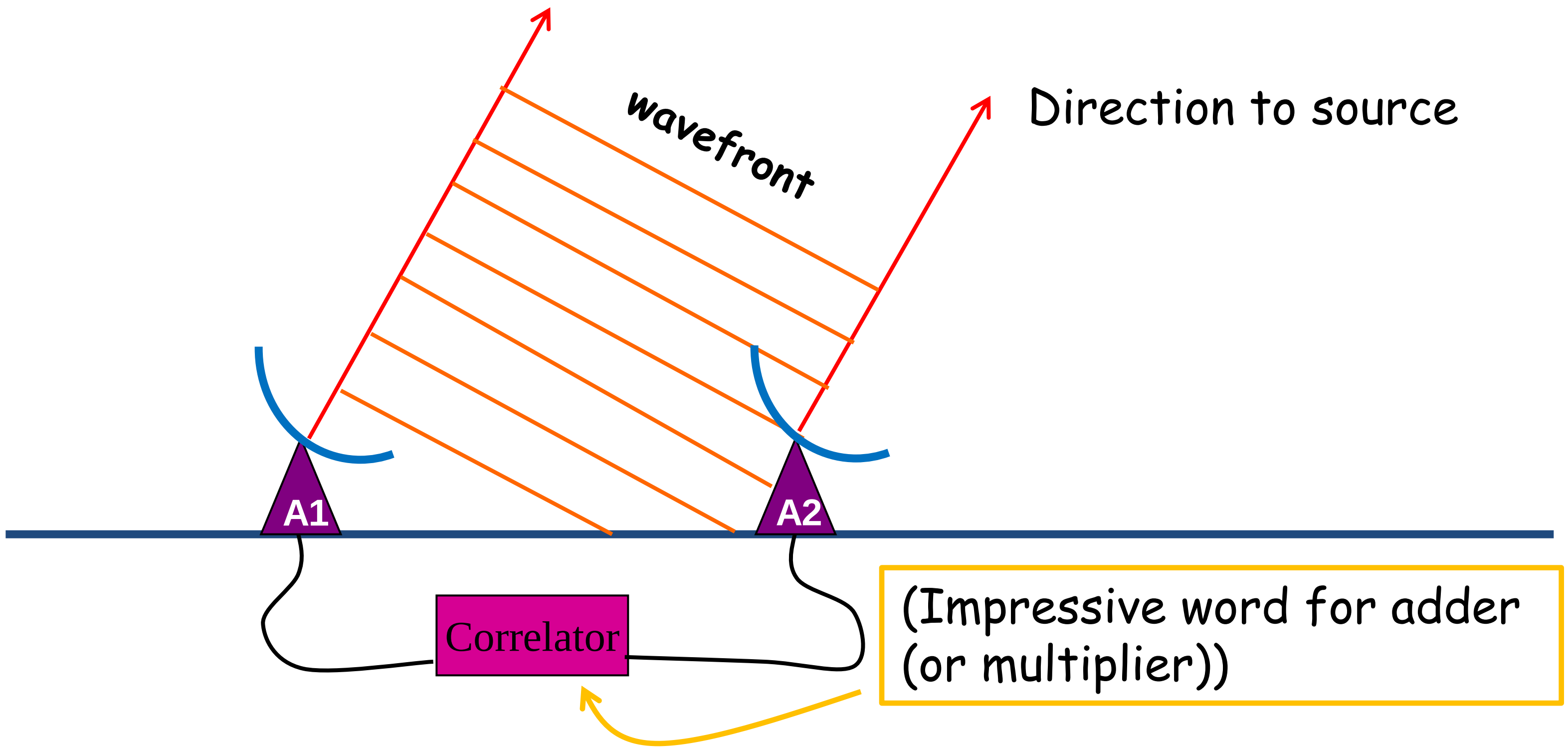
$$P_1 = e^{-(\phi \pi R / \lambda)^2}$$

ϕ = hour angle (°)
R = dish radius
λ = wavelength

$$\begin{aligned} \theta &= \text{angular resolution (beamwidth)} \\ &\approx 1.22\frac{\lambda}{D} \\ &\approx 1.22\frac{0.211}{5} \\ &\approx 0.051 \text{ rad } (2.95^\circ) \end{aligned}$$

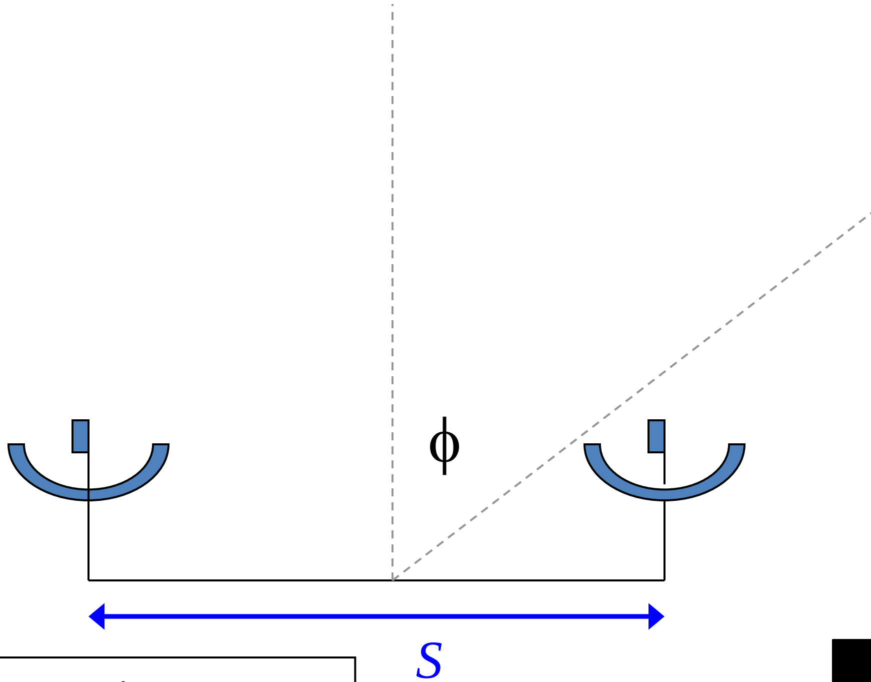


- An interferometer measures coherence in the electric field between pairs of points (baselines).



- Because of the geometric path difference, the incoming wavefront arrives at each antenna at a different phase (which varies with movement).

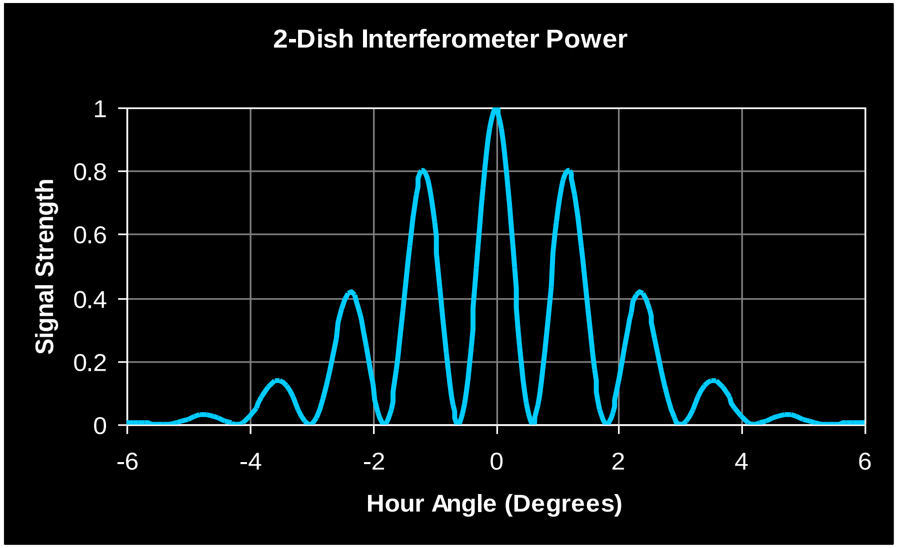
A Simple Interferometer



$$P_2 = e^{-(\phi \pi R / \lambda)^2} \cos^2\left(\frac{\psi}{2}\right)$$

$$\psi = \frac{2\pi S}{\lambda} \sin(\phi)$$

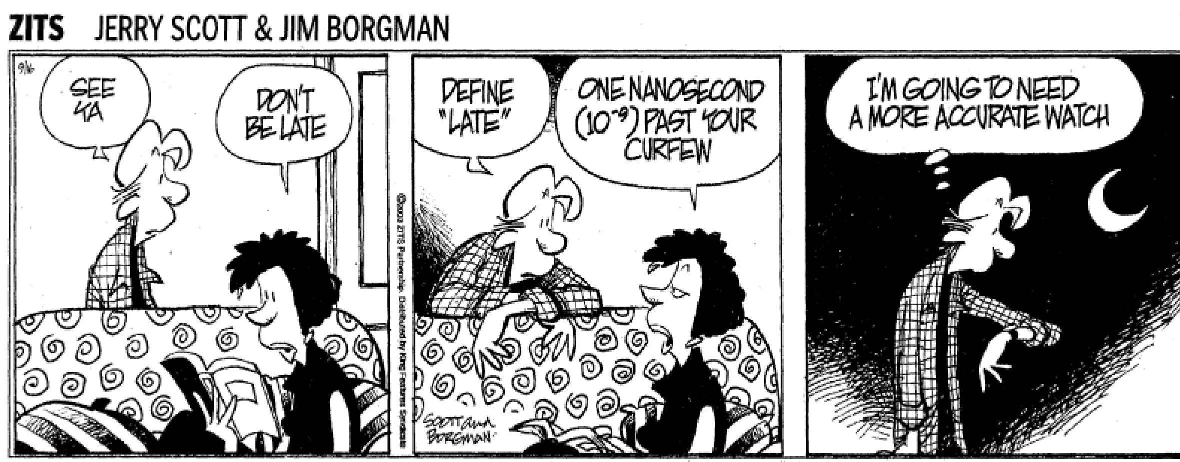
$$\theta \approx 1.02 \frac{\lambda}{S} \approx \frac{1.02 \times 0.211}{20} \approx 0.011 \text{ rad } (0.62^\circ)$$



Note improved resolution!

However, there is a small problem and……

It's About Time !!!!!



Consider an average digital watch which loses 1 s per day:

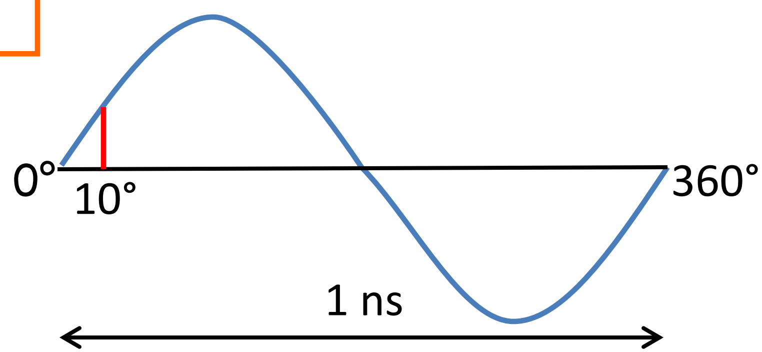
$$Stability = \frac{1}{24 \times 60 \times 60} = 1{,}16 \times 10^{-5}$$

over 1 day

To maintain phase coherence of 10° between 2 clocks (oscillators) at 1 GHz for 100 s you require:

$$Stability = \frac{(10/360) \times 1 \times 10^{-9}}{100} = 2{,}8 \times 10^{-13}$$

Over 100 s



This would be a watch that loses 1 s every 115308 years!

$$\left(\frac{1}{115308 \times 365 \times 24 \times 60 \times 60} = 2{,}8 \times 10^{-13} \right)$$

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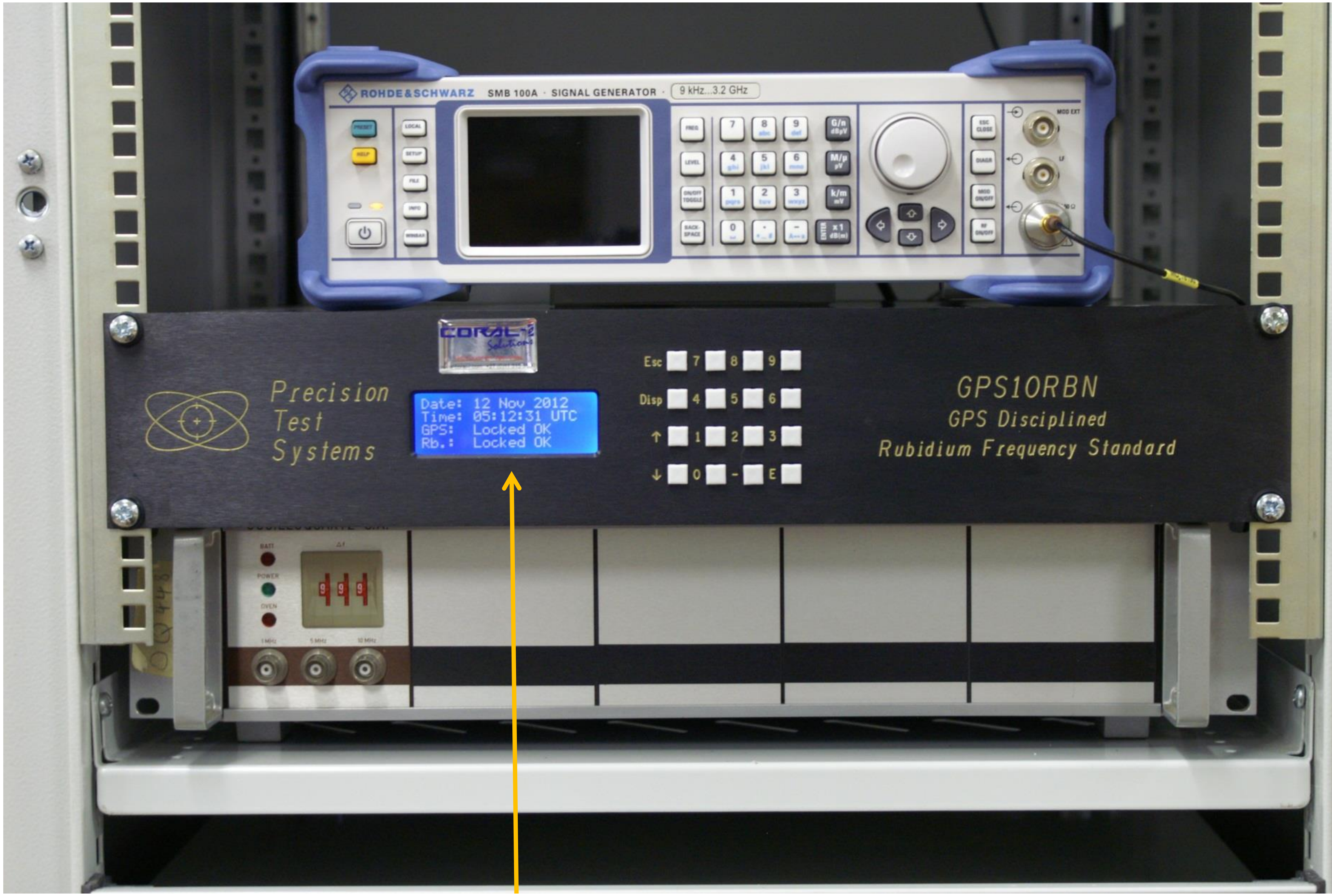

Our GPS Disciplined Rubidium Frequency Standard

(Allan variance = $2{,}8 \times 10^{-13}$)

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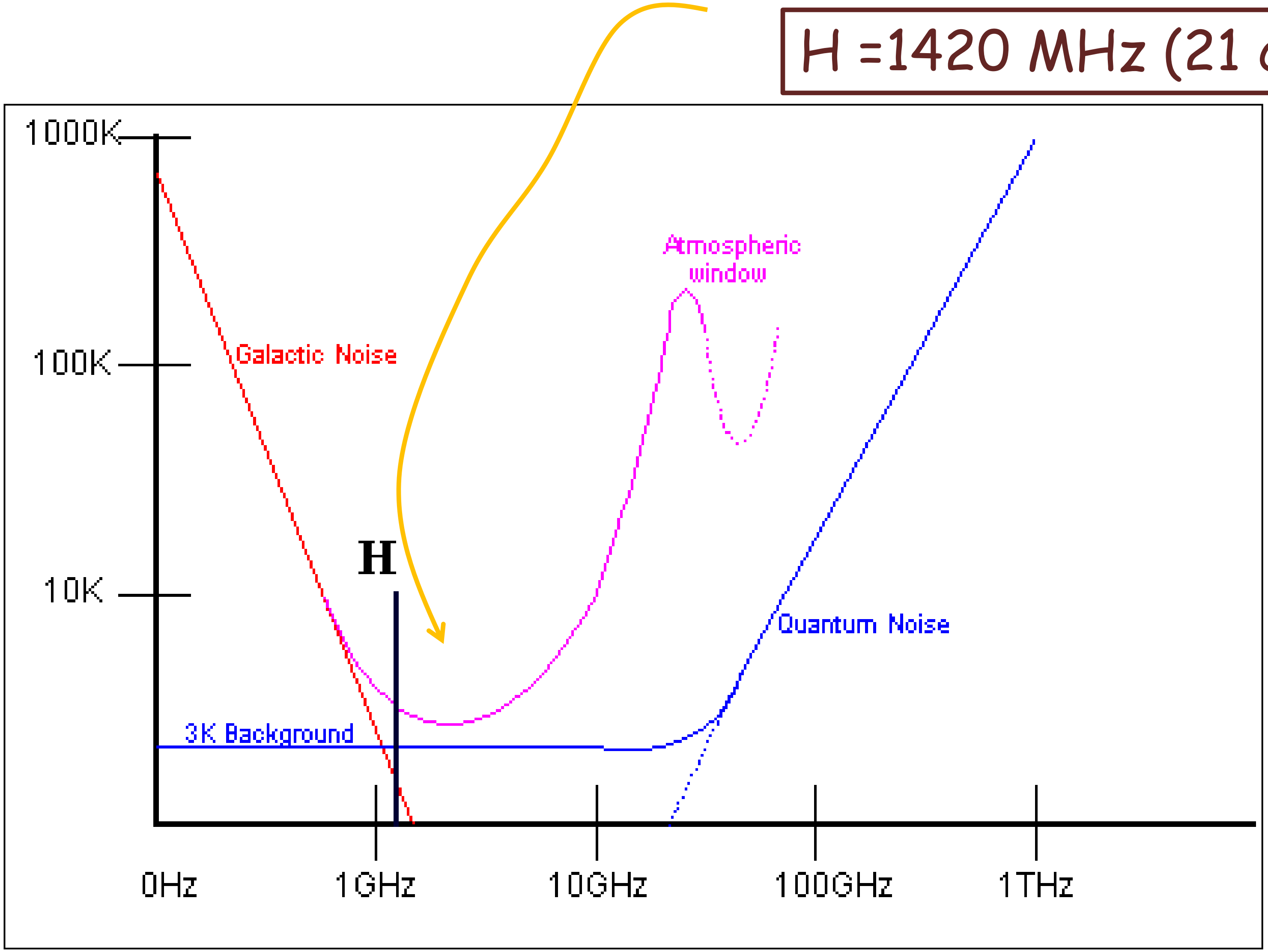
Indlebe Radio Telescope

- A transit telescope using a 5 m diameter parabolic reflector.
- Constructed by students, constructed from 8 petals bolted together on a very light steel frame.
- Operates at the 21 cm hydrogen line (1420 MHz).
- Receiver equivalent noise temperature (including feed losses) T_e=90 K.
- Receiver bandwidth = 80 MHz.
- Elevation control only - approximately 26° either side of the zenith.
- Fully operational – but not optimal.

"The cosmic watering hole"- reserved band for RA

H =1420 MHz (21 cm)



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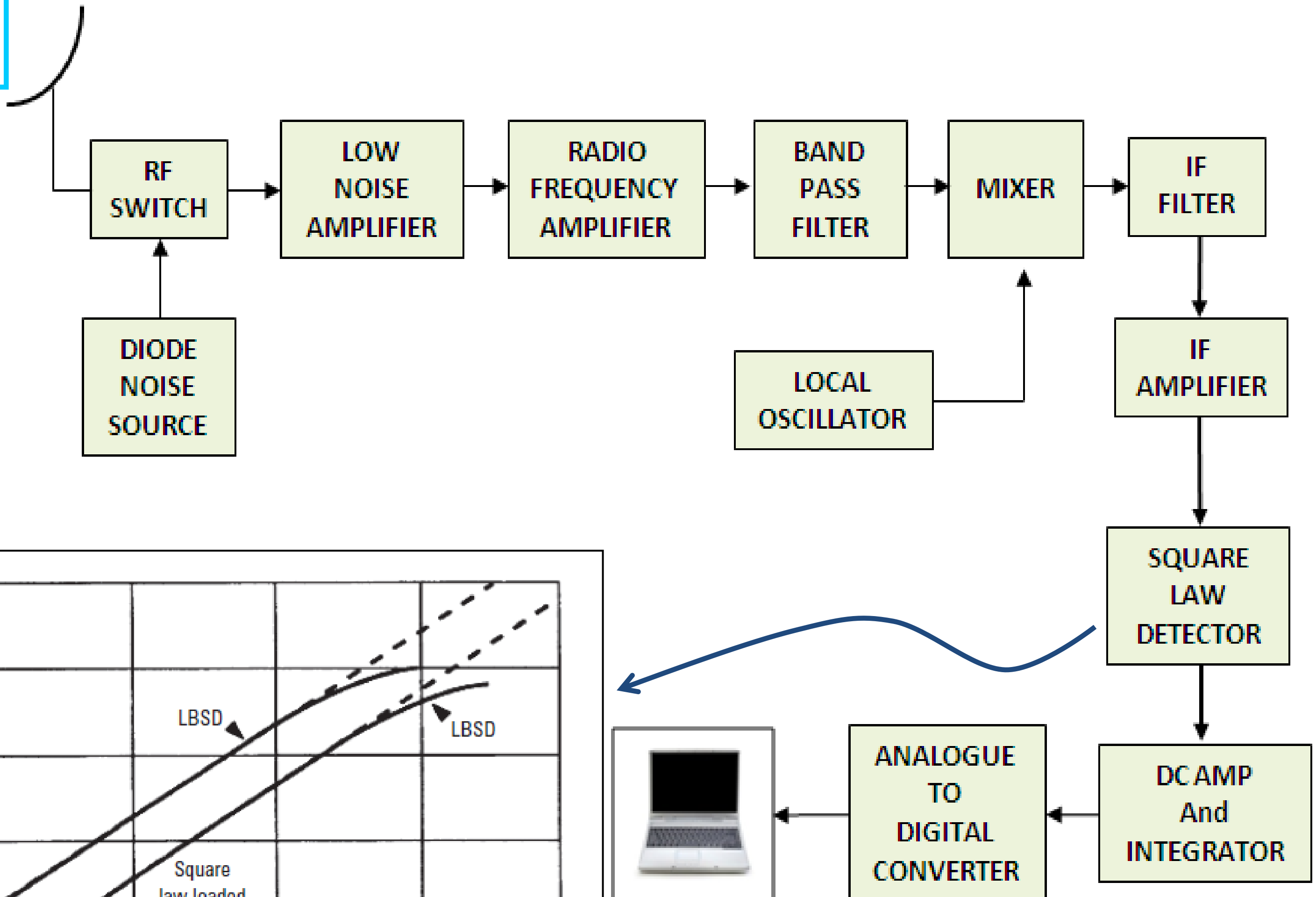
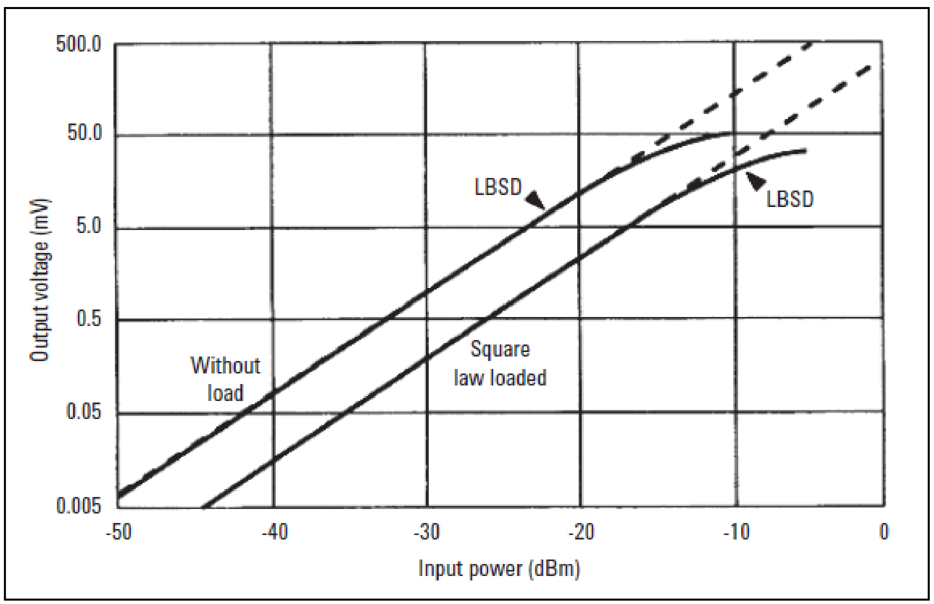
$$P_n = kT\Delta v$$

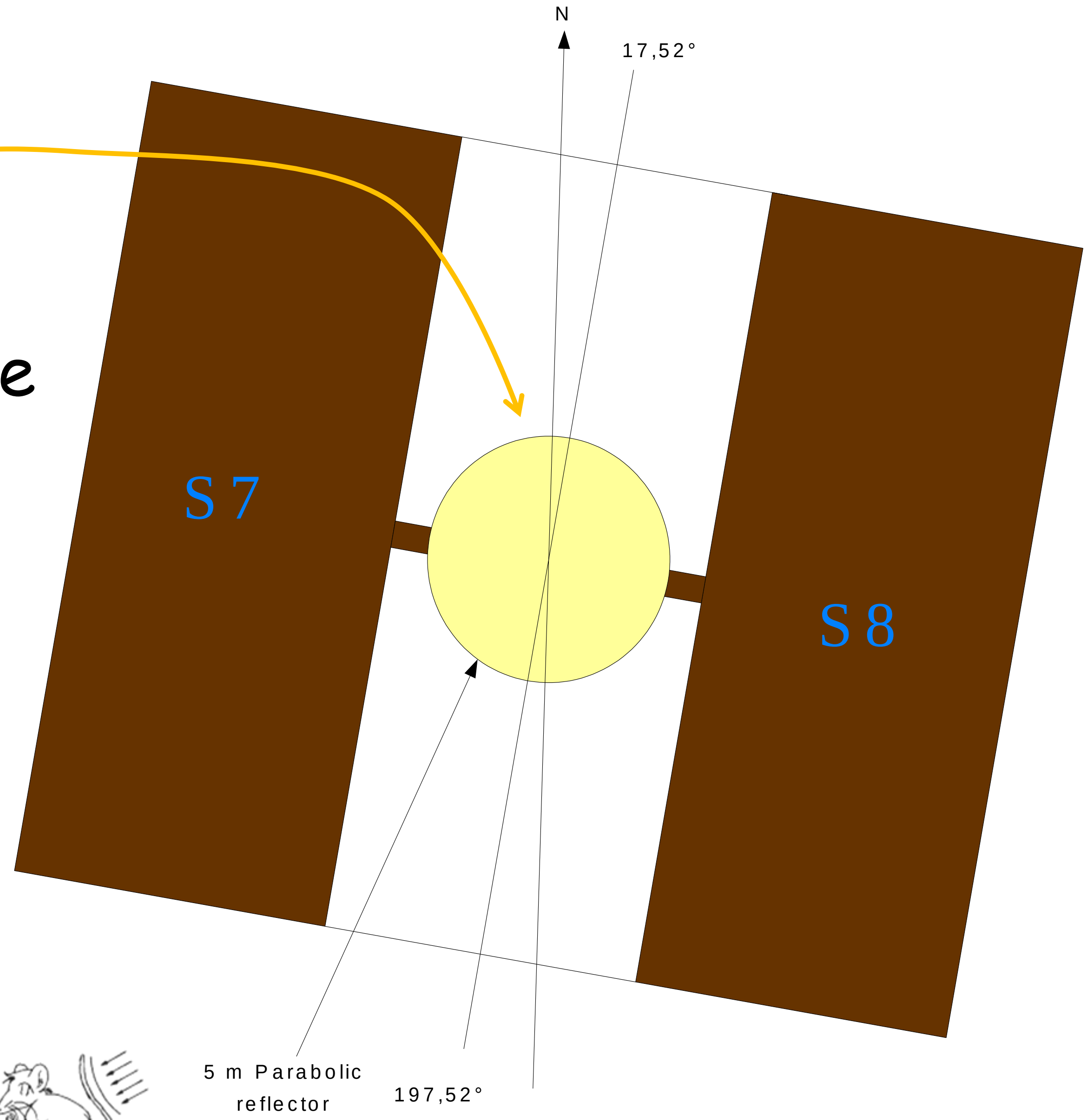


RF SWITCH
LOW NOISE AMPLIFIER
RADIO FREQUENCY AMPLIFIER
BAND PASS FILTER
MIXER
IF FILTER
DIODE NOISE SOURCE
LOCAL OSCILLATOR
IF AMPLIFIER
SQUARE LAW DETECTOR
DC AMP And INTEGRATOR
ANALOGUE TO DIGITAL CONVERTER



500.0
50.0
5.0
0.5
0.05
0.005
Output voltage (mV)
-50
-40
-30
-20
-10
0
Input power (dBm)
LBSD
LBSD
Without load
Square law loaded

The “in-door” radio telescope



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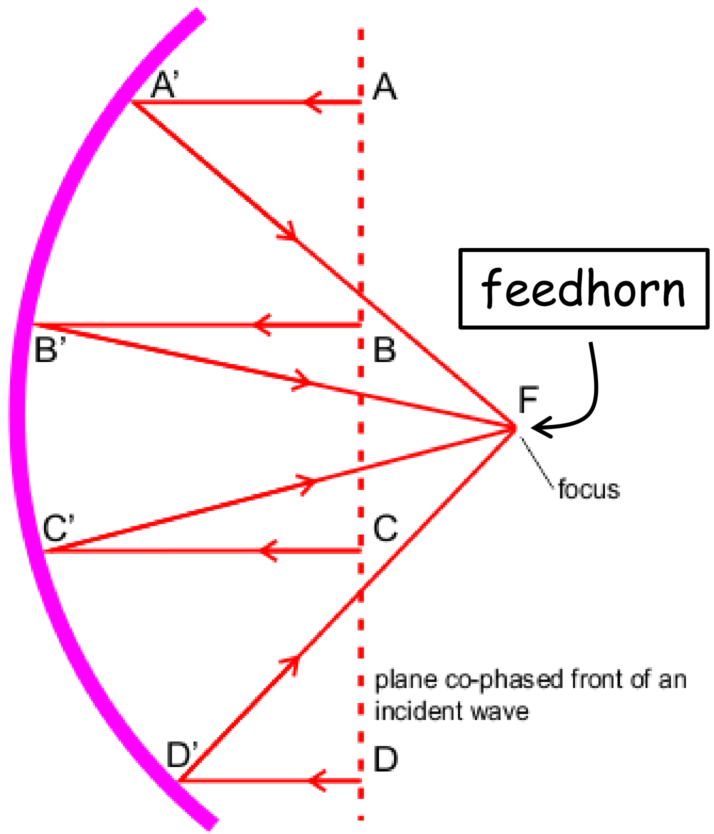

Prime focus
F/D ratio = 0.5
D=5m, F =2,5 m
Beamwidth=3°
VSWR< 2
G=35 dB (3162)

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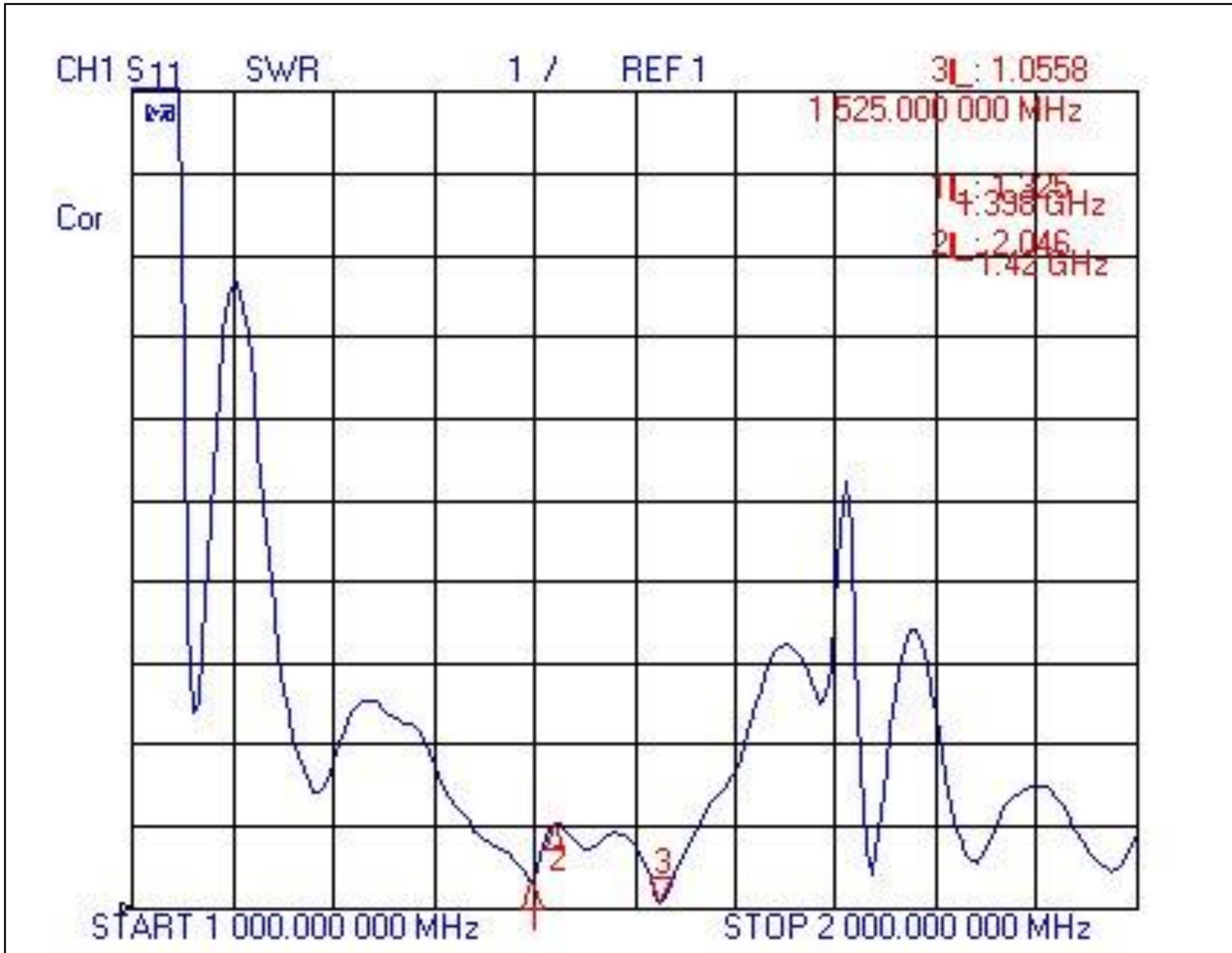
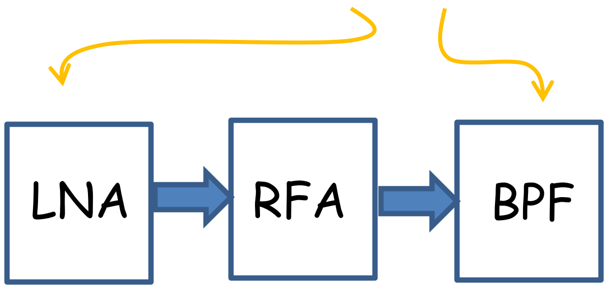


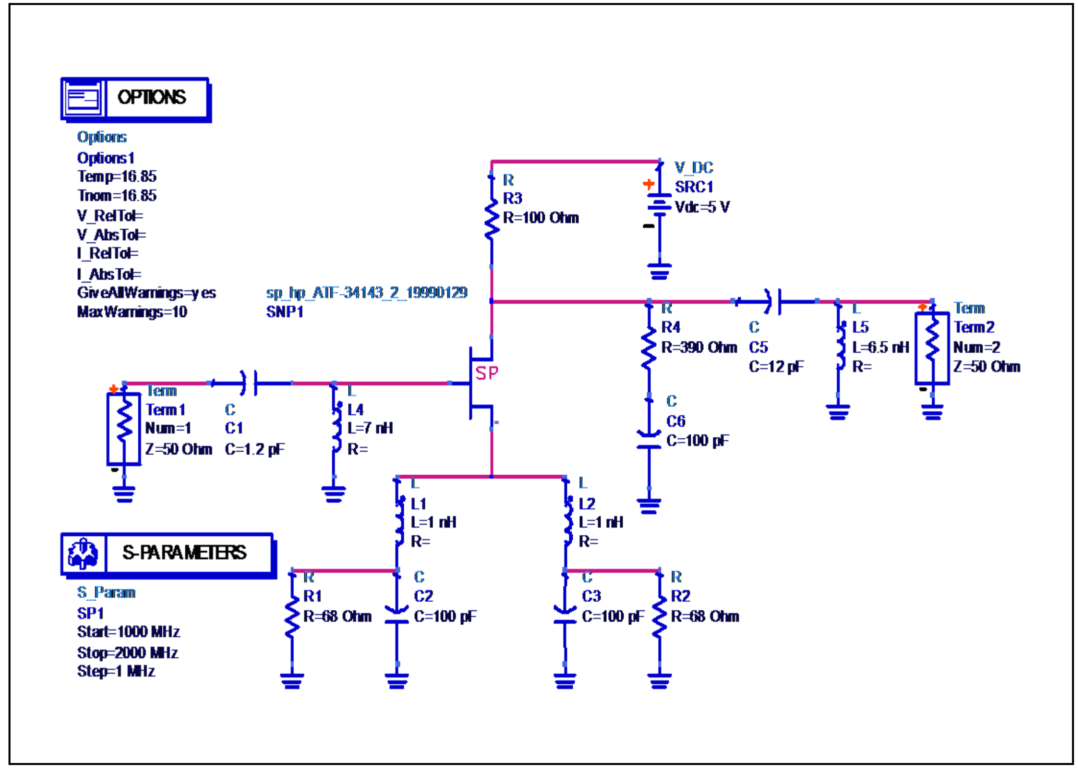
CH1 S11 SWR 1 / REF 1
Cor
3: 1.0558
1 525.000 000 MHz
START 1 000.000 000 MHz
STOP 2 000.000 000 MHz

$$P_n = kT_e\Delta v$$



$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \ldots$$

Friis's formula



NF=0,58 dB

T_e = 41 K

G = 15 dB

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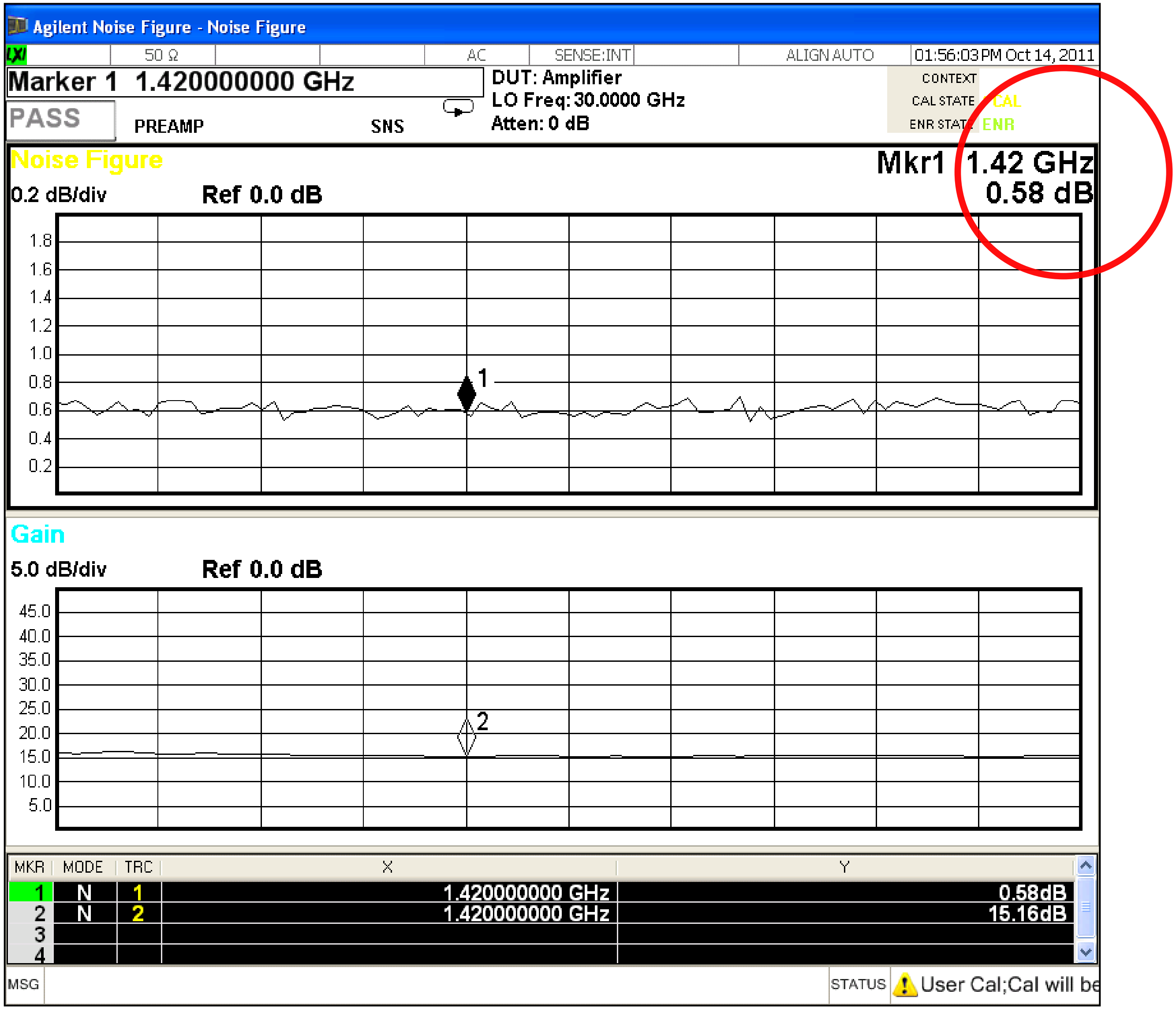
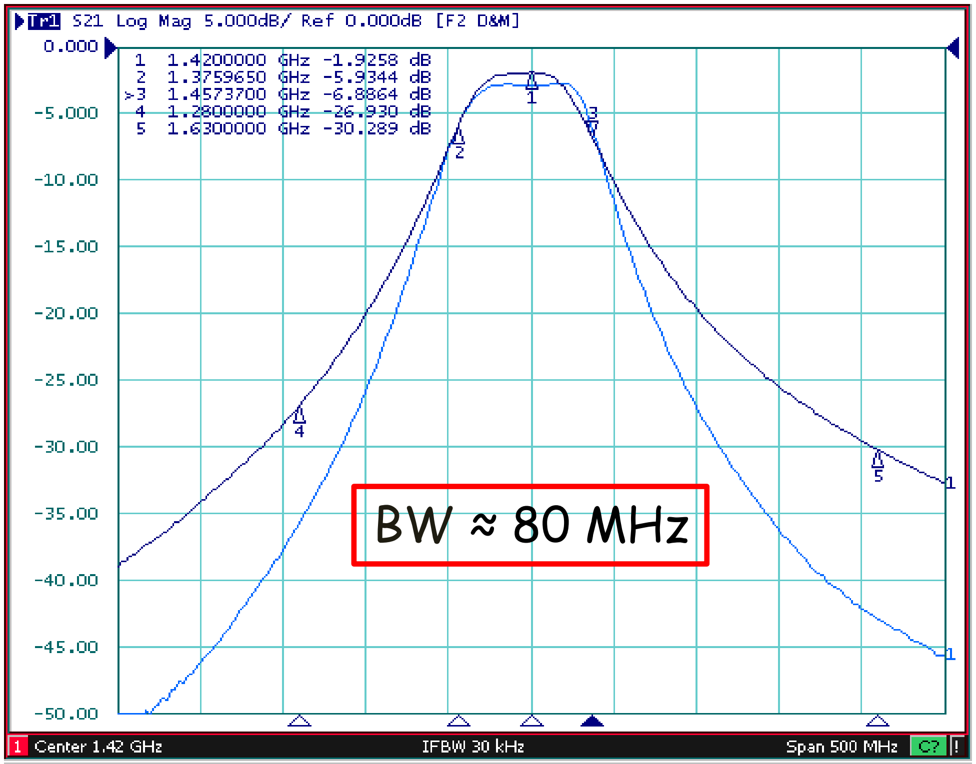
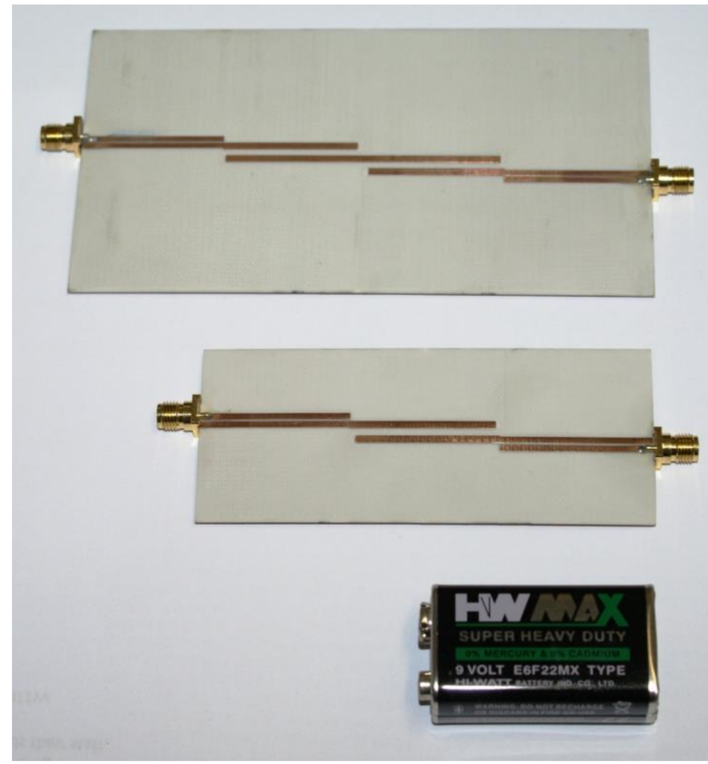

Agilent Noise Figure - Noise Figure
50 Ω
AC
SENSE:INT
ALIGN AUTO
01:56:03 PM Oct 14, 2011
Marker 1 1.420000000 GHz
PASS
PREAMP
SNS
DUT: Amplifier
LO Freq: 30.0000 GHz
Atten: 0 dB
CONTEXT
CAL STATE
CAL
ENR STATE
ENR
Noise Figure
0.2 dB/div
Ref 0.0 dB
Mkr1 1.42 GHz
0.58 dB
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1
Gain
5.0 dB/div
Ref 0.0 dB
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
2
MKR MODE TRC X Y
1 N 1 1.420000000 GHz 0.58dB
2 N 2 1.420000000 GHz 15.16dB
3
4
MSG
STATUS
User Cal;Cal will be





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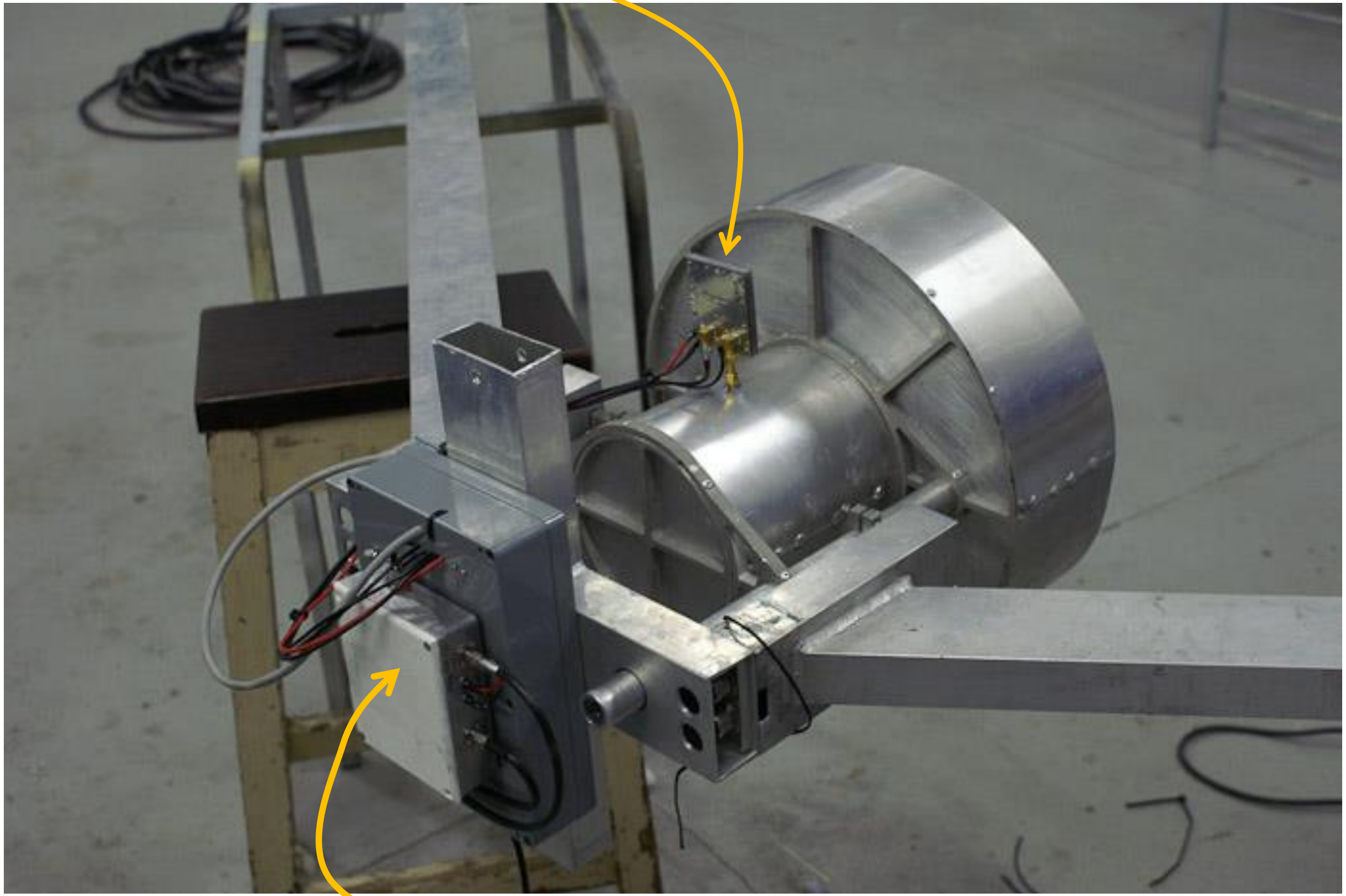
LNA as close to feed as possible
(1 dB loss on connector adds 75 K to T_e!)



RFA, BPF and down-converter
(original)

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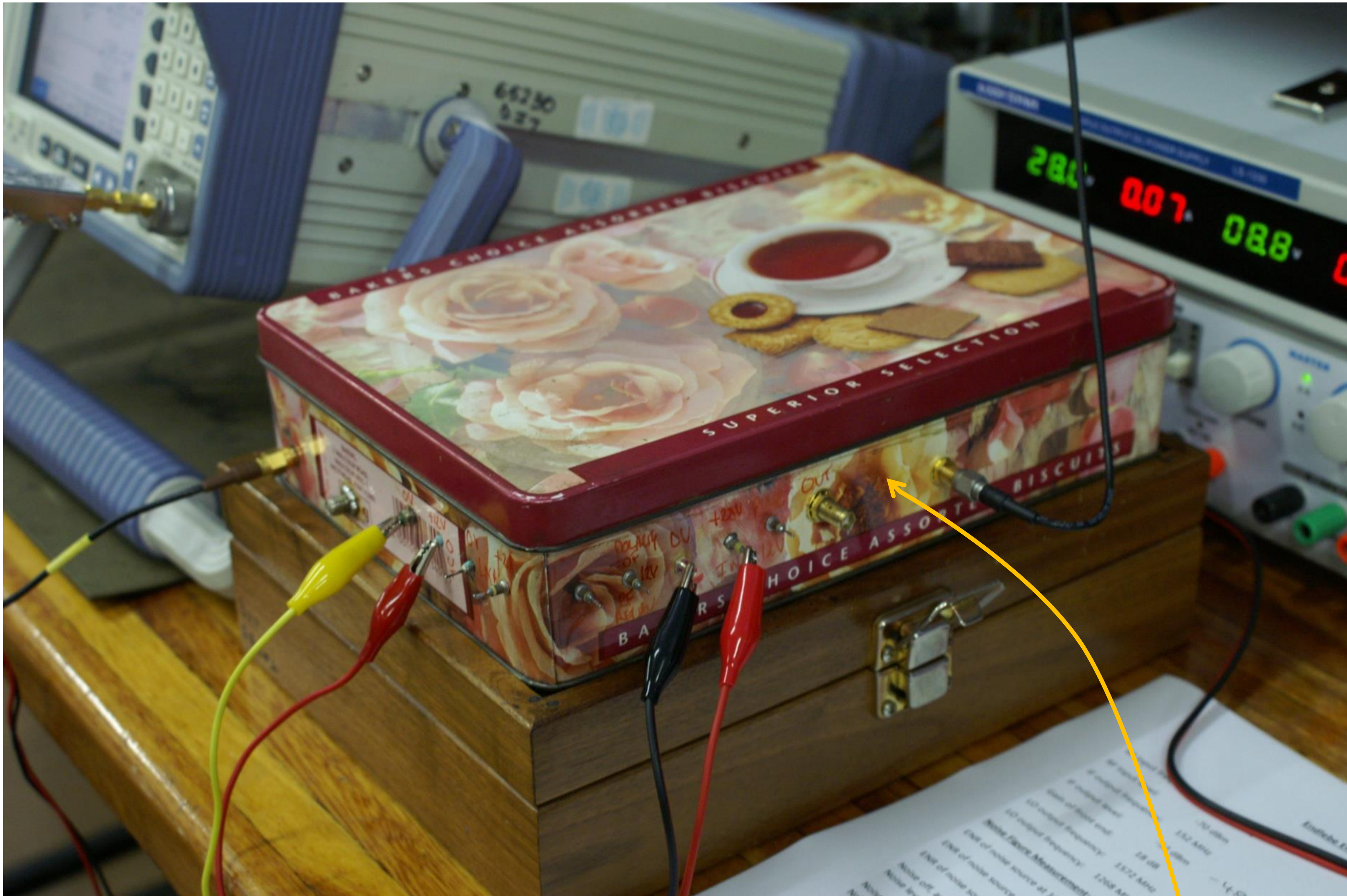
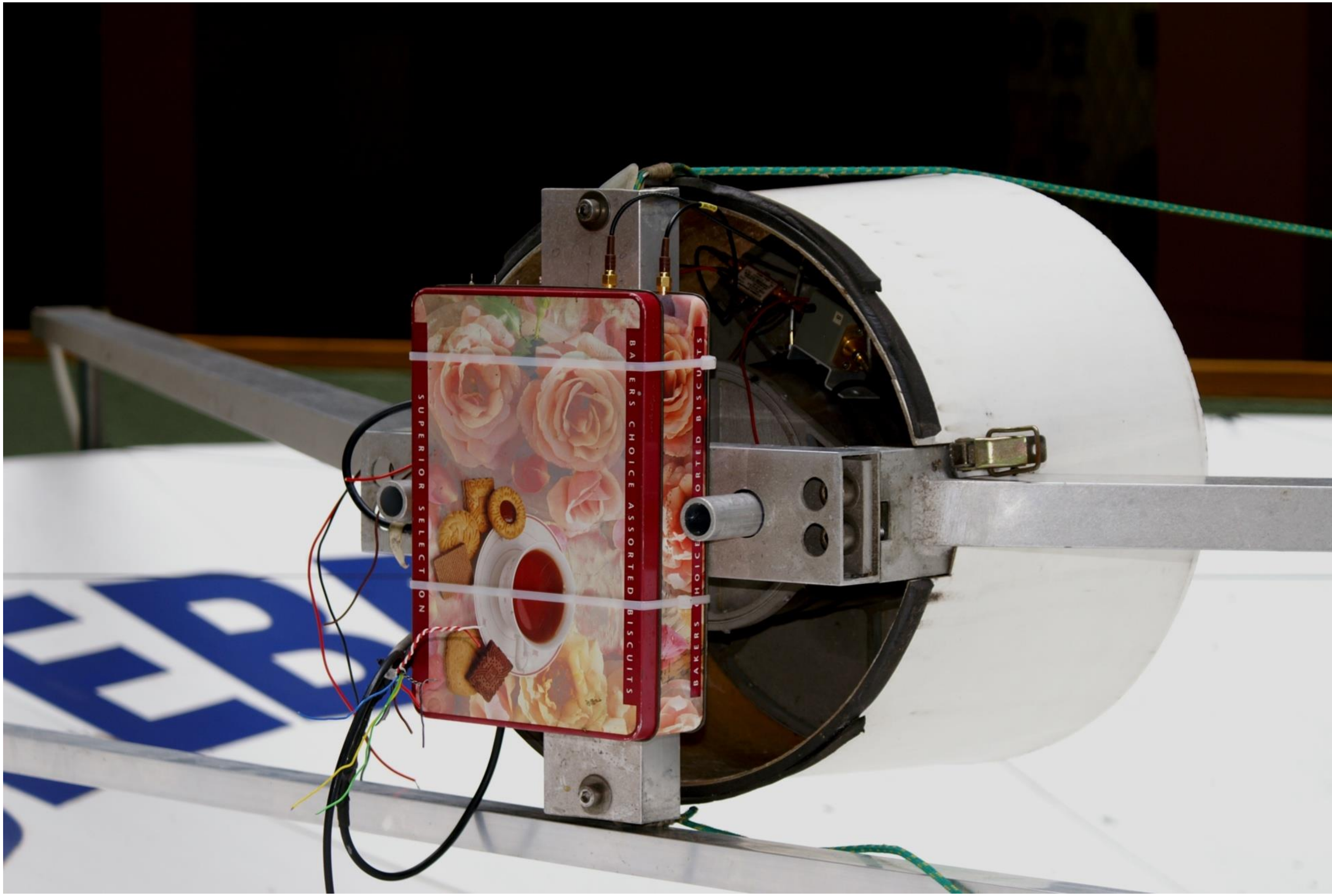


RF shielded enclosure!



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R2D2

Look familiar?

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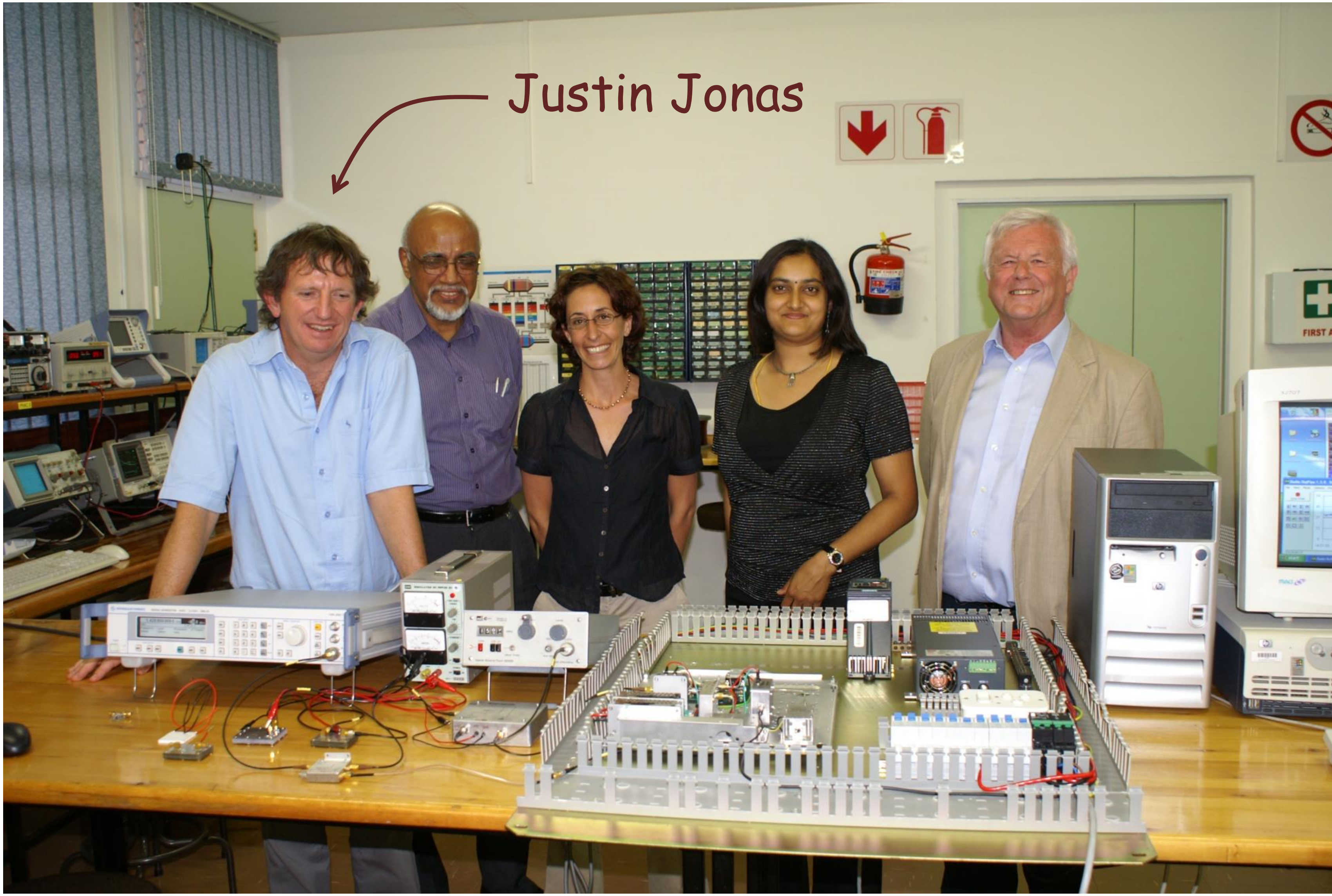

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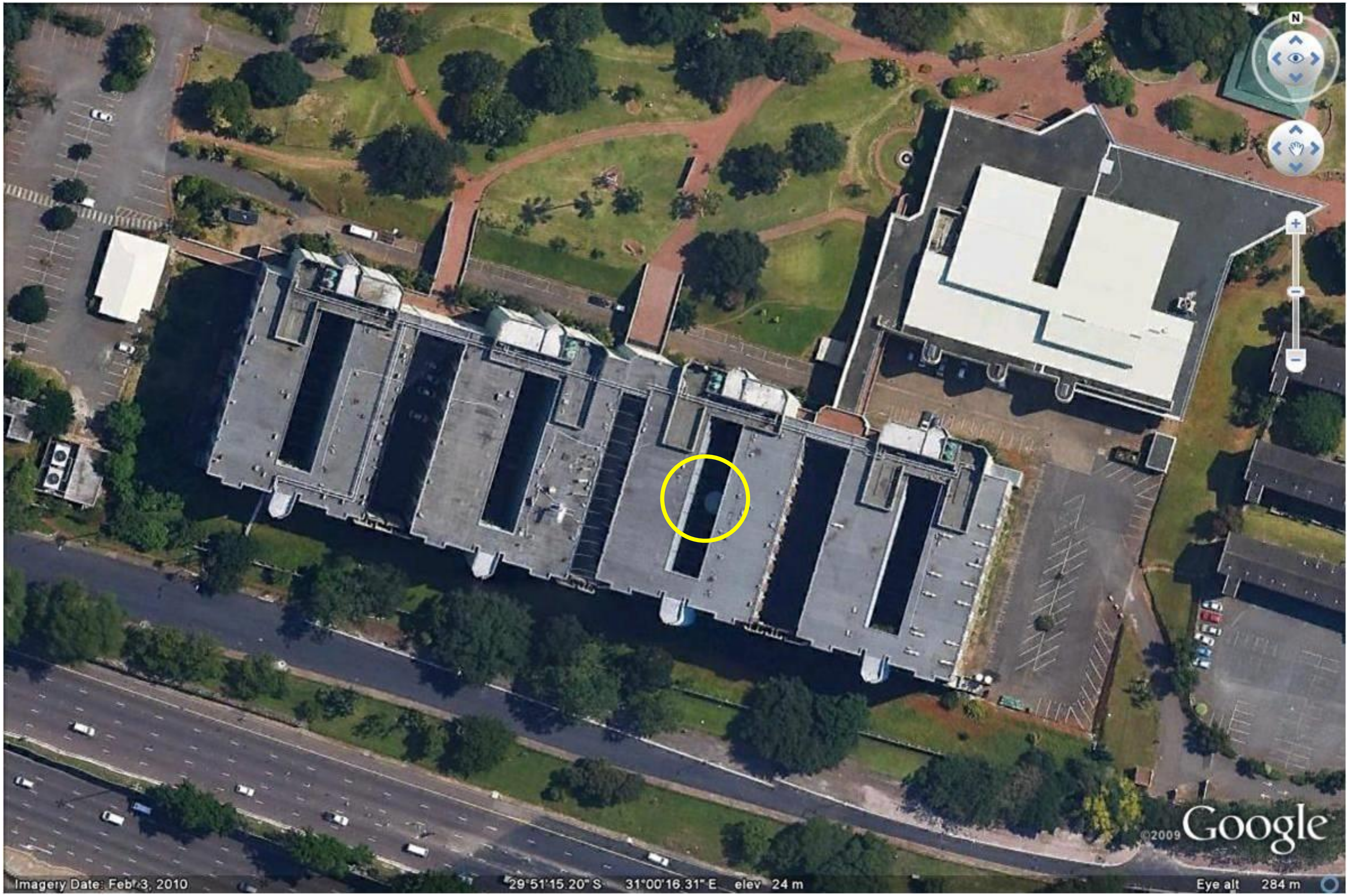

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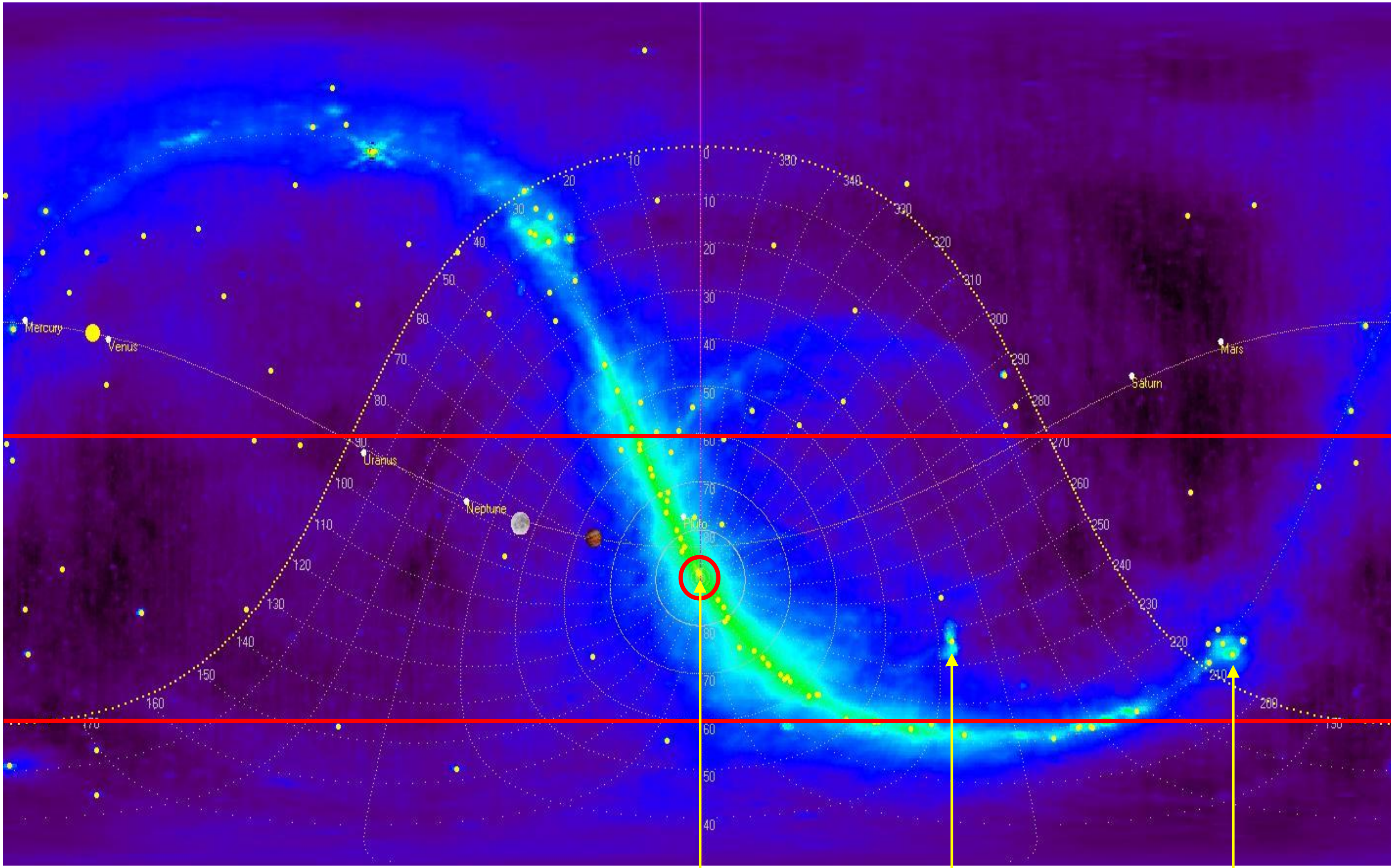

Sagittarius A
Centre of Milky Way 26000 ly

Centaurus A
Radio Galaxy 14 Mly

Vela X
Supernova remnant 1630 ly

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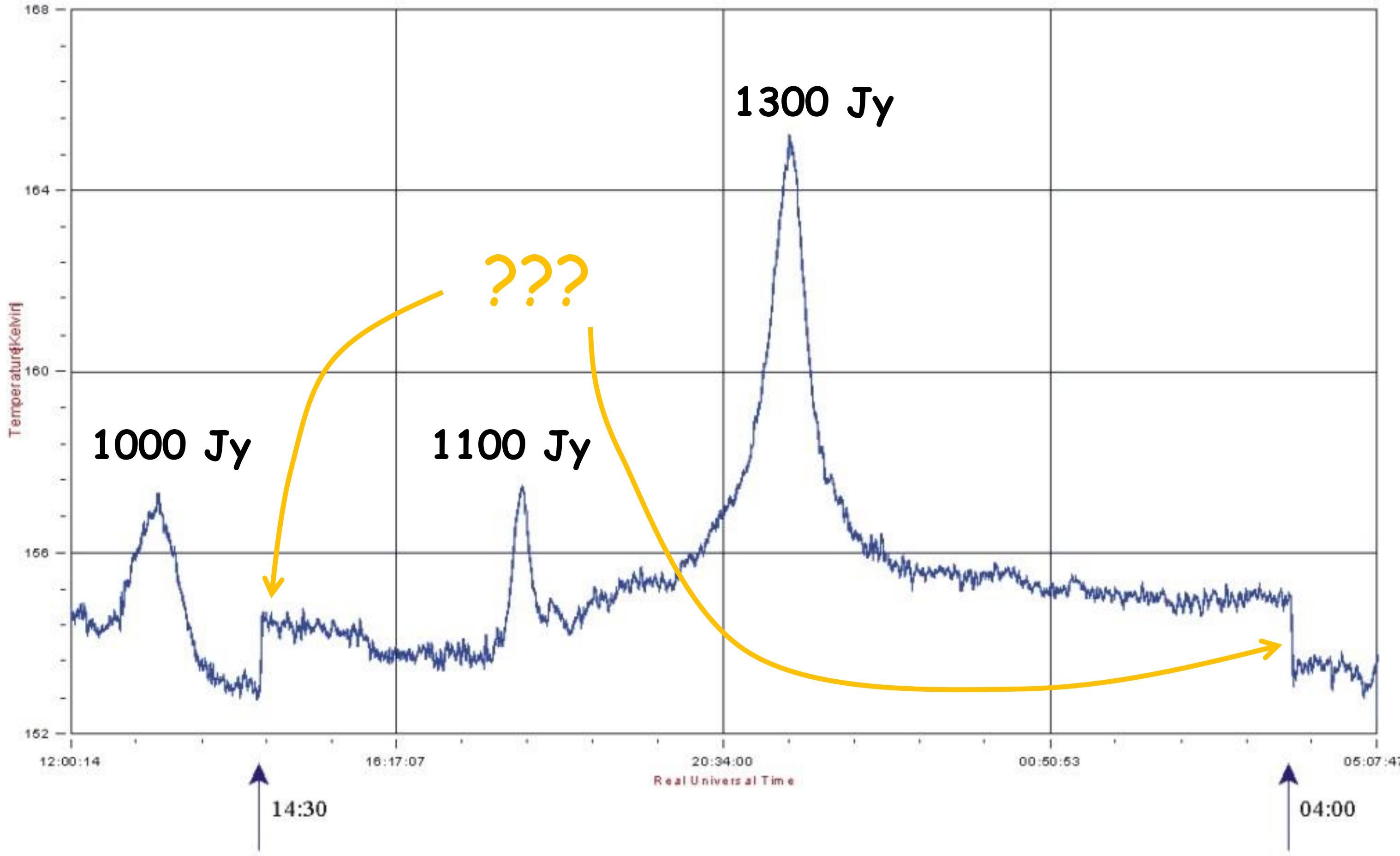
Vela X, Centaurus A, Sagittarius A



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Mini Sun's!

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So what's a Jansky (Jy)?

Flux density S is measured in Jy, where 1 Jy = 1×10^{-26} W/m²/Hz.

Consider a cellphone transmitting isotropically
(equally in all directions) on the moon.

Transmit Power = 0.5 W
Channel bandwidth (Δv) =12,5 kHz
Distance to earth = 380×10^3 km

$$S_{cellphone} = \frac{P_t}{4\pi r^2 \Delta v} = \frac{0{,}5}{4\pi \times (380 \times 10^6)^2 \times 12 \times 10^3}$$

$$= 2{,}3 \times 10^{-23}\ \text{W/m}^2\text{/Hz}$$

$$= 2300\ \text{Jy}$$

So a cellphone on the Moon appears 1000 Jy stronger than Sag.A!

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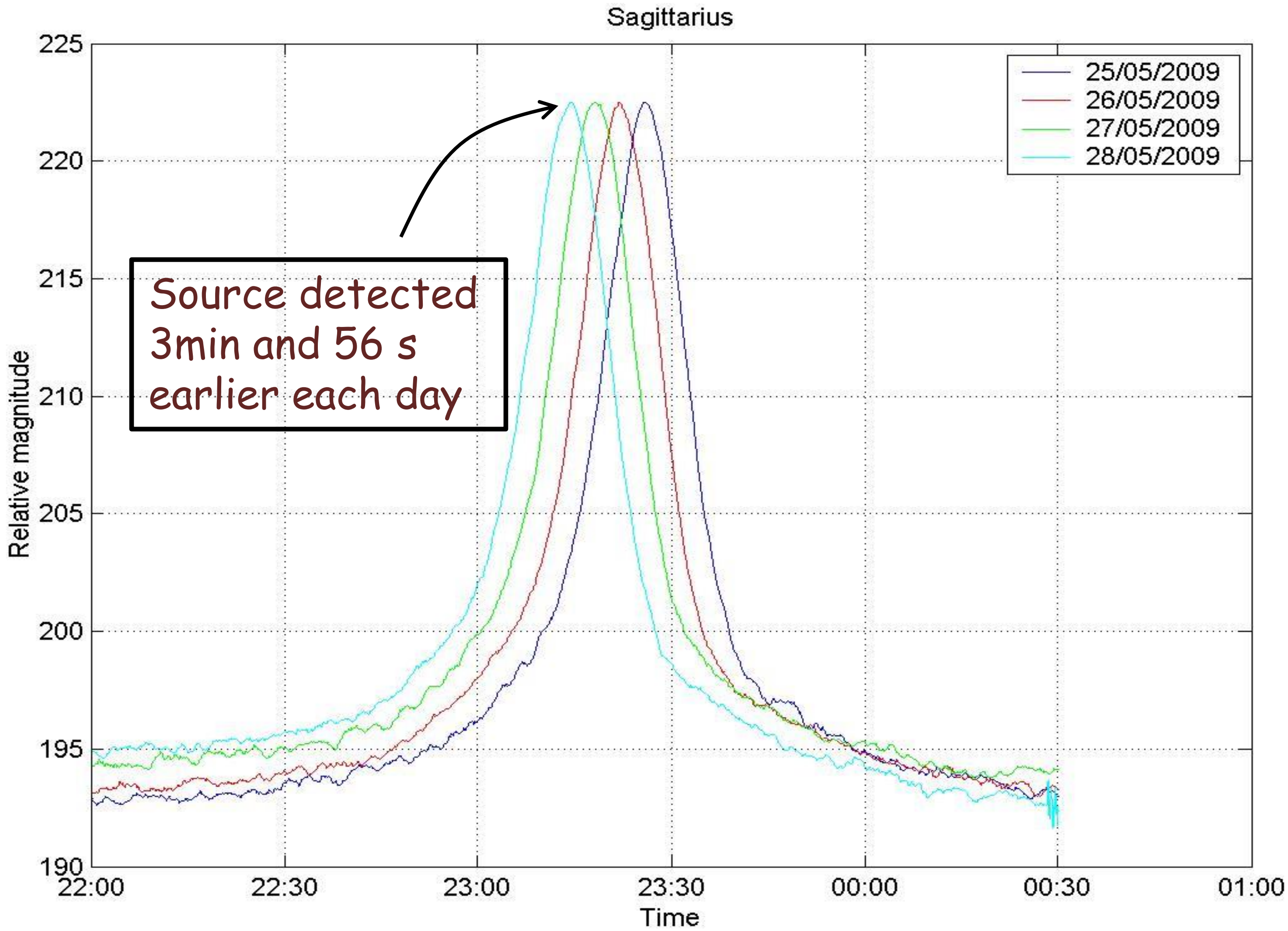

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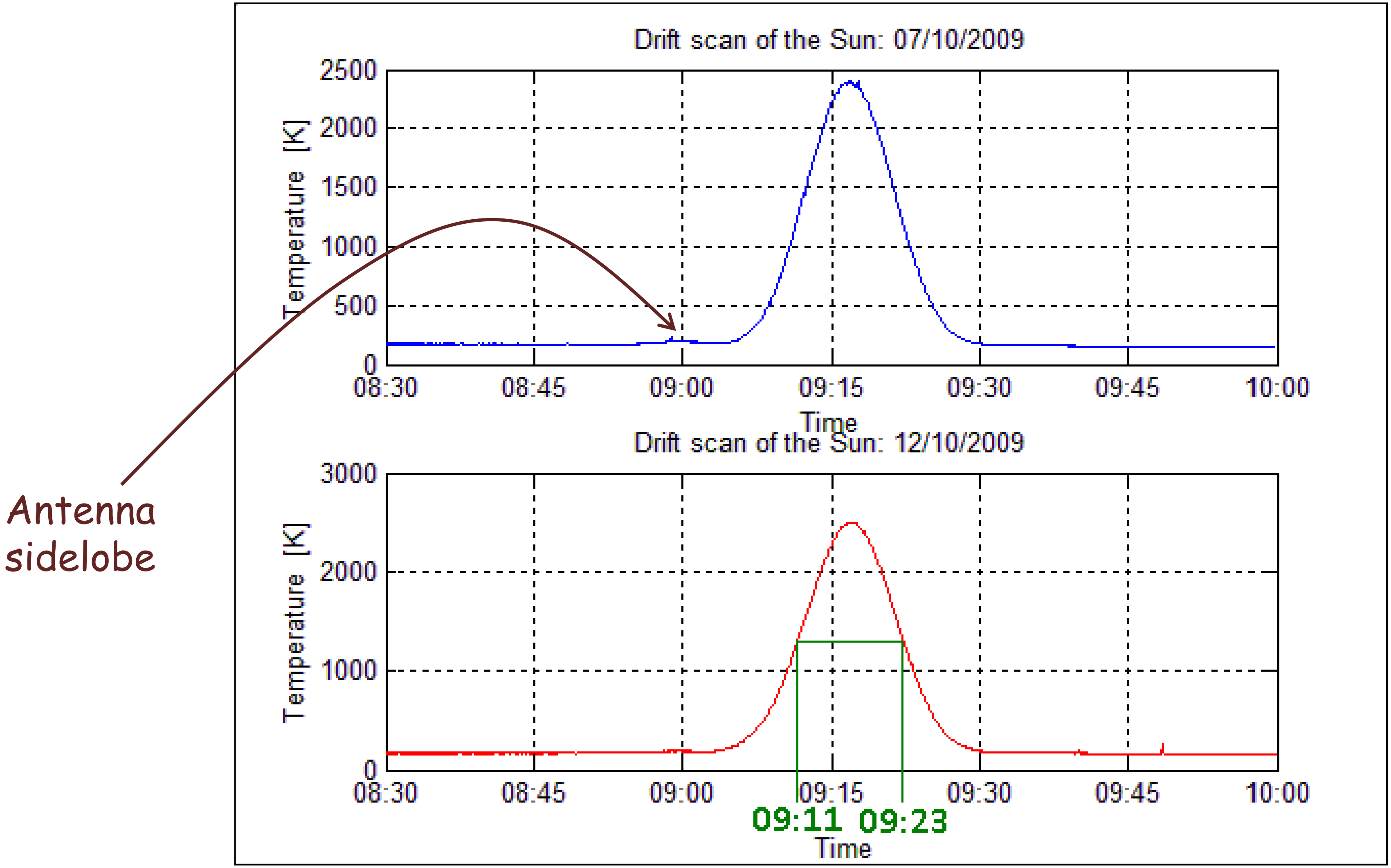
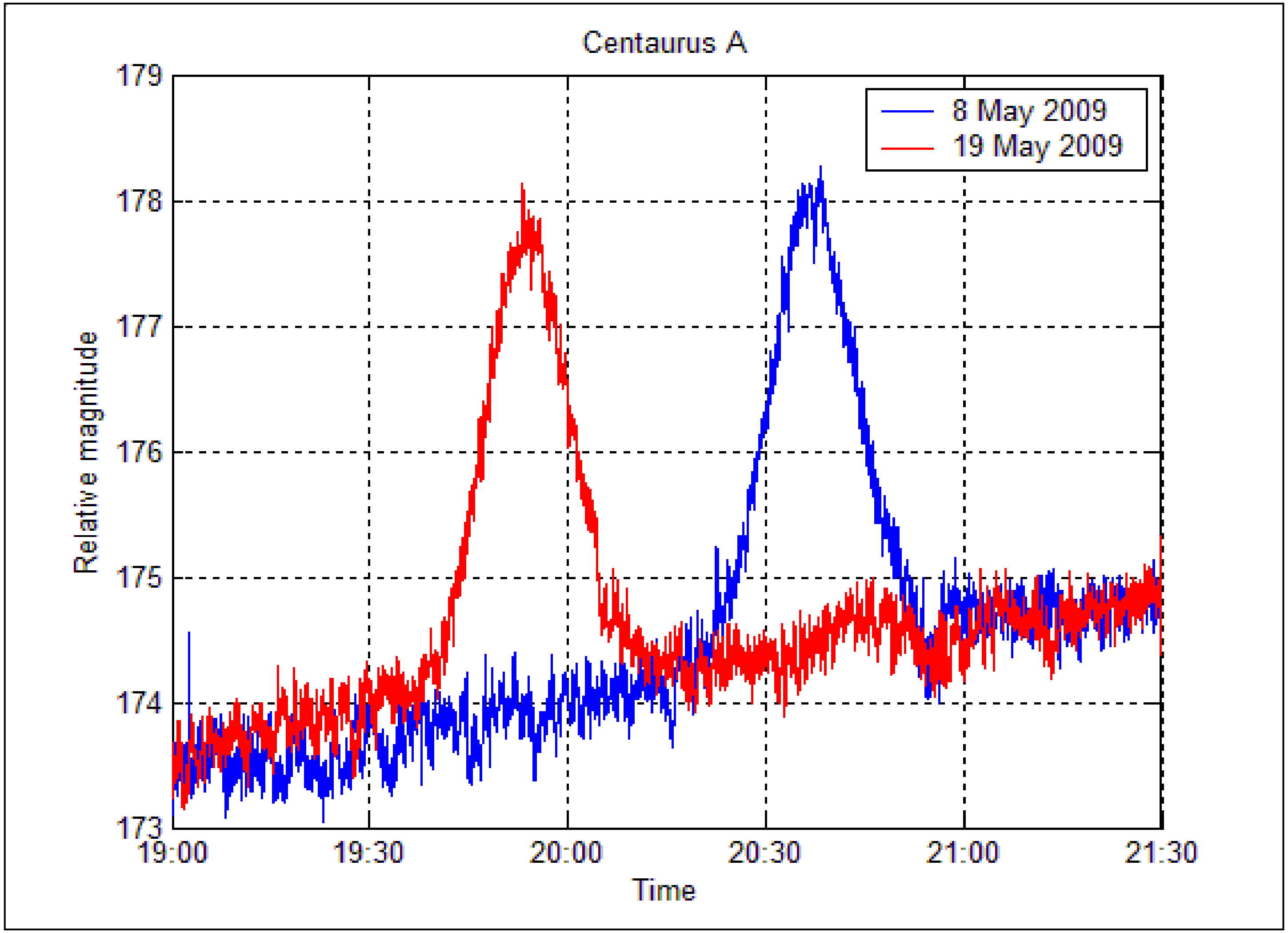
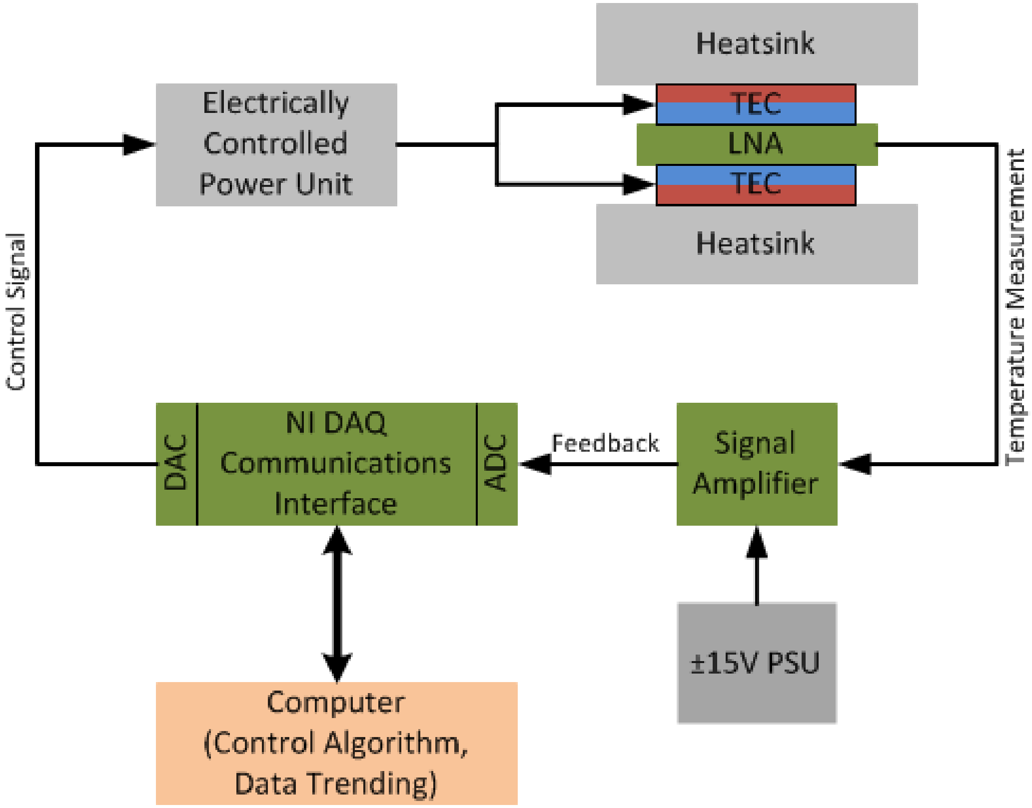
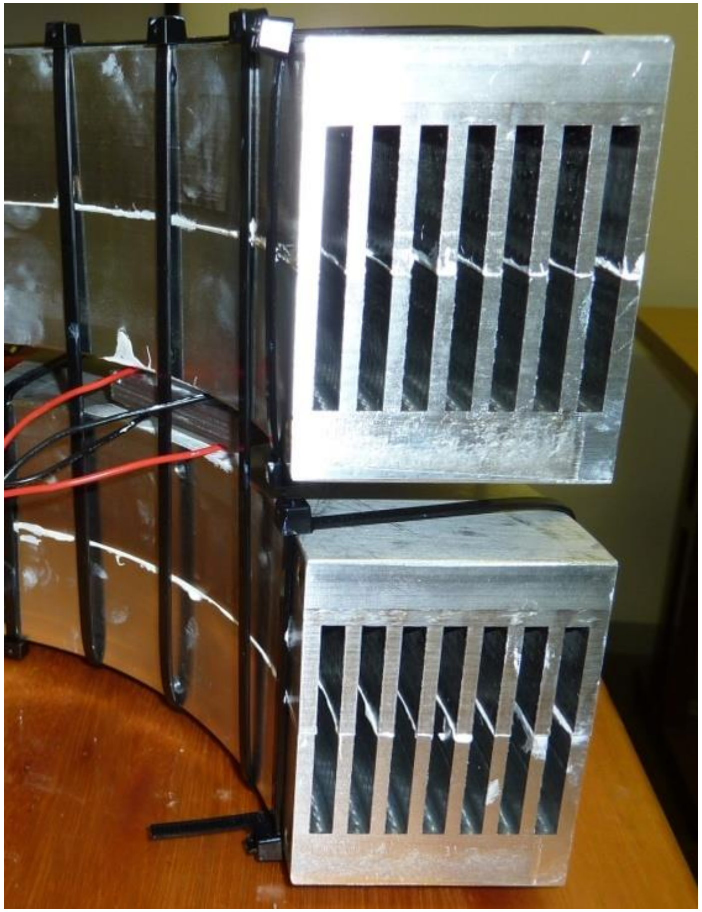

Drift scan of the Sun: 07/10/2009
Temperature [K]
2500
2000
1500
1000
500
0
08:30
08:45
09:00
09:15
09:30
09:45
10:00
Time
Antenna sidelobe
Drift scan of the Sun: 12/10/2009
Temperature [K]
3000
2000
1000
0
08:30
08:45
09:00
09:15
09:30
09:45
10:00
09:11
09:23
Time


Centaurus A
Relative magnitude
Time
8 May 2009
19 May 2009
179
178
177
176
175
174
173
19:00
19:30
20:00
20:30
21:00
21:30

74°C

Thermo electric coolers (Peltier coolers)





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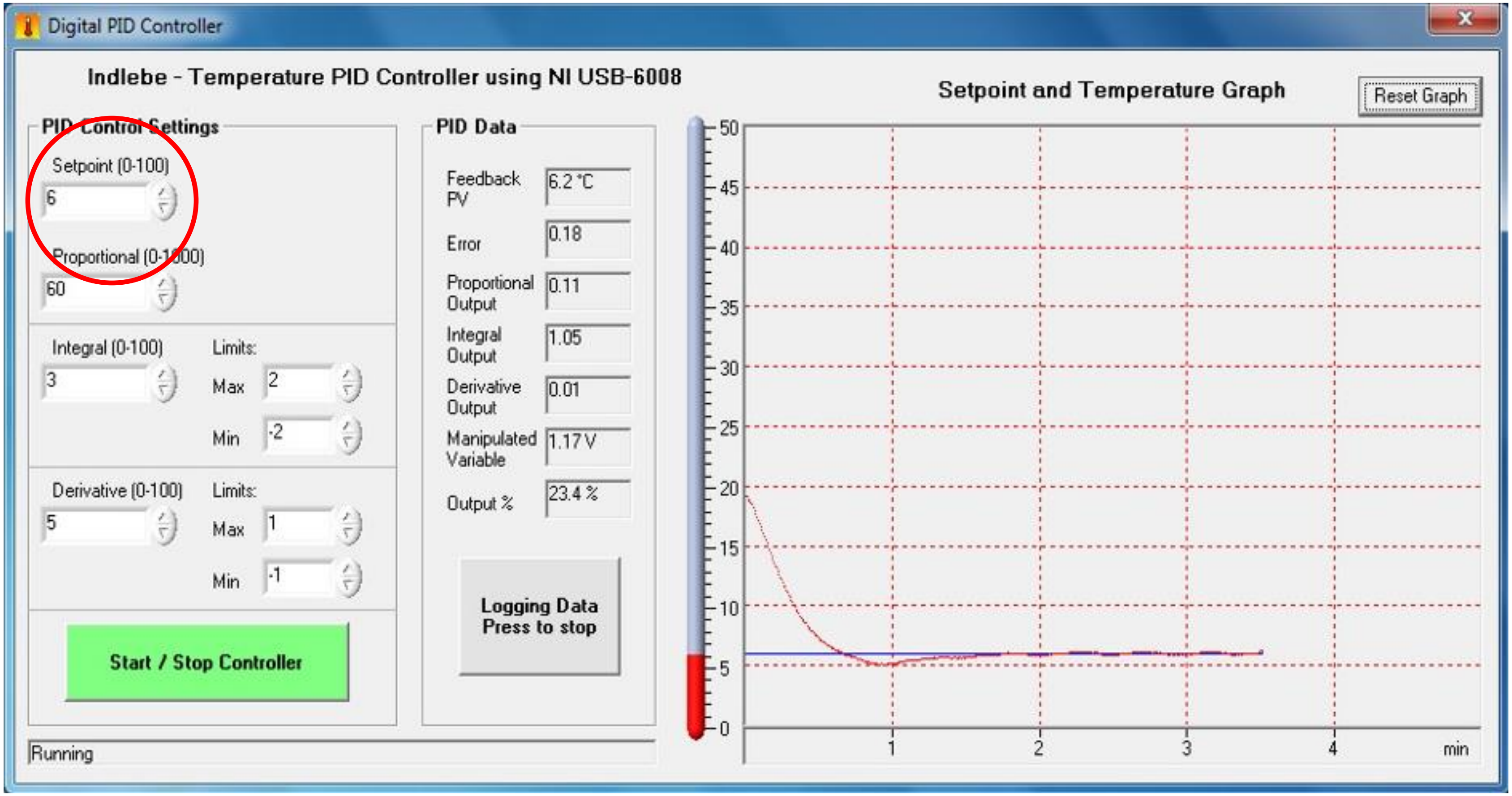

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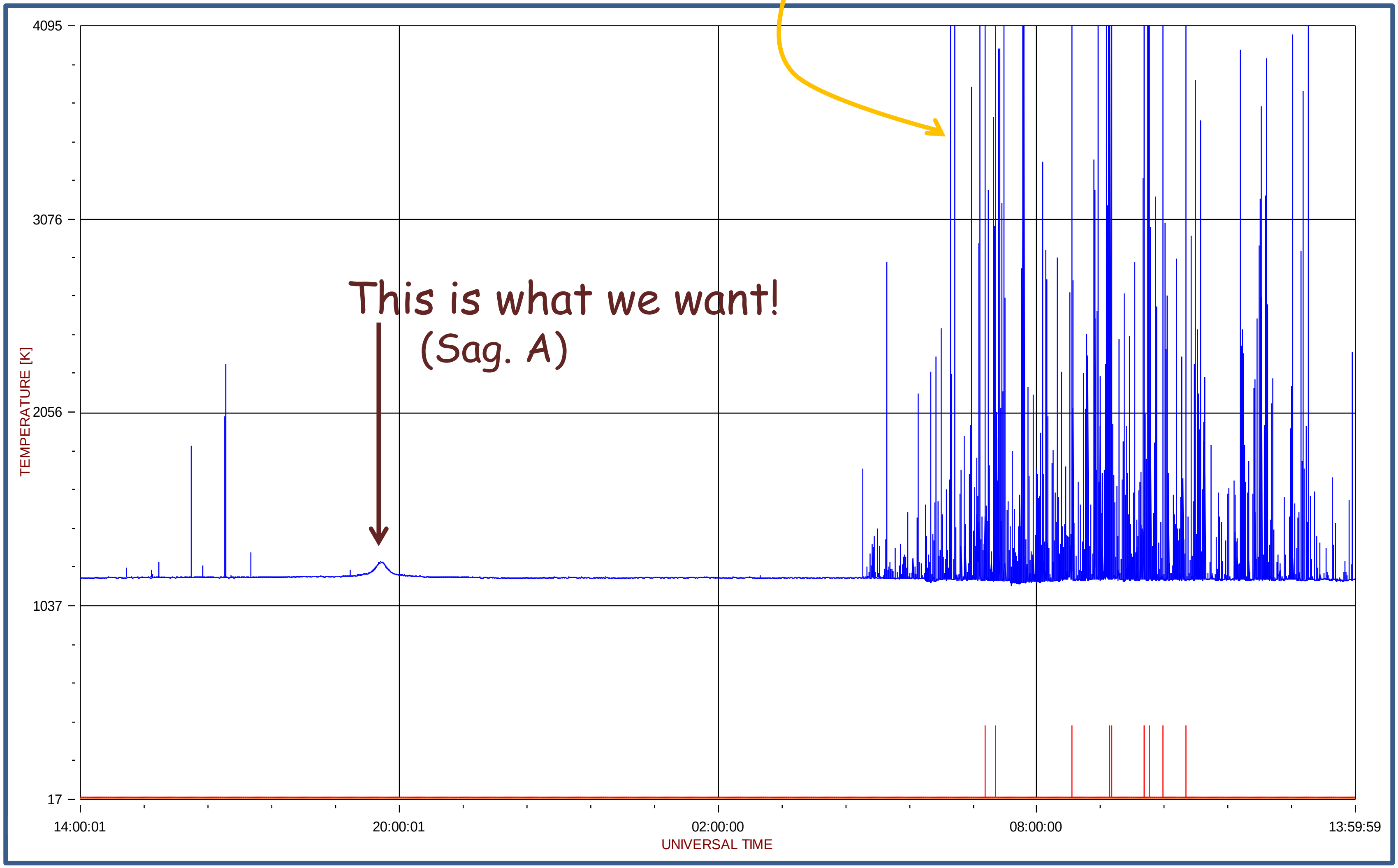
Students supposed to be in lectures!



Indlebe Enkulu Radio Telescope

- Also operating at the hydrogen line frequency this telescope consists of 16 quad loop Yagi antennas, configured in a 4×4 array (BW = 4°)
- Located at Monteseel 45 km from Durban.
- Equivalent Noise Temperature (feed losses not included) T_e = 54 K
- The intention is to implement a simple 2 element interferometer with Indlebe.

SKA supported students starting their work integrated learning (WIL)

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Tower Installation

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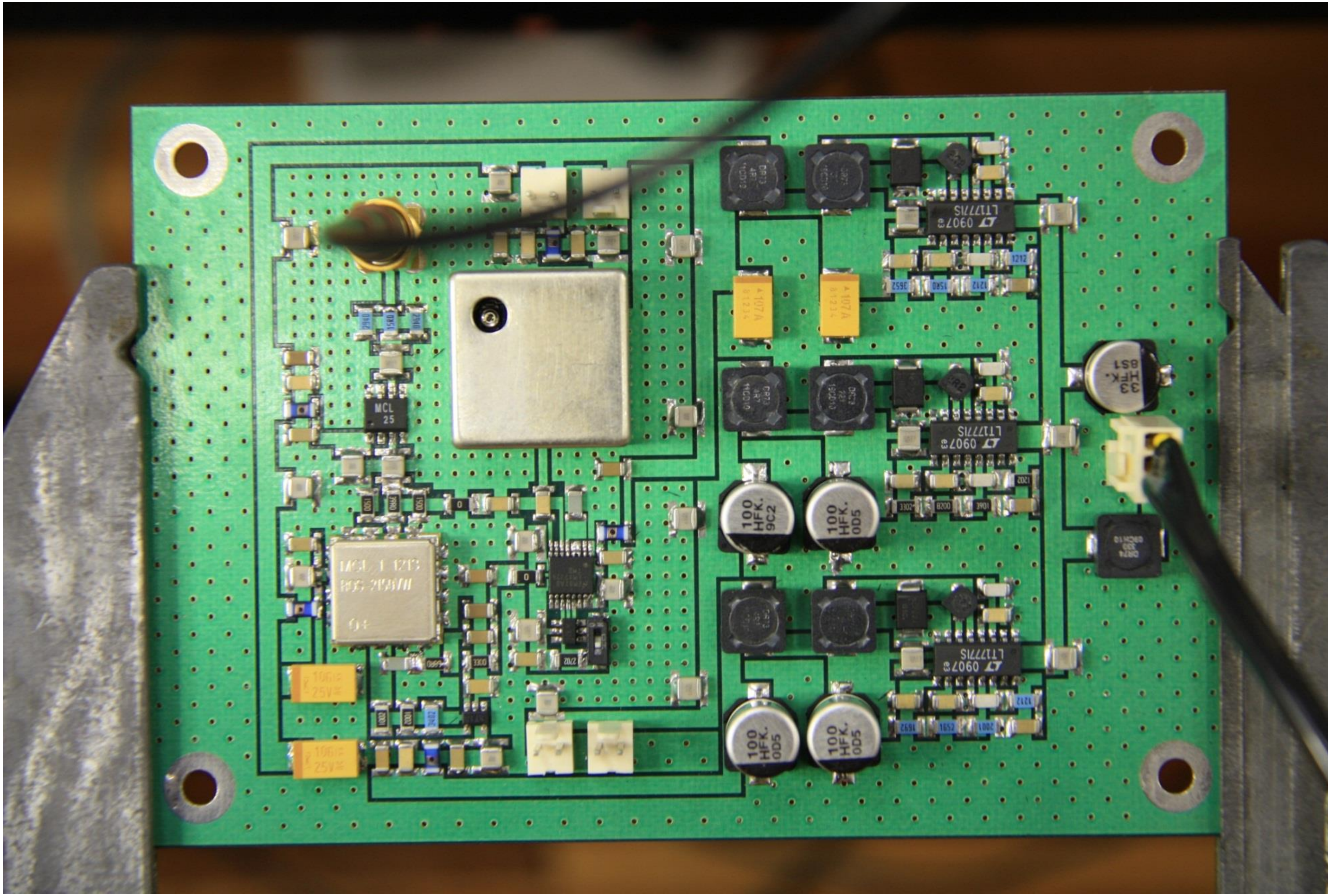
Antenna testing - Paardefontein

Phasing harness
(Phased Array)



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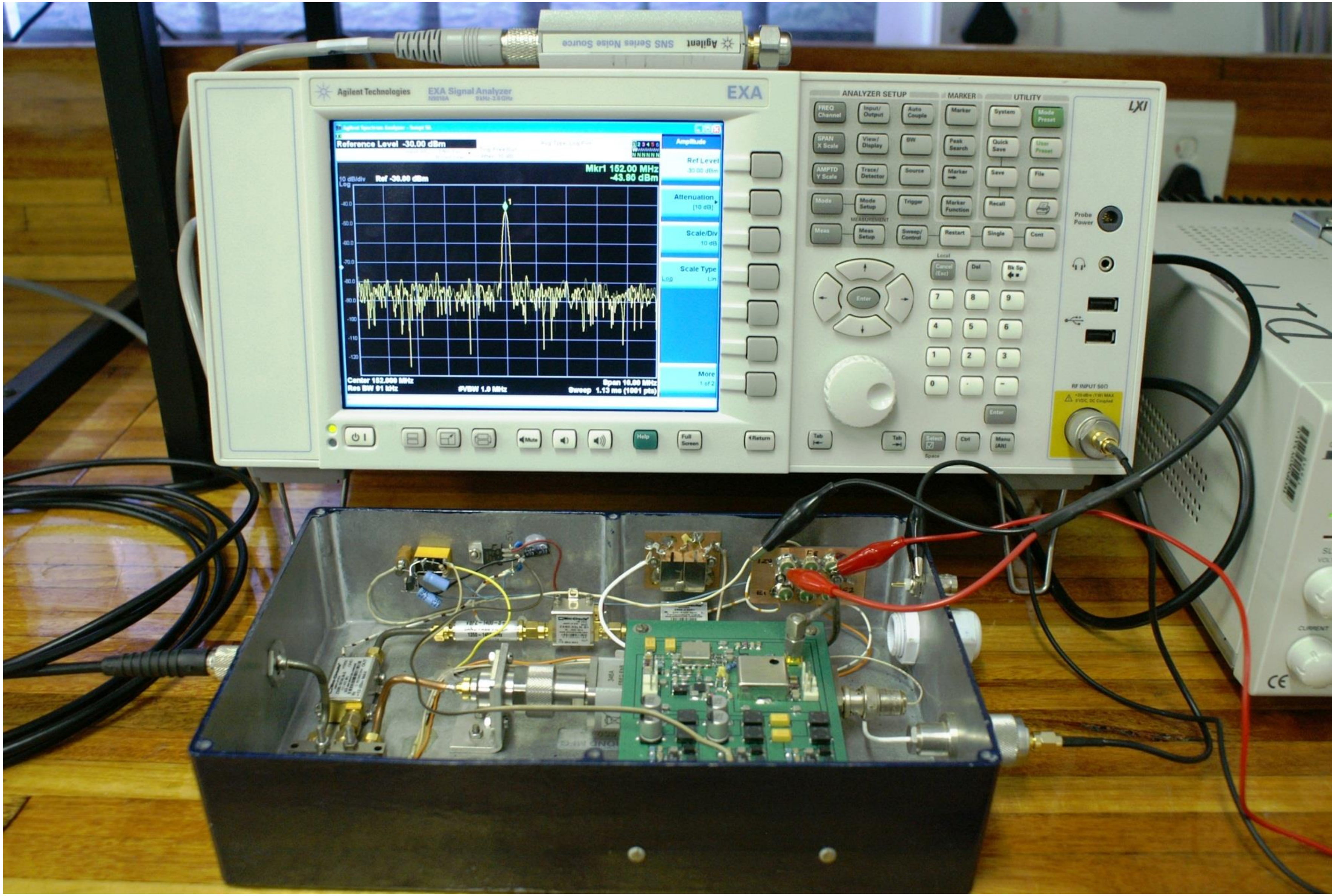
Local Oscillator Synthesizer



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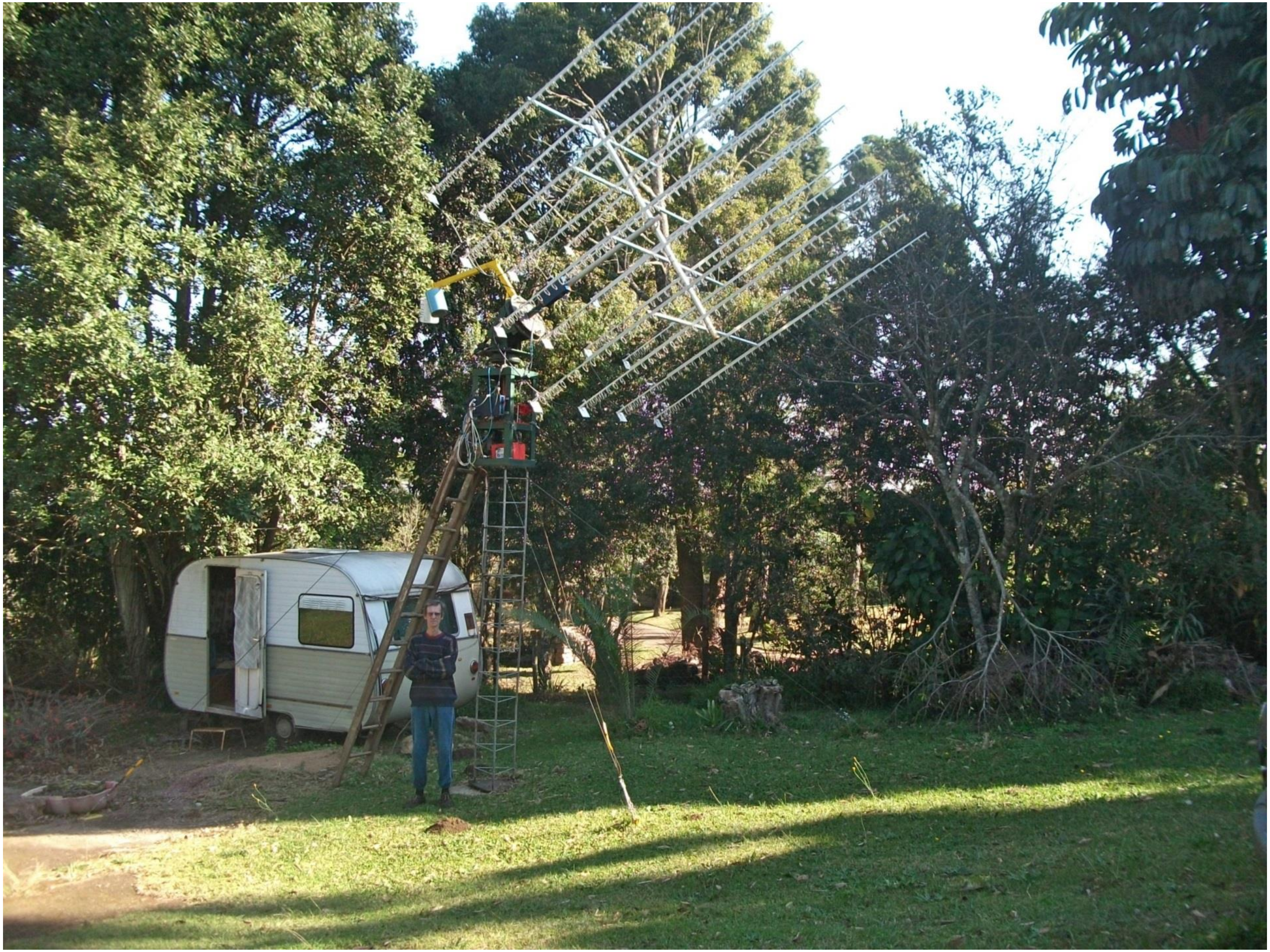
Receiver front-end



Complete Array - 16 Quad-Loop Yagi antennas

Eish!!

New Indlebe Enkulu Radio Telescope

Phased Experimental Demonstrator (PED-2)

- Originally built as a pre-curser to KAT 7, it was de-commissioned in 2011 and the hardware split between DUT and UCT.
- The DUT array consists of two 2,6 m parabolic reflectors operating at the hydrogen line.
- The array is fully steerable.
- The antennas have been completely refurbished.
- Uses a digital back-end.

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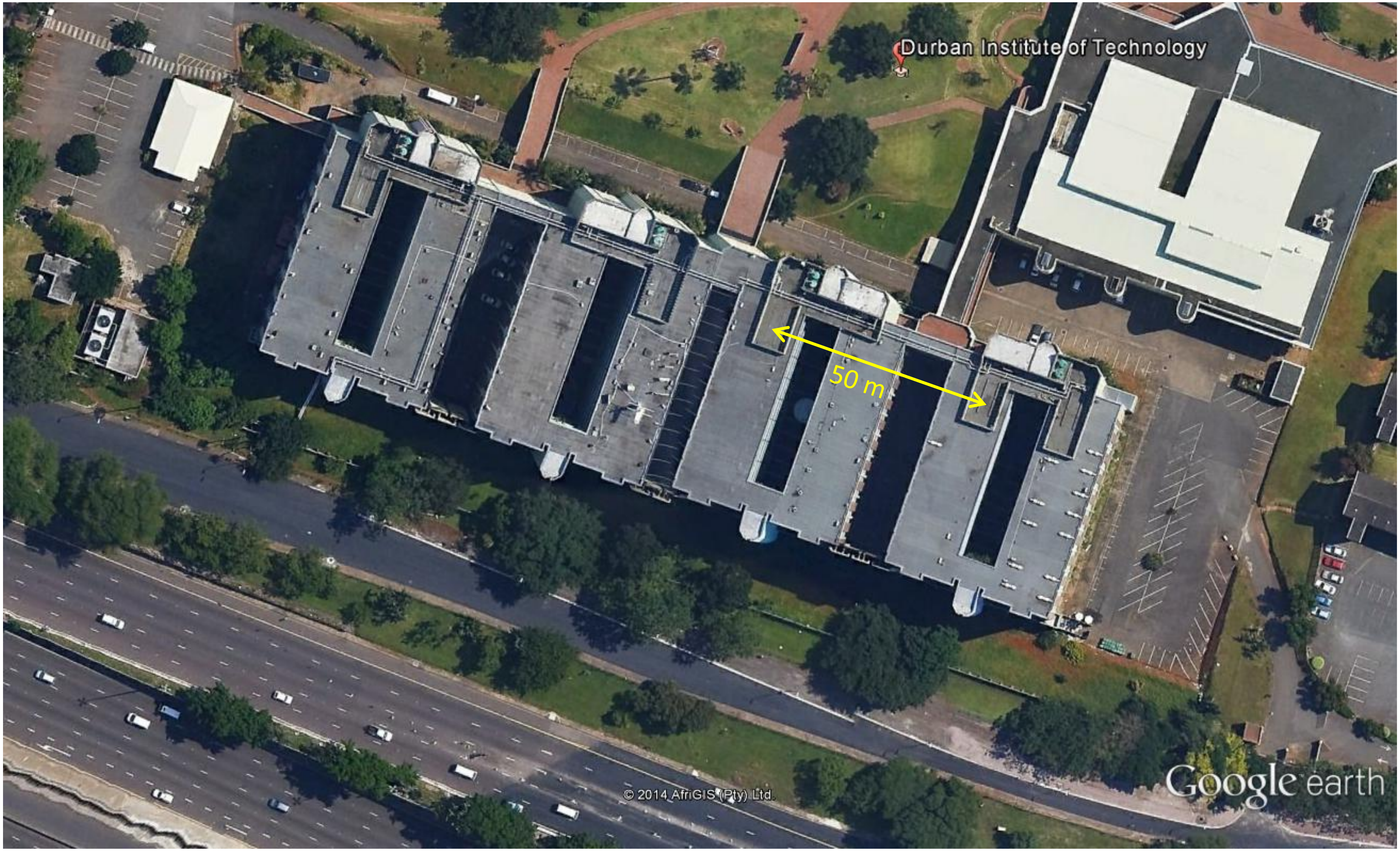

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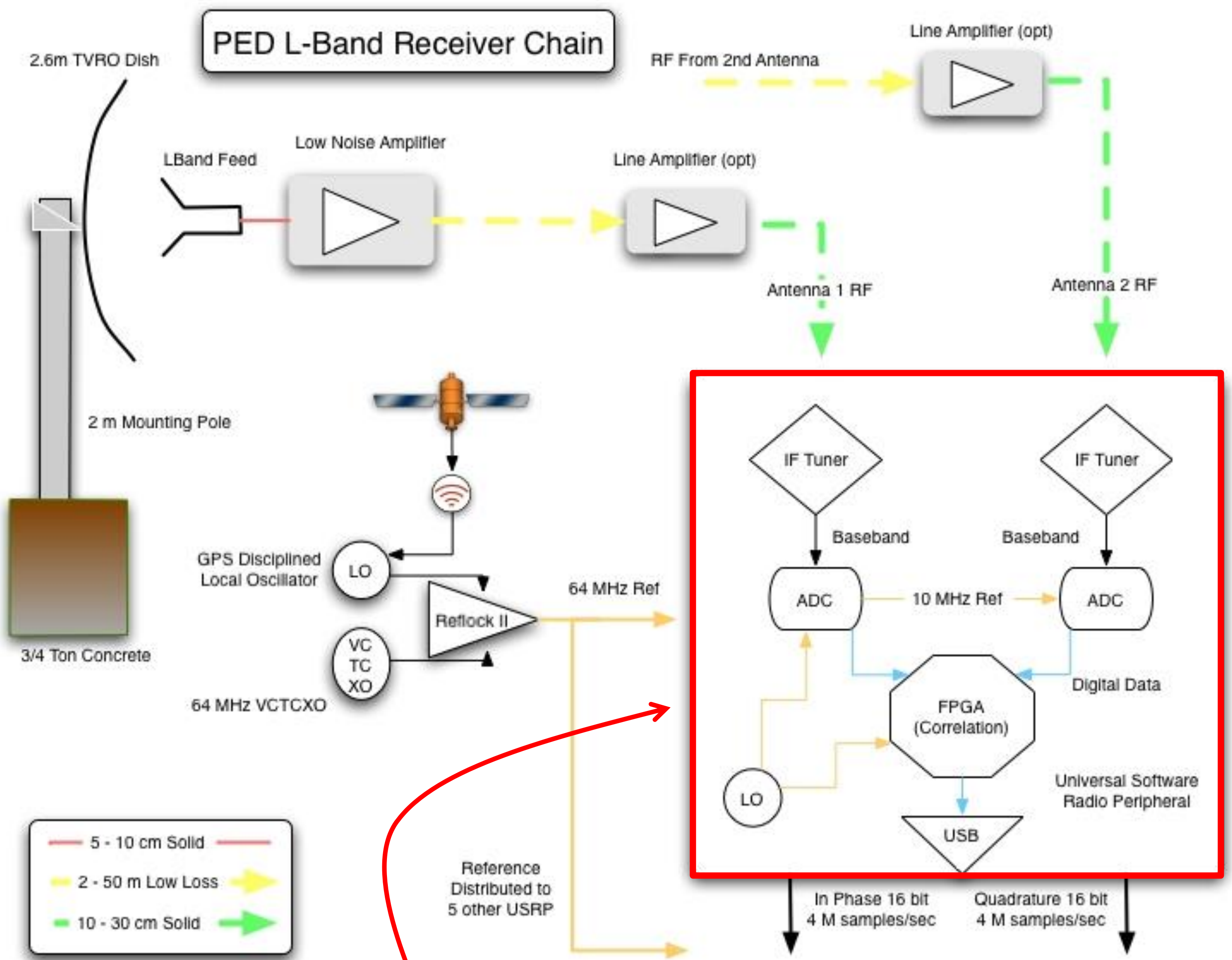

SDR Digital back-end

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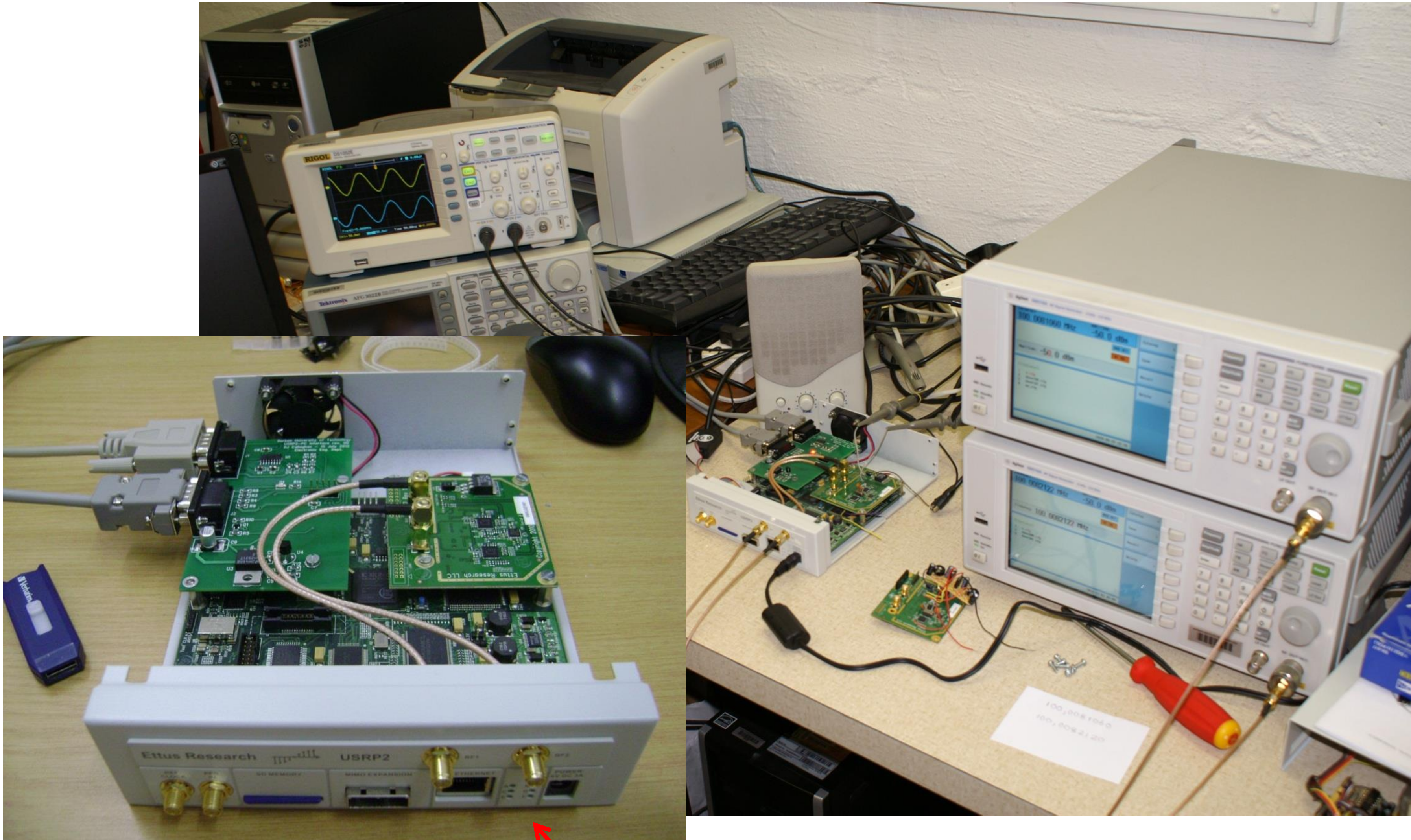

SDR Digital back-end

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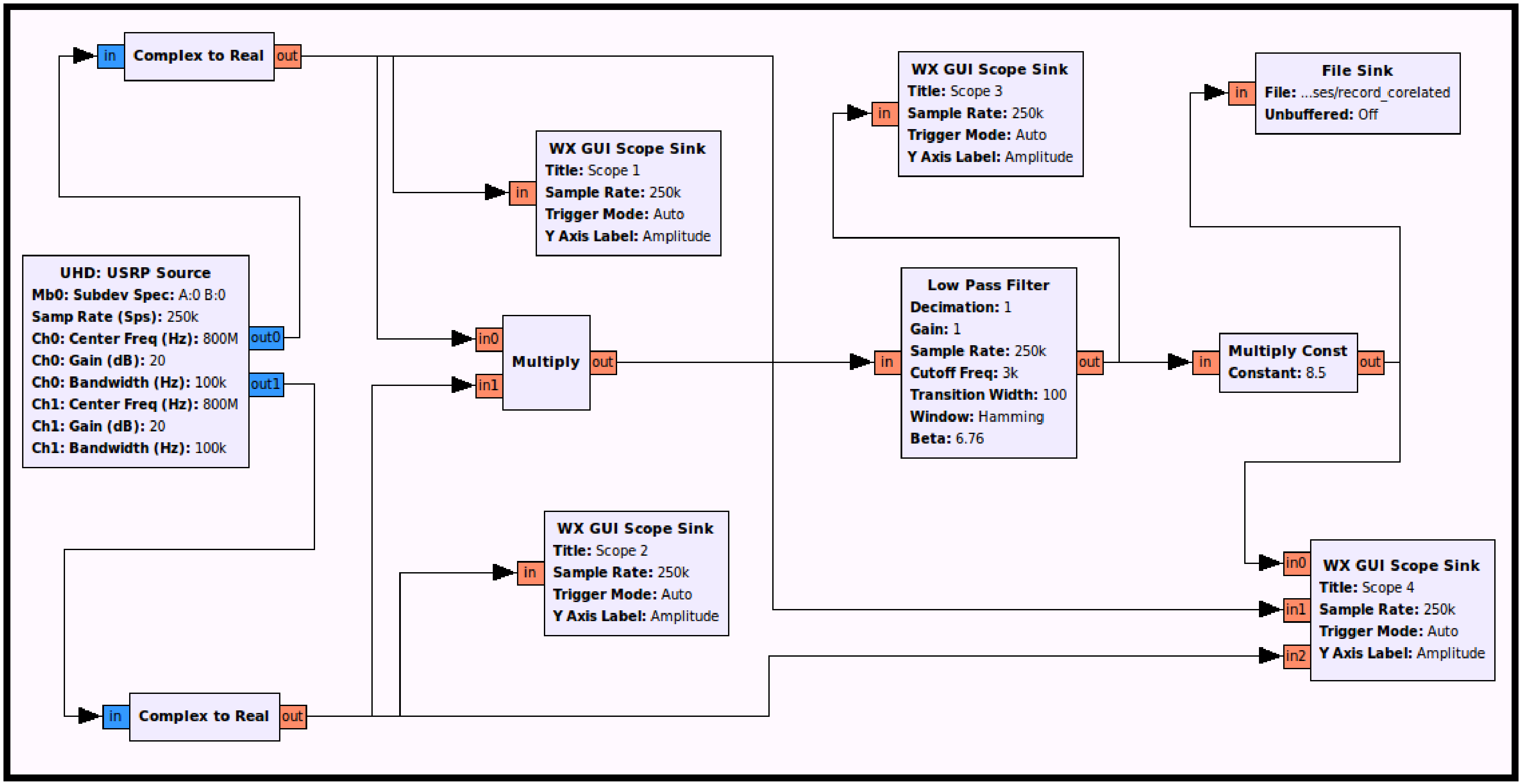
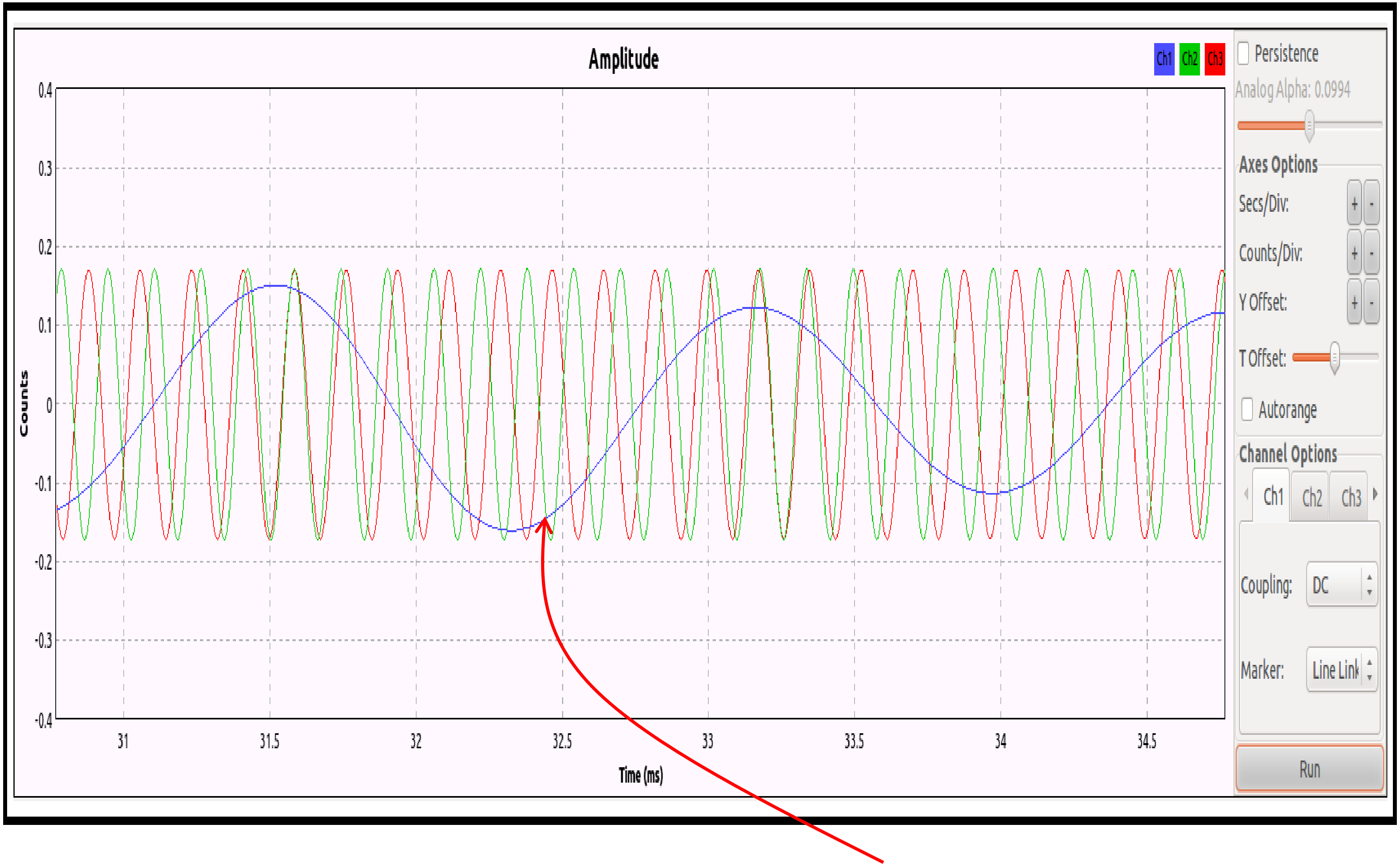
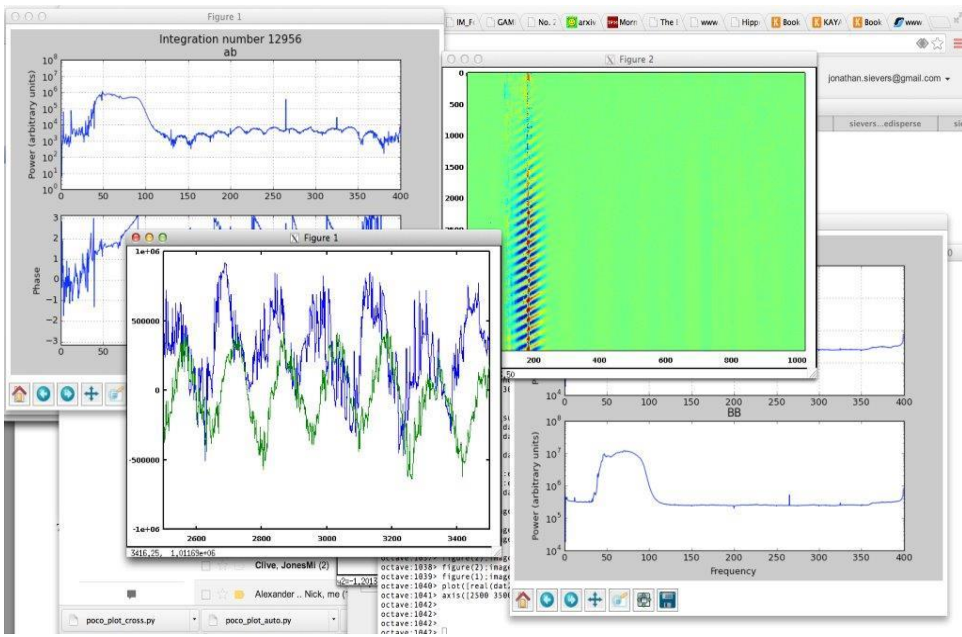
Software Defined Radio Astronomy





Correlator output

First Light 11 July 2014



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Multi Frequency Interferometer Telescope for Radio Astronomy (MITRA)

- MITRA is a joint venture between the University of Mauritius (UoM) and DUT.
- Initially it will consist of arrays of 16 LPDA's located in each country with the long term goal of doing VLBI on a 2400 km baseline.
- Operating frequency is 200 MHz to 800 MHz.

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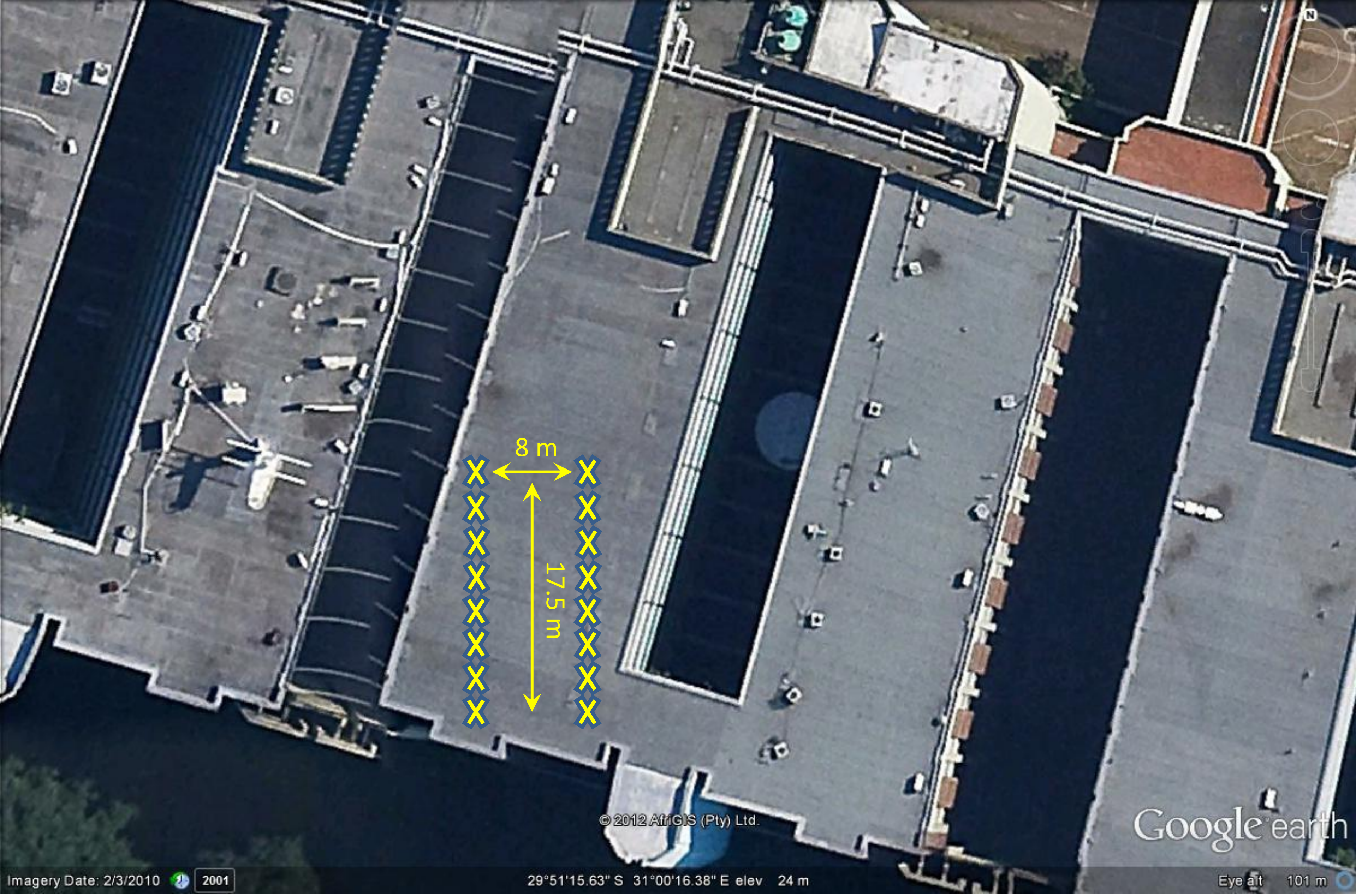

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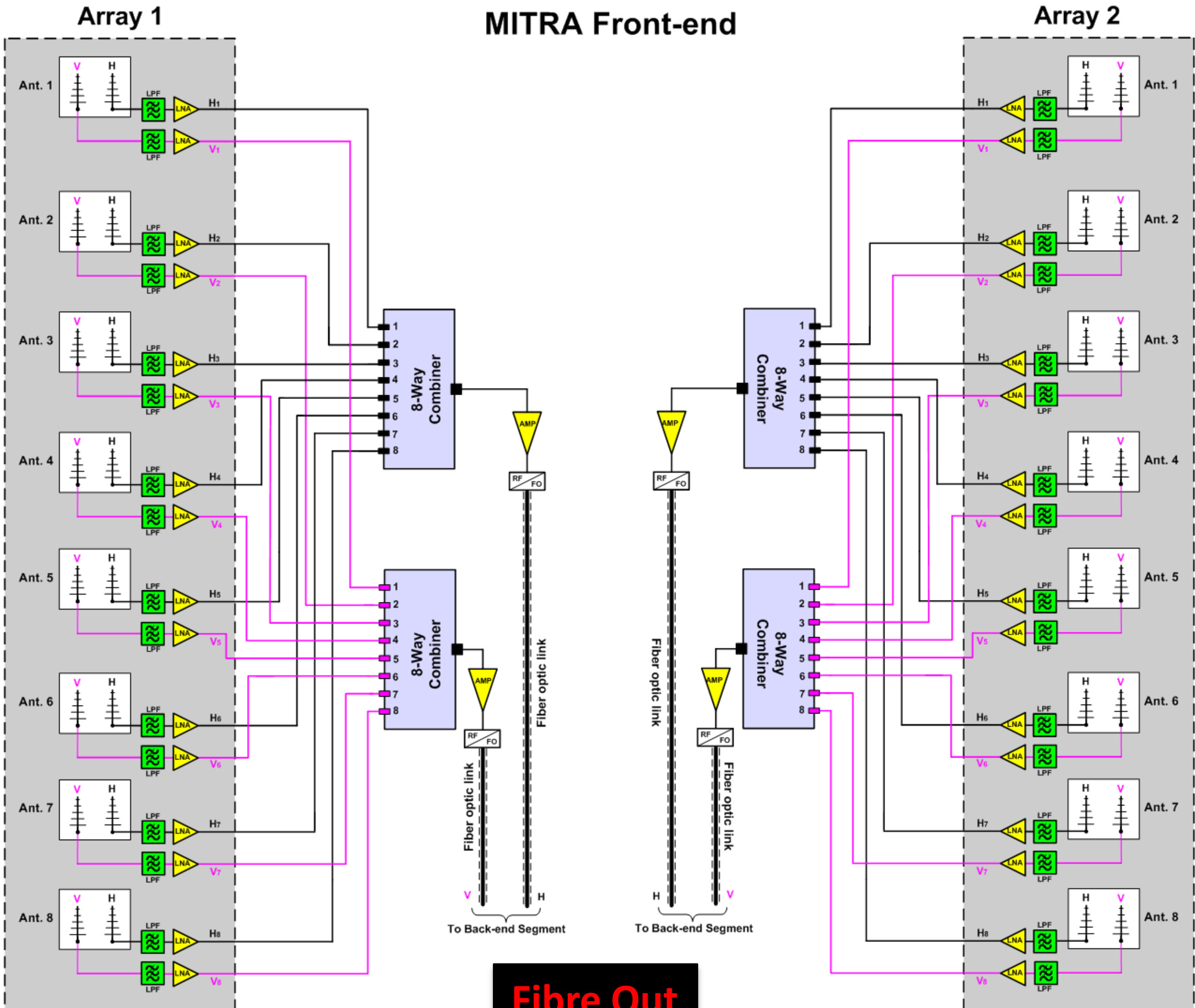
MITRA Front-end



Fibre Out

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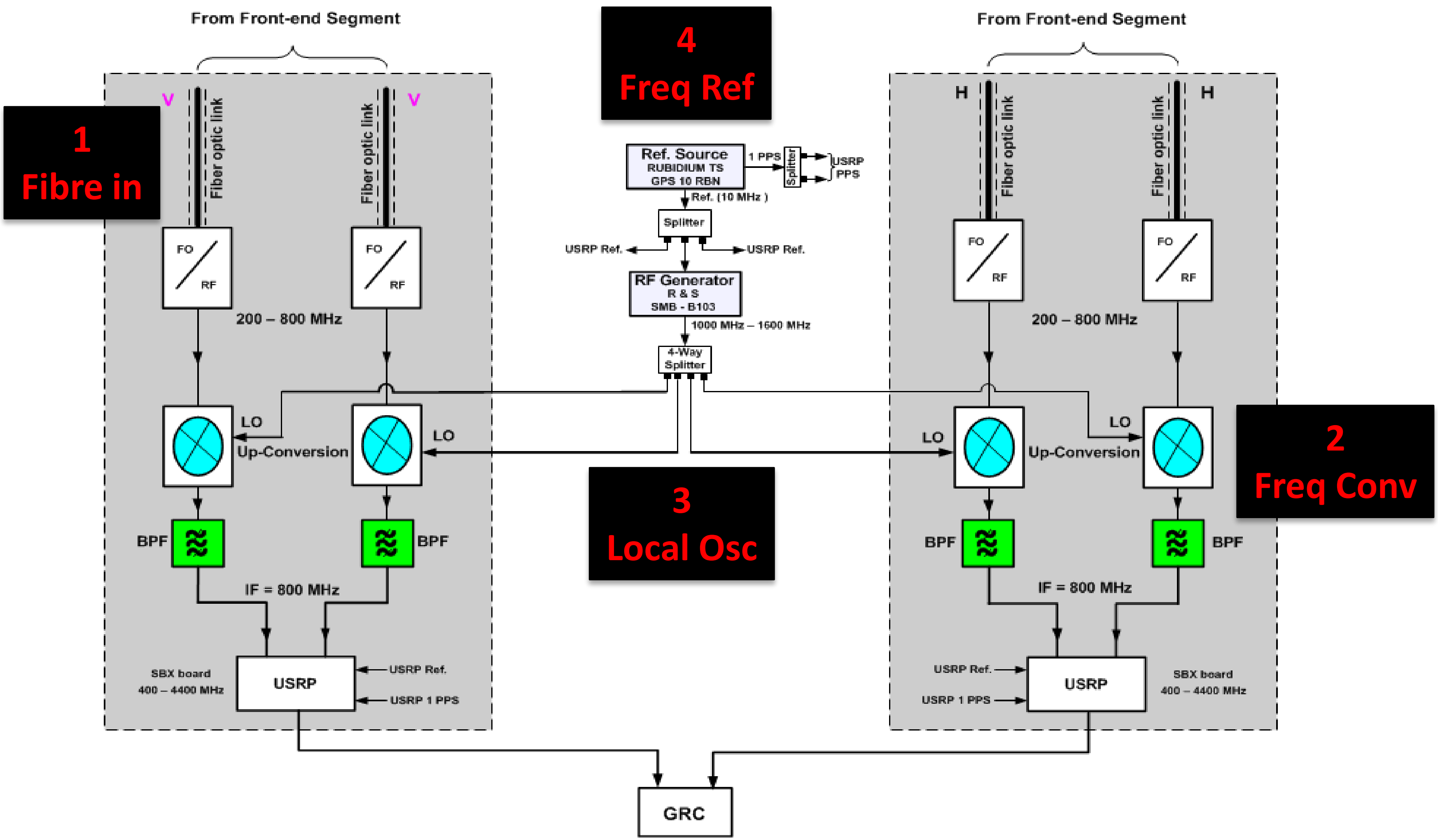
MITRA Back-end



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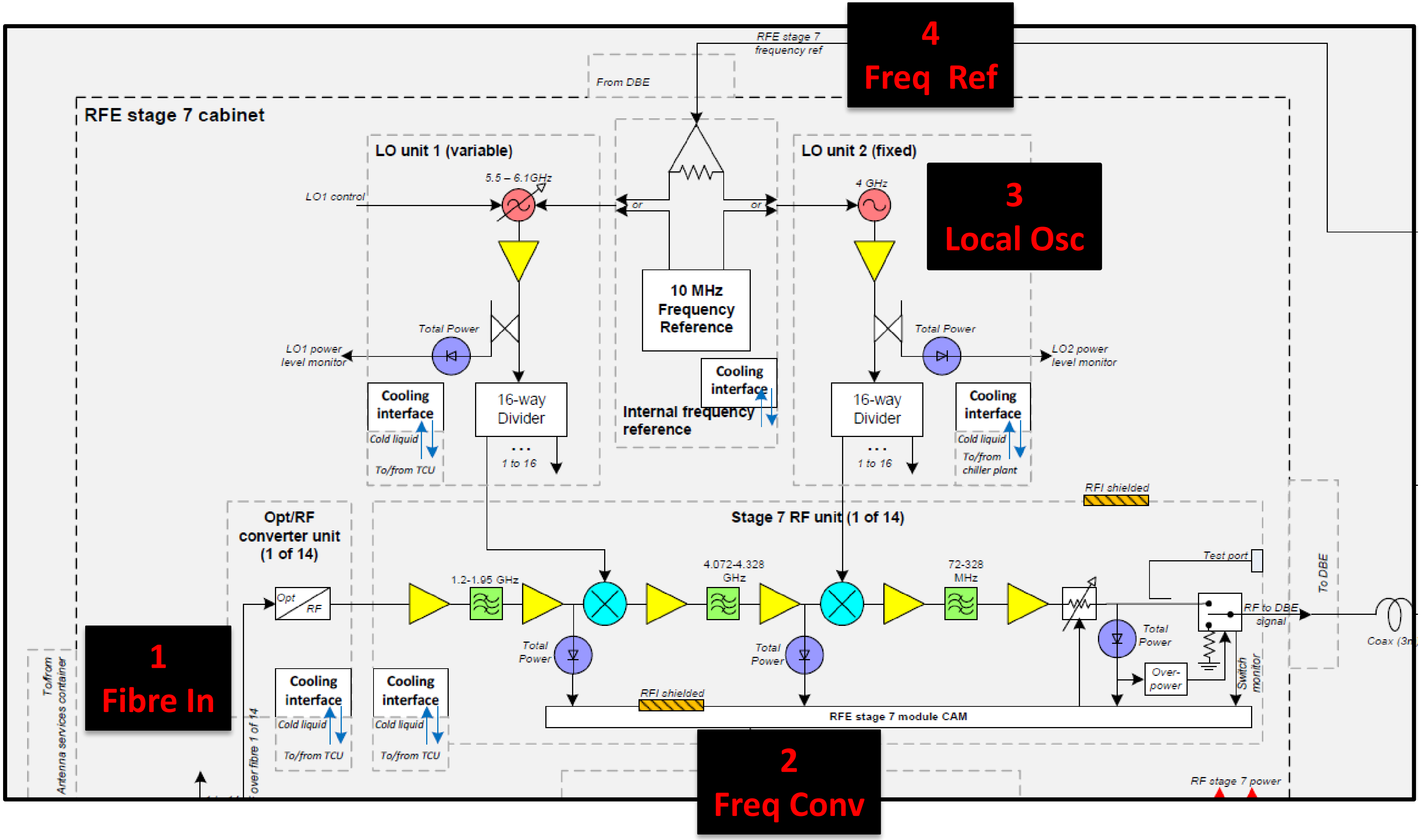
KAT 7 RF Stage 7



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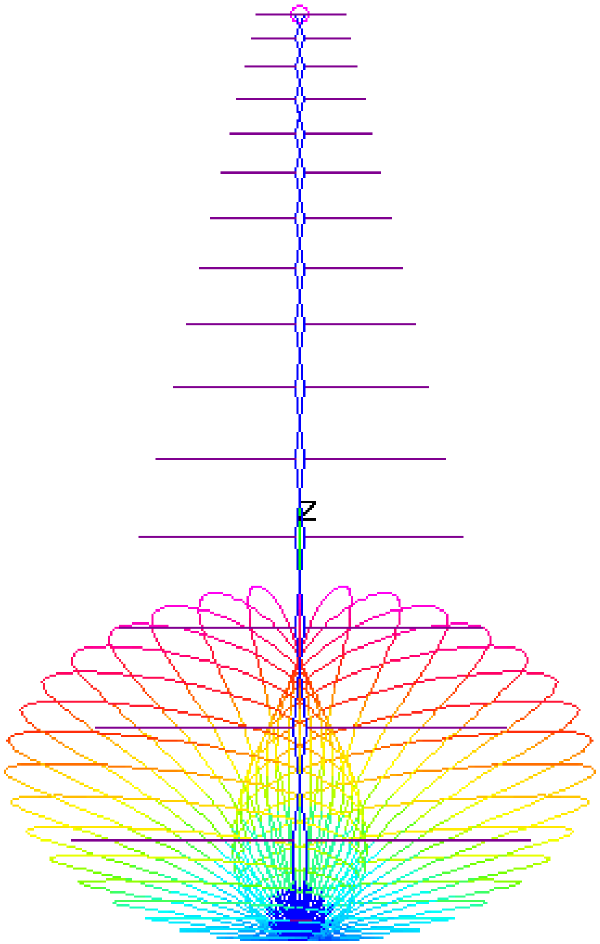

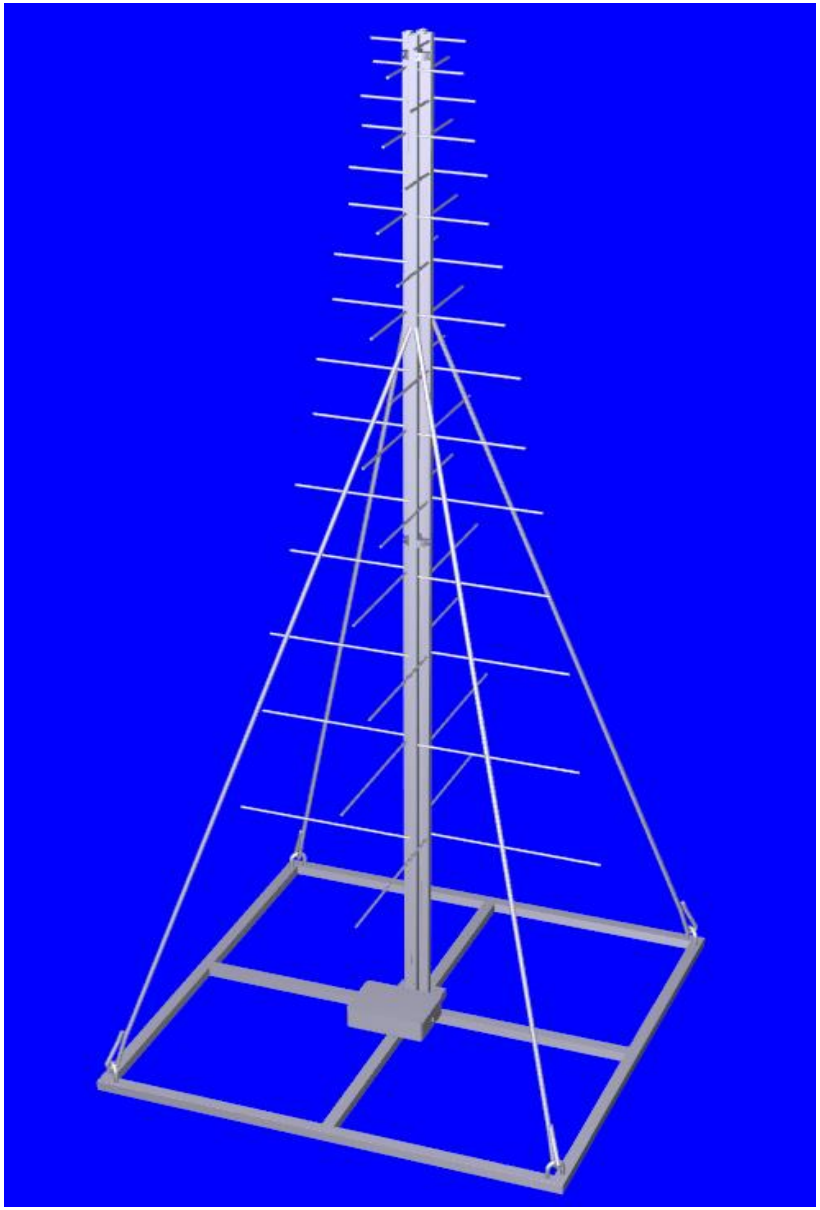

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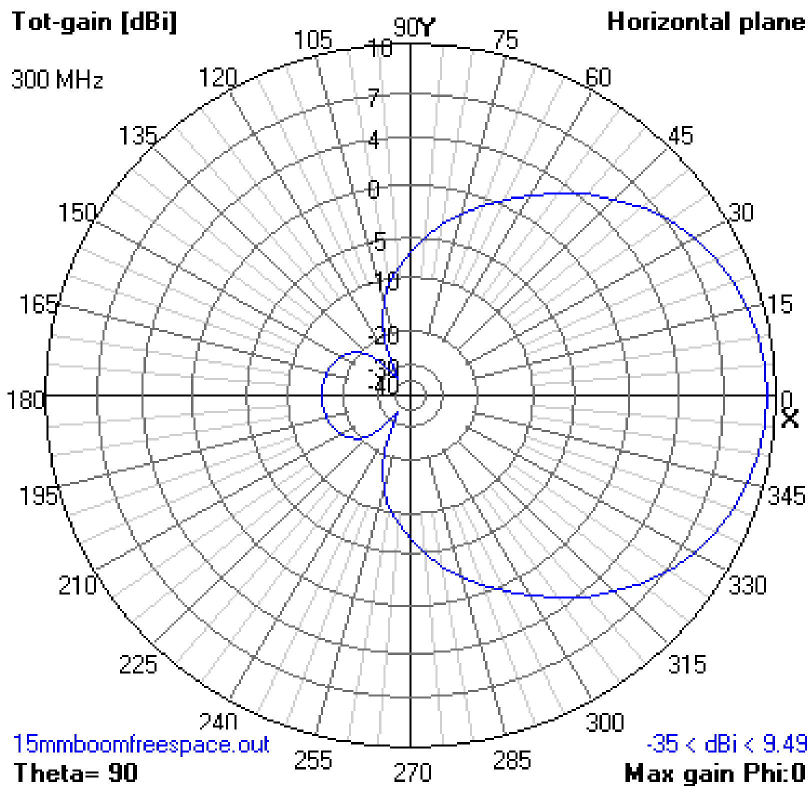

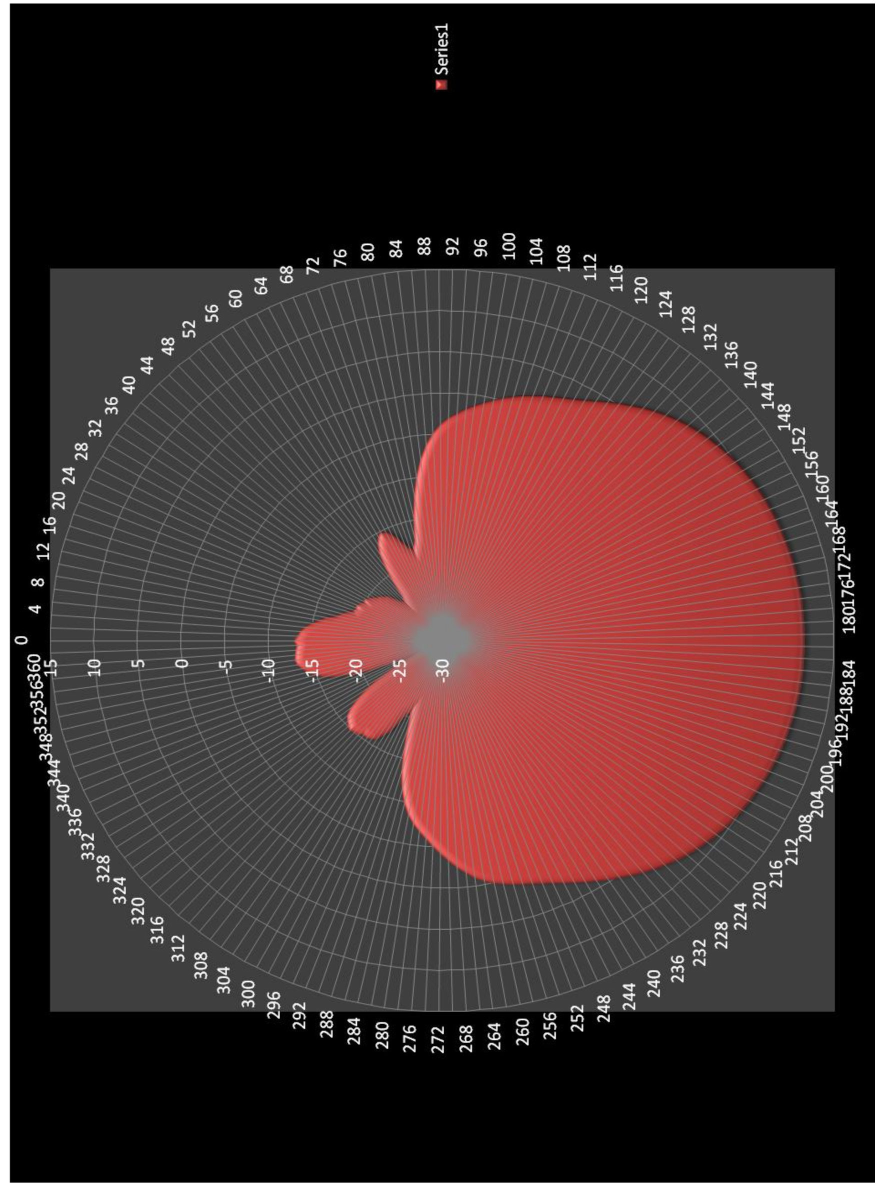

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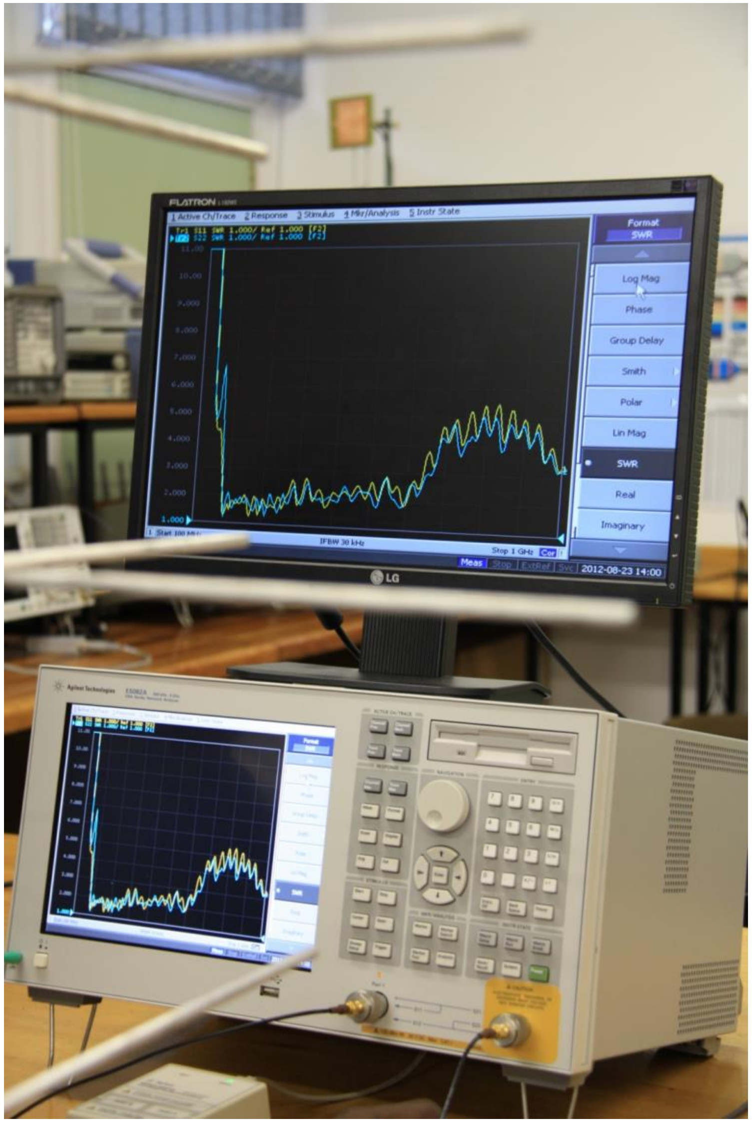

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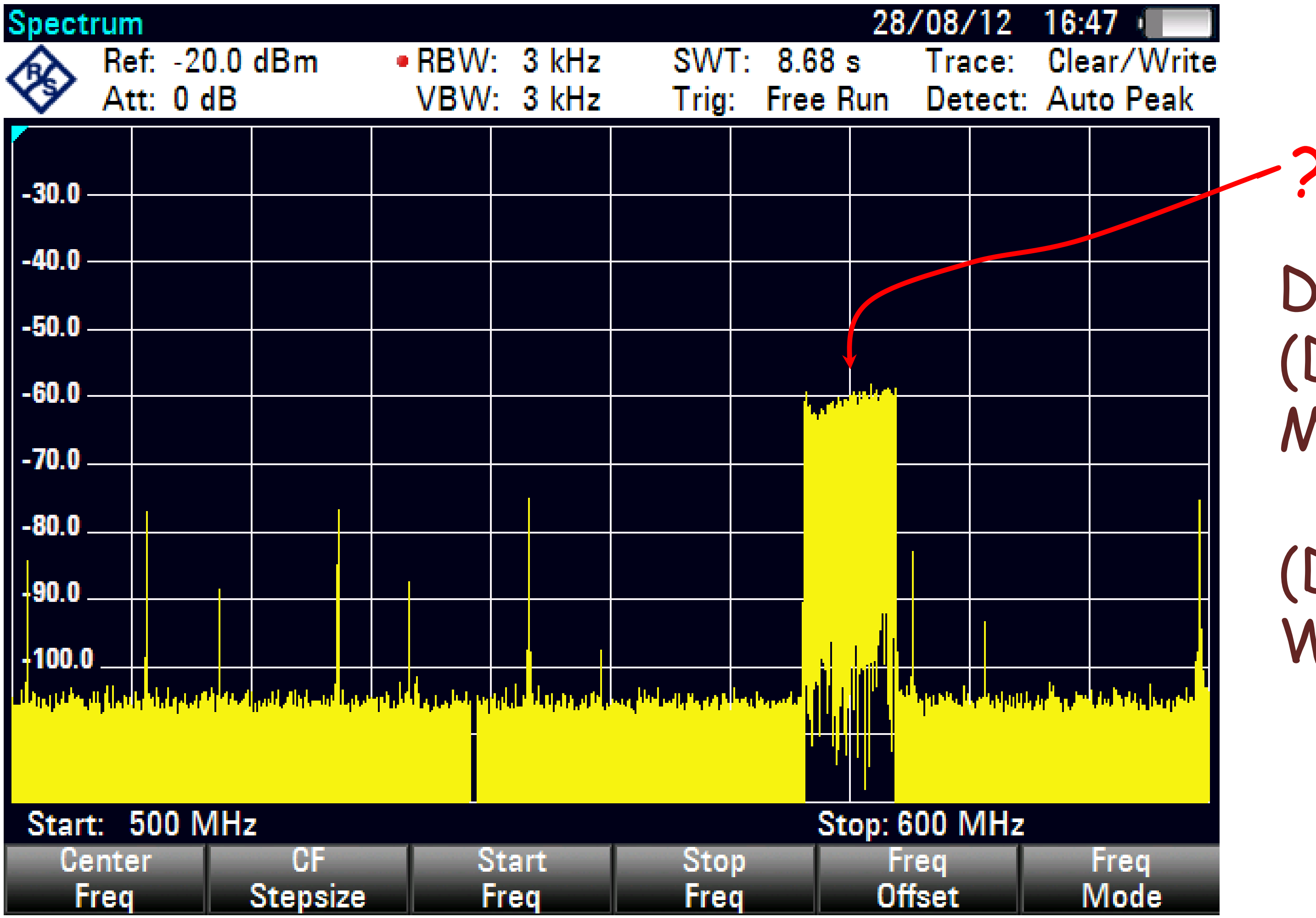
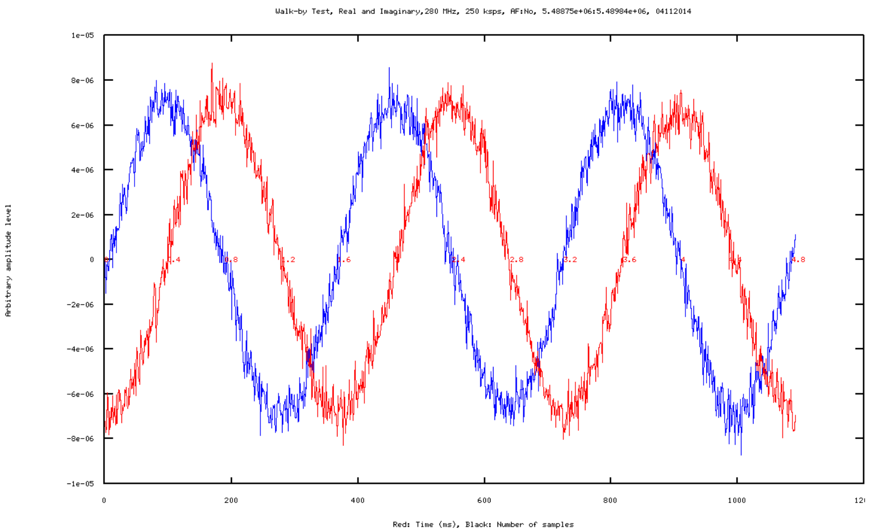
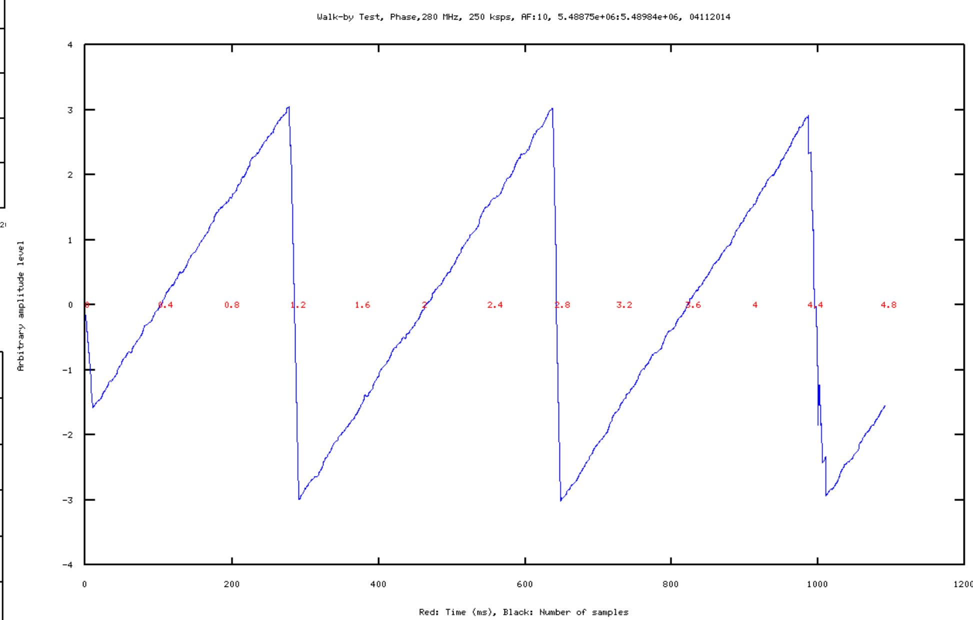


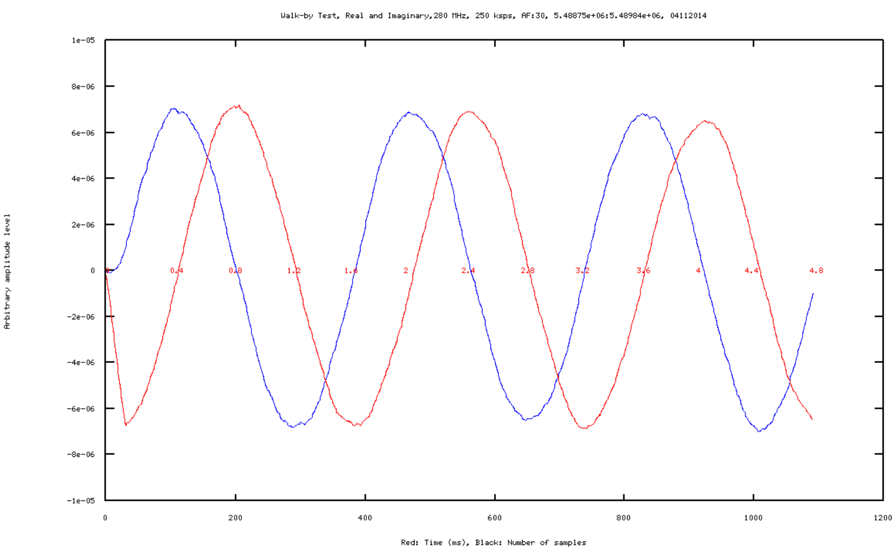
DVB-H (DSTV-Mobile)

(Drifta/ Walka)

MITRA walk-by test
04 November 2014







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SQUARE KILOMETRE ARRAY

- International consortium with a plan to build a radio telescope with a collecting area of 1 square kilometre.
- Most of this to be built in South Africa with some in Australia and other African countries.
- Getting to the SKA requires several precursors to prove that it will work:
  - Phased Experimental Demonstrator (2005).
  - eXperimental Development Model (2007).
  - Karoo Array Telescope (2010).
  - MeerKAT (under construction, complete in 2017).
  - Square Kilometre Array (2024).

XDM

15m diameter
Solid fibreglass dish
Fully steerable
First light in July 2007

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KAT 7 Seven 12m diameter dishes
Baseline up to 185m
Same construction as XDM

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MeerKAT

64 Dishes
13,5m diameter
Maximum baseline of 20km
First light in 2017

SQUARE KILOMETRE ARRAY

- Will eventually consist of 2400 antennas.
- Construction to start in 2017 (phase 1).
- Completion is scheduled to be in 2024.
- Some facts:
    - The data collected by the SKA in a single day would take nearly 2 million years to play back on an iPod.
    - The SKA central computer will have the processing power of about 100 million PCs.
    - The dishes of the SKA will produce 10 times the global internet traffic.
    - The SKA will use enough optical fibre to wrap around the Earth twice.

26 m dish at HartRAO

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