UNIVERSITY OF CAMBRIDGE

REACH

REACH Receiver

Daniel Molnar

Cavendish Astrophysics

Structure of the talk

- Intro and receiver team
- Radiometer system
  - Receiver design
  - Modelling directions
- 2nd Receiver
- Future directions

The receiver team

- The references for this talk
- [1]: N. Razavi-Ghods, I.Roque et al: Radiometer Design for the REACH global 21-cm experiment (arxiv:[2307.00099v2.pdf (arxiv.org)](https://arxiv.org/pdf/2307.00099v2.pdf))
- [2]: I.L.V.Roque et al: Bayesian Noise wave calibration for 21-cm global experiments

Current team

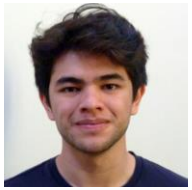
Rohan Patel: RA

Kaan Artuc: PhD student

John Ely: Engineer

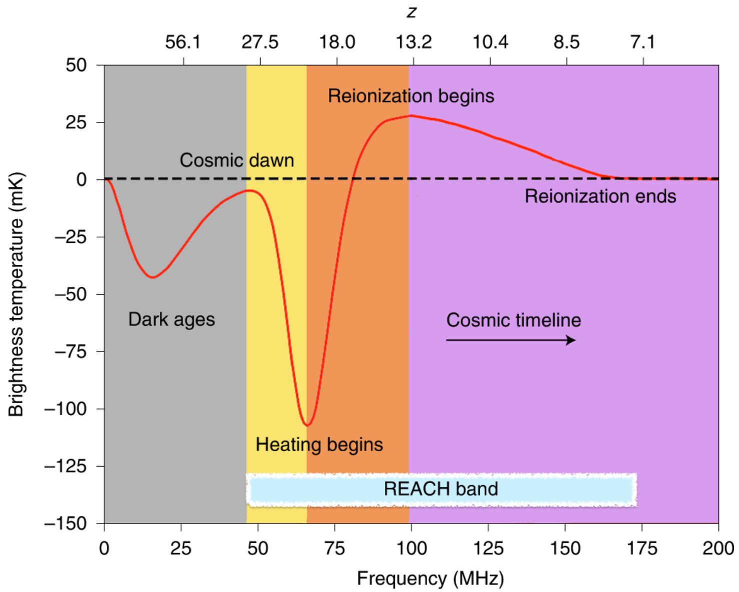
Paul Scott- Emeritus

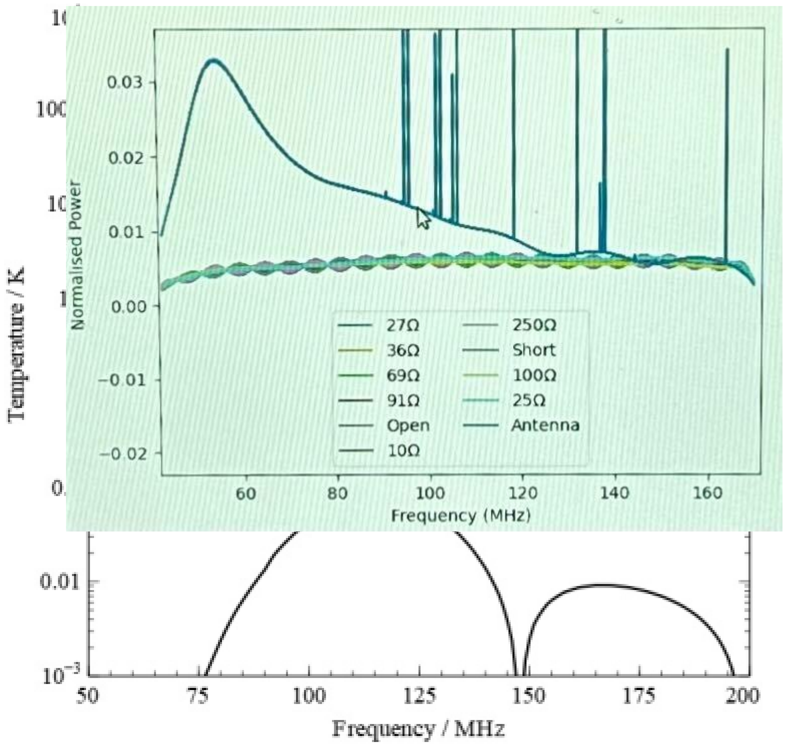
Steve Carey- Engineer (ret)



Ian Roque: PhD student

The task: detect the first light

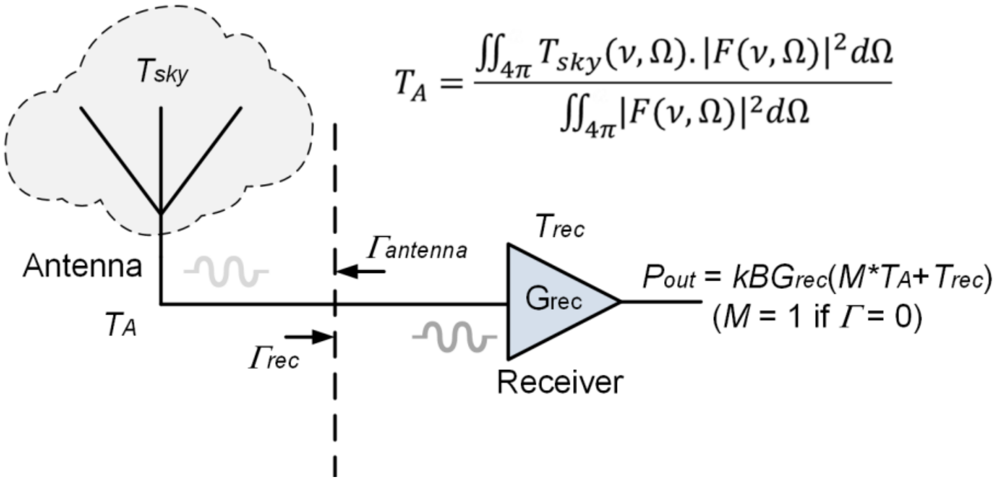




From J.Cumner et al: Radio Antenna Design for Sky-Averaged 21 cm Cosmology Experiments: The REACH Case

Calibration

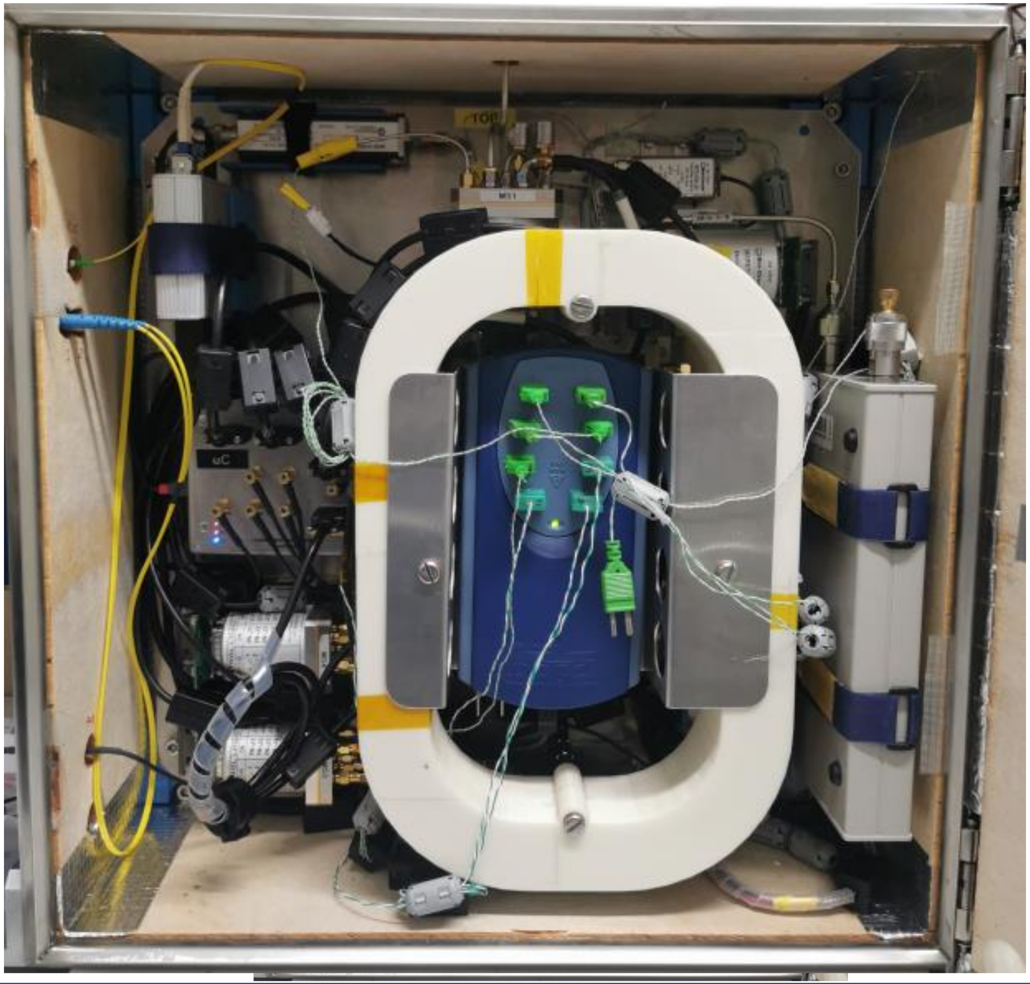
- The radiometer is based on the 3-way Dicke switching
- Calibration is based on EDGES (noise waves, more from Harry) formalism



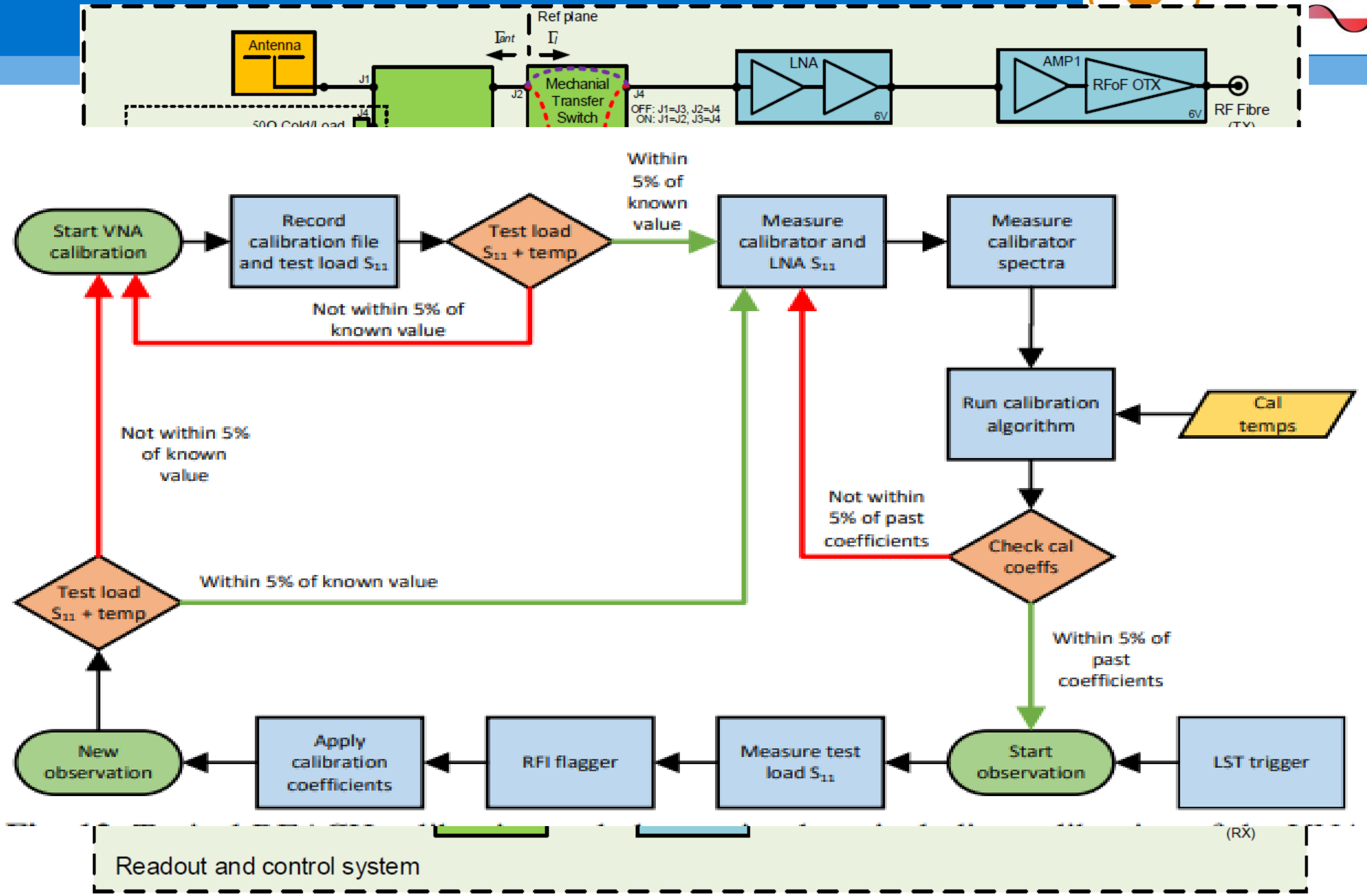
$$T_{\mathrm{NS}}\left(\frac{P_{\mathrm{source}} - P_{\mathrm{L}}}{P_{\mathrm{NS}} - P_{\mathrm{L}}}\right) + T_{\mathrm{L}} = T_{\mathrm{source}}\left[\frac{1 - |\Gamma_{\mathrm{source}}|^2}{|1 - \Gamma_{\mathrm{source}}\Gamma_{\mathrm{rec}}|^2}\right] + T_{\mathrm{unc}}\left[\frac{|\Gamma_{\mathrm{source}}|^2}{|1 - \Gamma_{\mathrm{source}}\Gamma_{\mathrm{rec}}|^2}\right] + T_{\mathrm{cos}}\left[\frac{\mathrm{Re}\left(\frac{\Gamma_{\mathrm{source}}}{1-\Gamma_{\mathrm{source}}\Gamma_{\mathrm{rec}}}\right)}{\sqrt{1 - |\Gamma_{\mathrm{rec}}|^2}}\right] + T_{\mathrm{sin}}\left[\frac{\mathrm{Im}\left(\frac{\Gamma_{\mathrm{source}}}{1-\Gamma_{\mathrm{source}}\Gamma_{\mathrm{rec}}}\right)}{\sqrt{1 - |\Gamma_{\mathrm{rec}}|^2}}\right]$$

Receiver design

- Components and sensitivity was designed for 20mK sensitivity
- The different sources trying to cover the Smith chart
- The entire receiver is in a steel box with an RFI gasket and is also thermally isolated under the antenna and ground plane

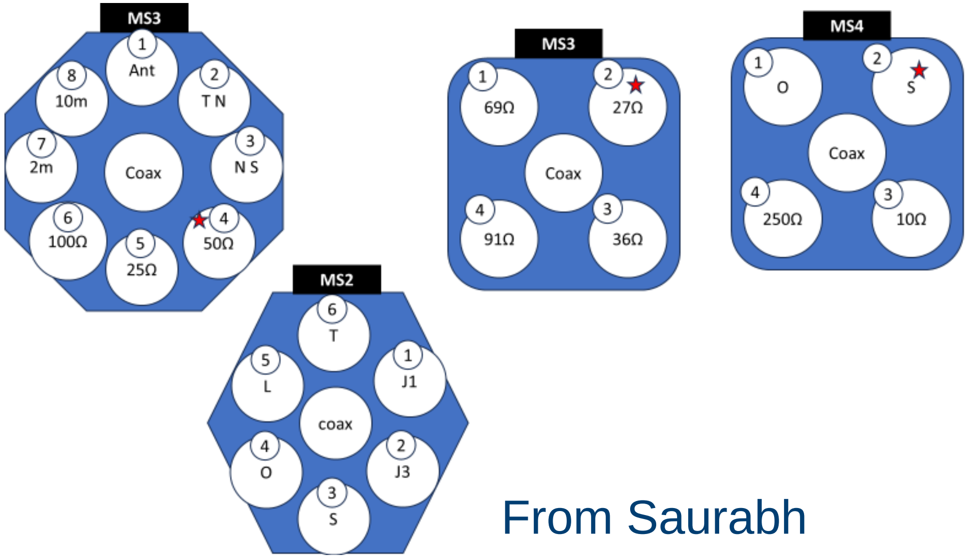


Schematic of the Receiver



Thermal managements and measurements

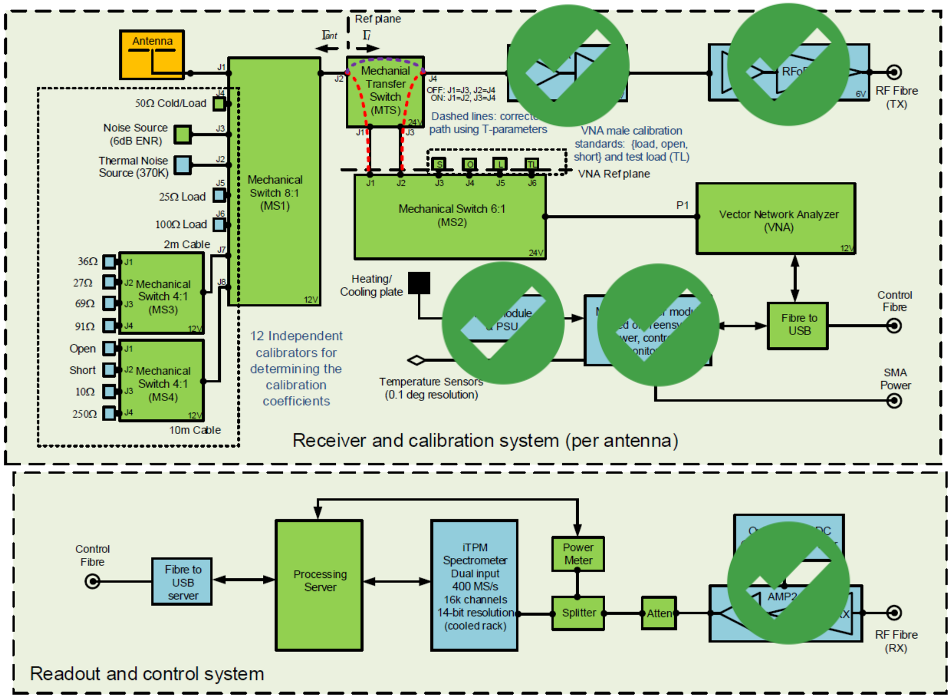
- 8 thermocouple measurements
- MS1, MS3, MS4, hot load, 2m, 10m cable, LNA and antenna feeding cable to 0.1K accuracy
- Plan: Switch the LNA to sensor to internal antenna (further temp sensors)
- FEM models can inform decisions on temp sensor placements



From Saurabh

2nd Receiver

- We will have an identical one to the first one(blue: custom made, green: commercial) (for now)
- We can test new features and calibration on a complete system-> at Lord's Bridge with a dipole
- Can be used to debug (moon vehicle principle)
- Eventually a 2nd antenna will be used on site
- Observations can inform where to change

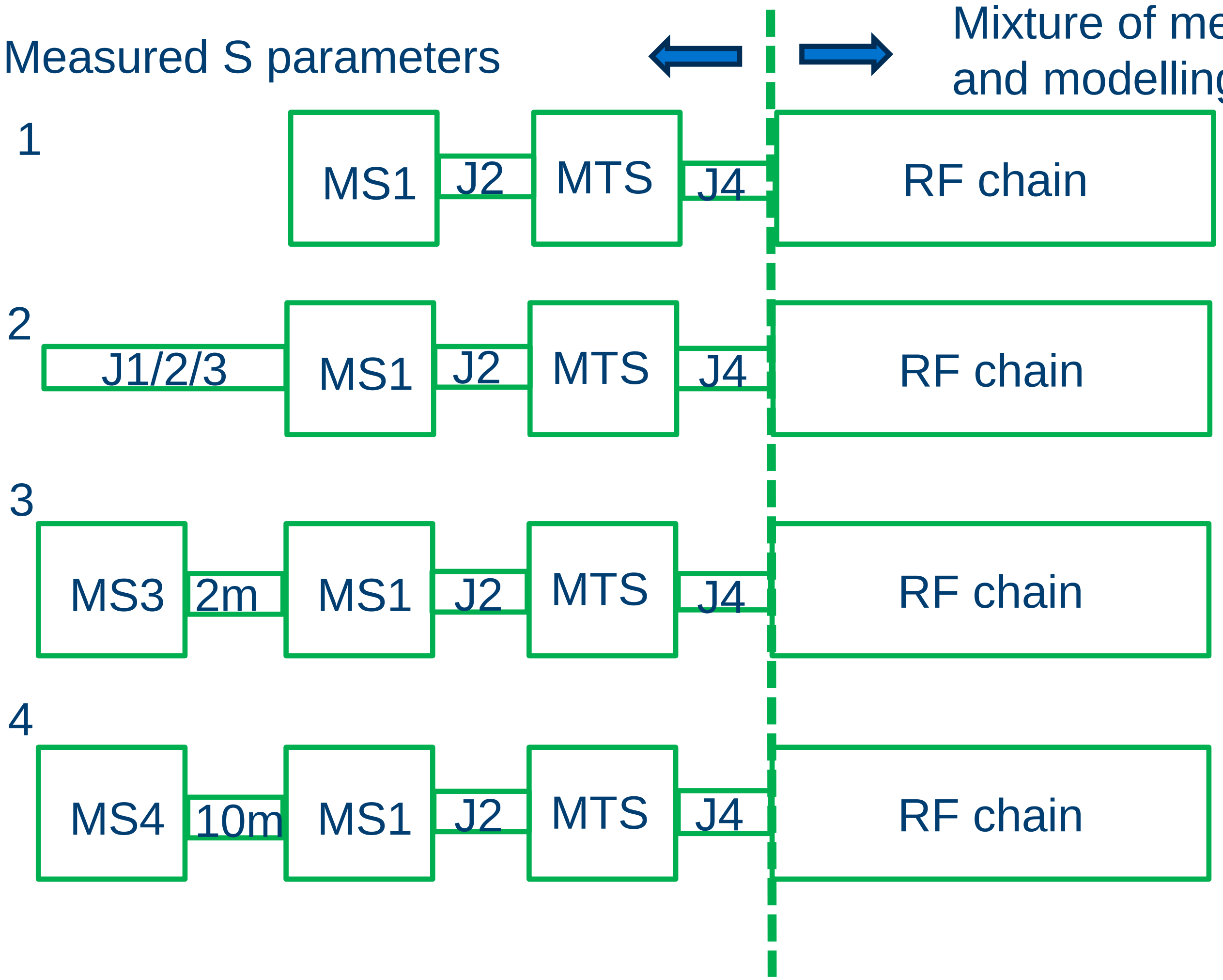


S-parameters for simulations

Current efforts: building models for mock data generation

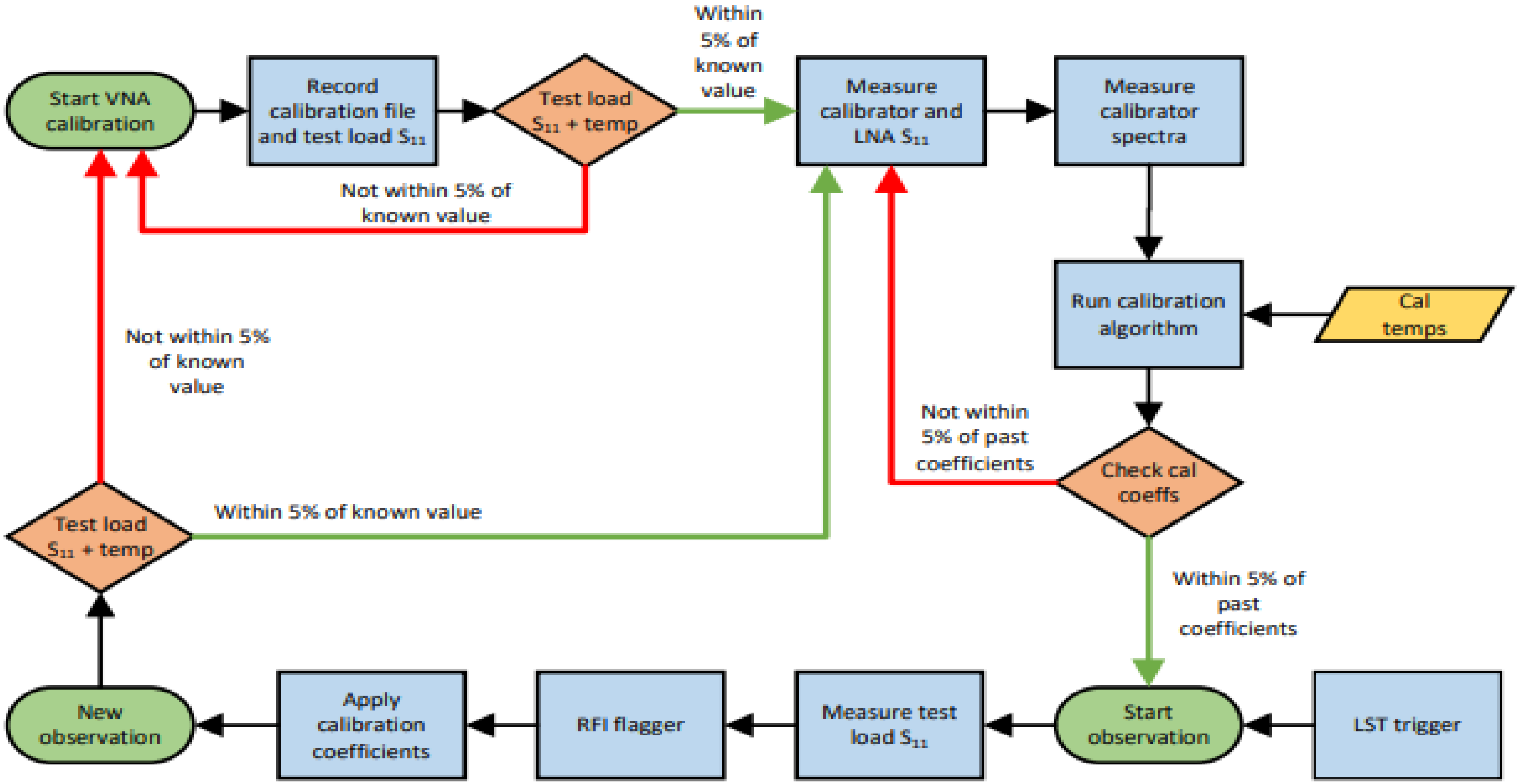
Each configuration(1-4) meant to represent a possible RF path

For each block we have S parameters



Ji: small semi rigid coax 2m/10m: the long coax cables (for these two we also have simulation)

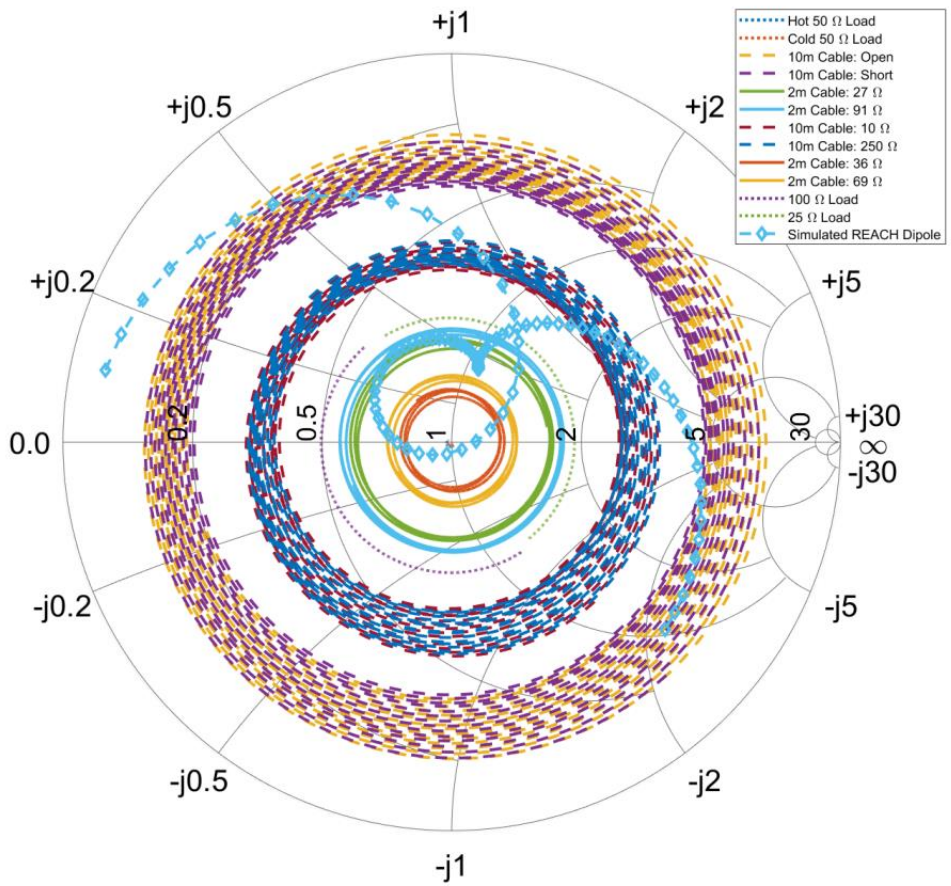
Future directions



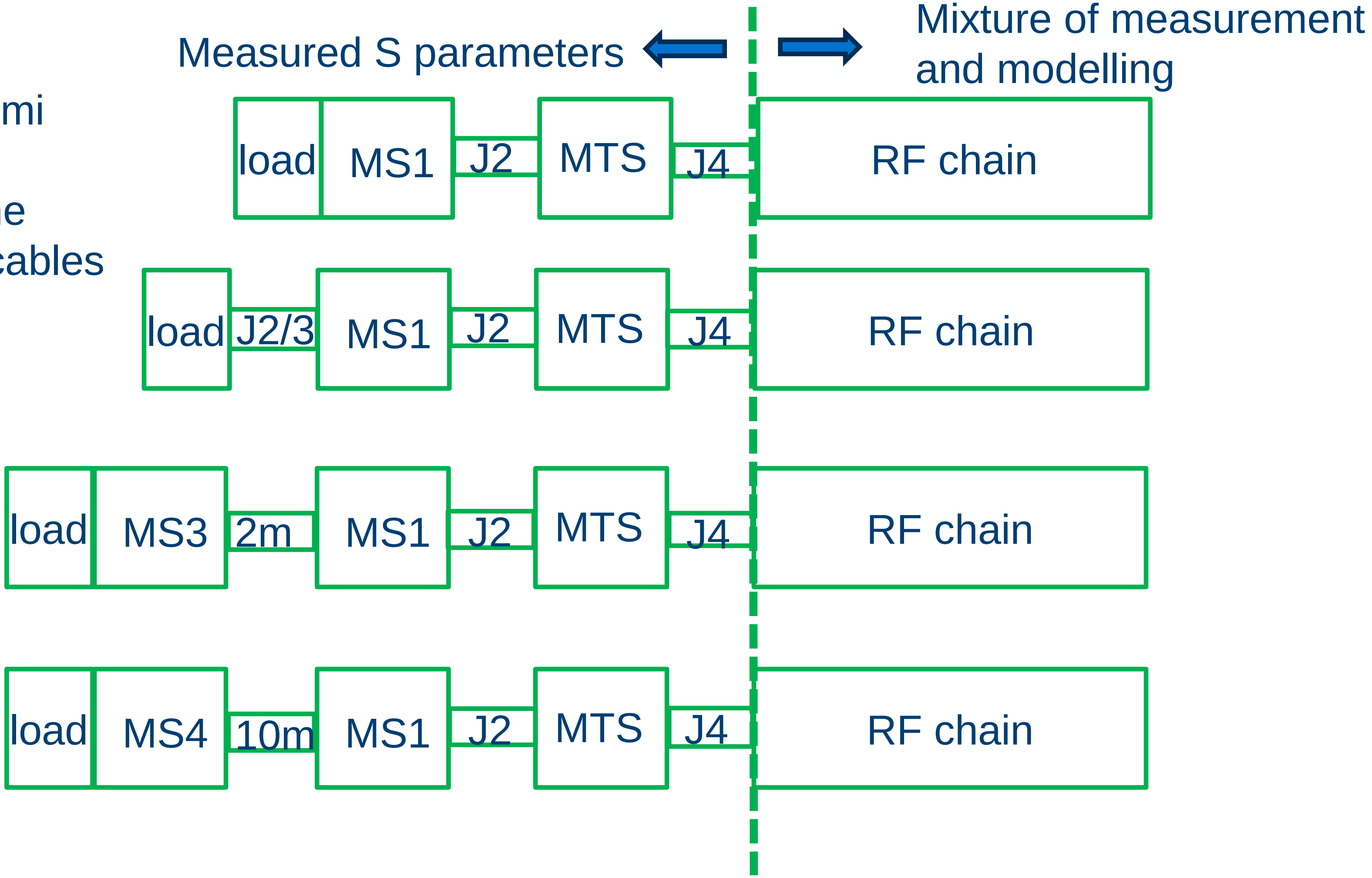
Thanks

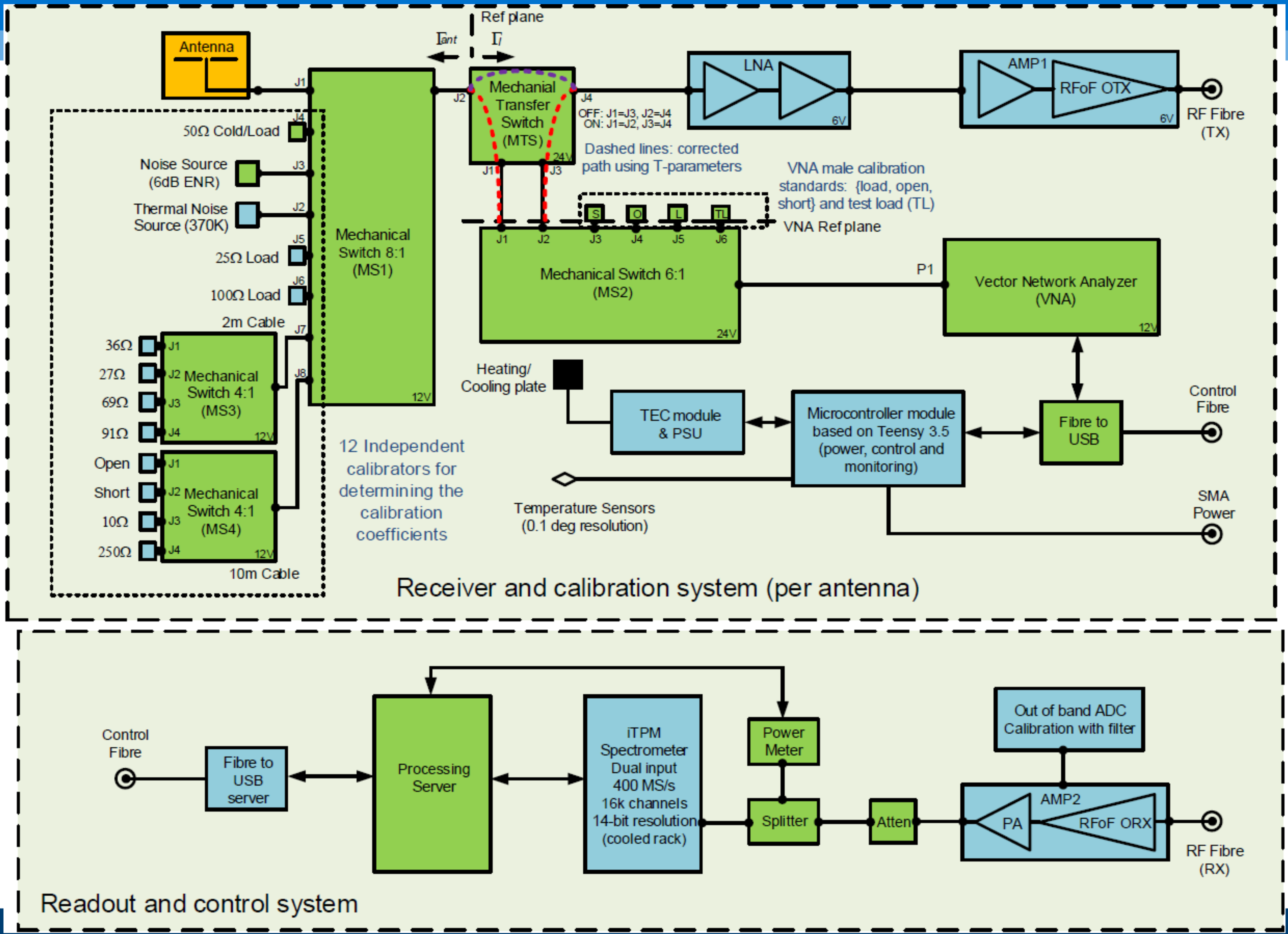
Antenna and calibrator impedances

- Smith Chart showing the simulated dipole antenna impedance and the sources
- Antenna impedance shown is between 50-150MHz

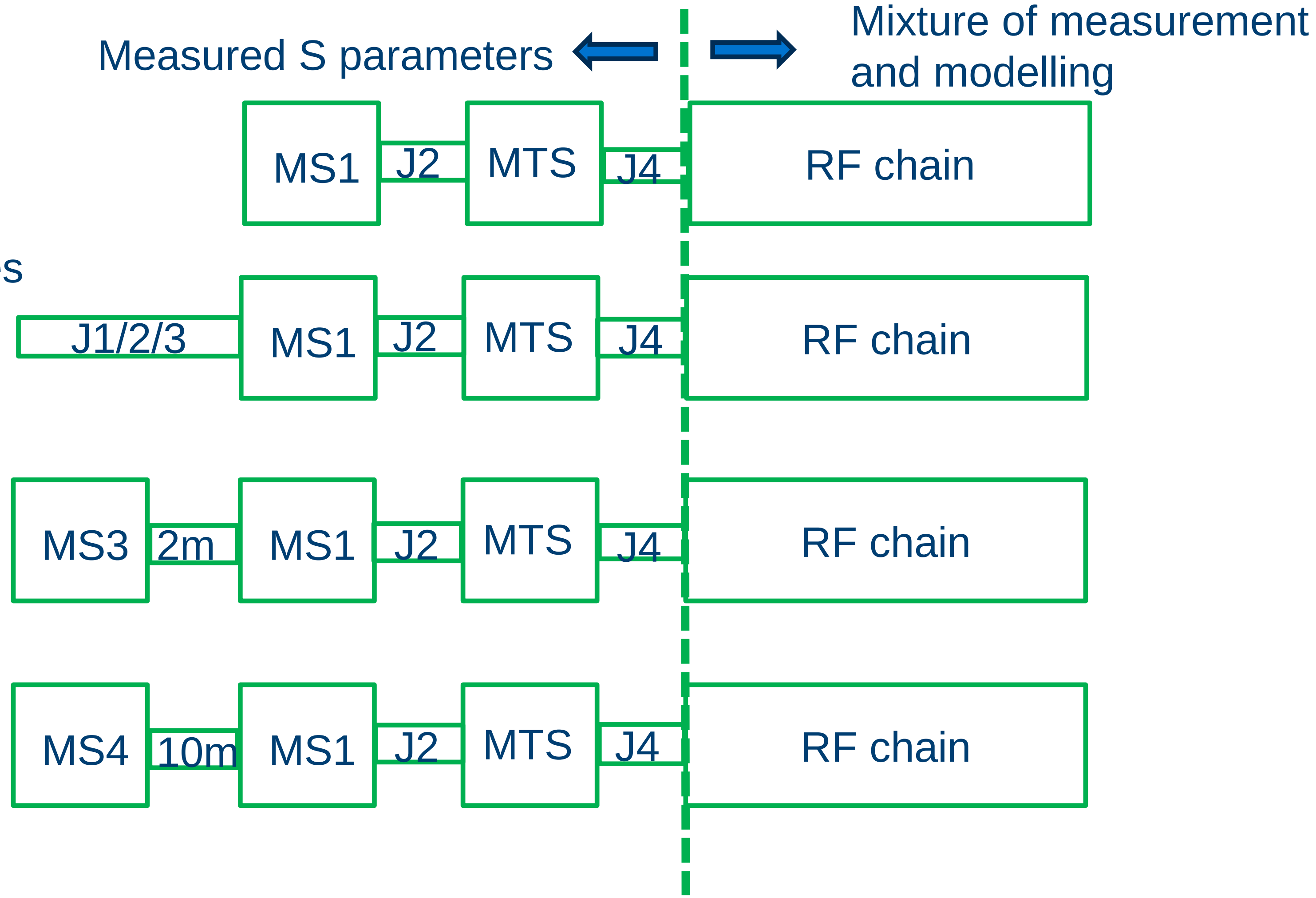


Ji: small semi rigid coax
2m/10m: the long coax cables

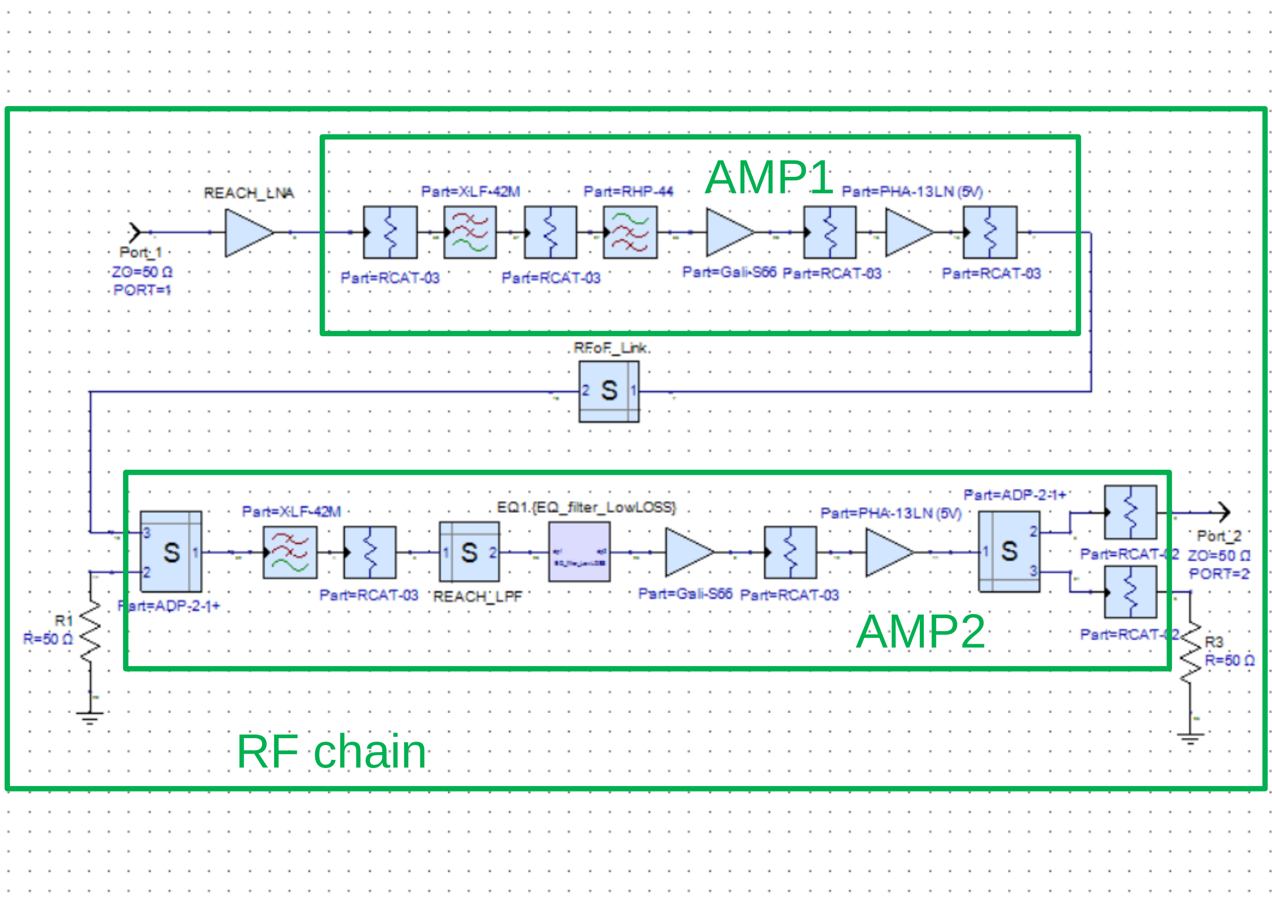



Antenna
Ref plane
Mechanial Transfer Switch (MTS)
OFF: J1=J3, J2=J4
ON: J1=J2, J3=J4
Dashed lines: corrected path using T-parameters
LNA
AMP1
RFoF OTX
RF Fibre (TX)
50Ω Cold/Load
Noise Source (6dB ENR)
Thermal Noise Source (370K)
25Ω Load
100Ω Load
2m Cable
Mechanical Switch 8:1 (MS1)
VNA male calibration standards: {load, open, short} and test load (TL)
VNA Ref plane
Mechanical Switch 6:1 (MS2)
P1
Vector Network Analyzer (VNA)
36Ω
27Ω
69Ω
91Ω
Mechanical Switch 4:1 (MS3)
Open
Short
10Ω
250Ω
Mechanical Switch 4:1 (MS4)
10m Cable
Heating/ Cooling plate
TEC module & PSU
Microcontroller module based on Teensy 3.5 (power, control and monitoring)
Fibre to USB
Control Fibre
12 Independent calibrators for determining the calibration coefficients
Temperature Sensors (0.1 deg resolution)
SMA Power
Receiver and calibration system (per antenna)
Control Fibre
Fibre to USB server
Processing Server
iTPM Spectrometer Dual input 400 MS/s 16k channels 14-bit resolution (cooled rack)
Power Meter
Splitter
Atten
Out of band ADC Calibration with filter
AMP2
PA
RFoF ORX
RF Fibre (RX)
Readout and control system

Ji: small semi rigid coax
2m/10m: the long coax cables

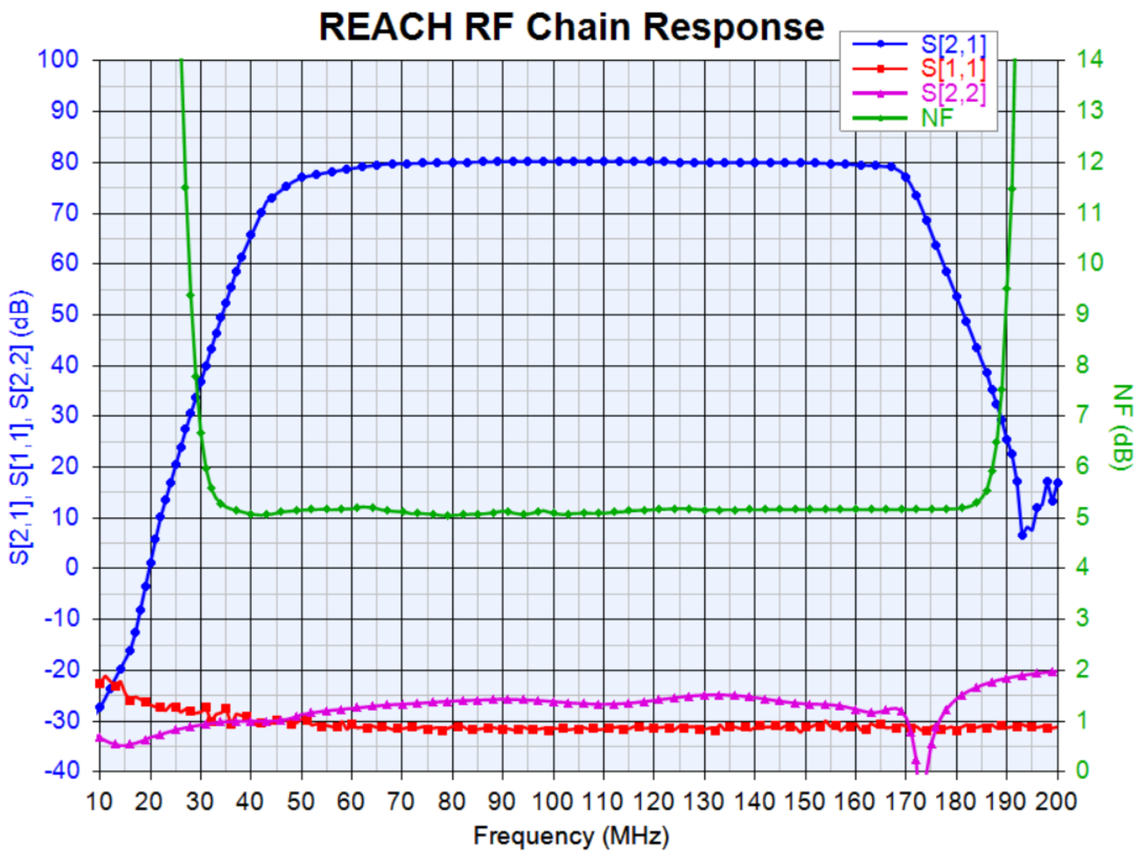


- Block diagram of RF chain (analogue part)
- Note that the LNA is based on S parameter measurement done in Cambridge



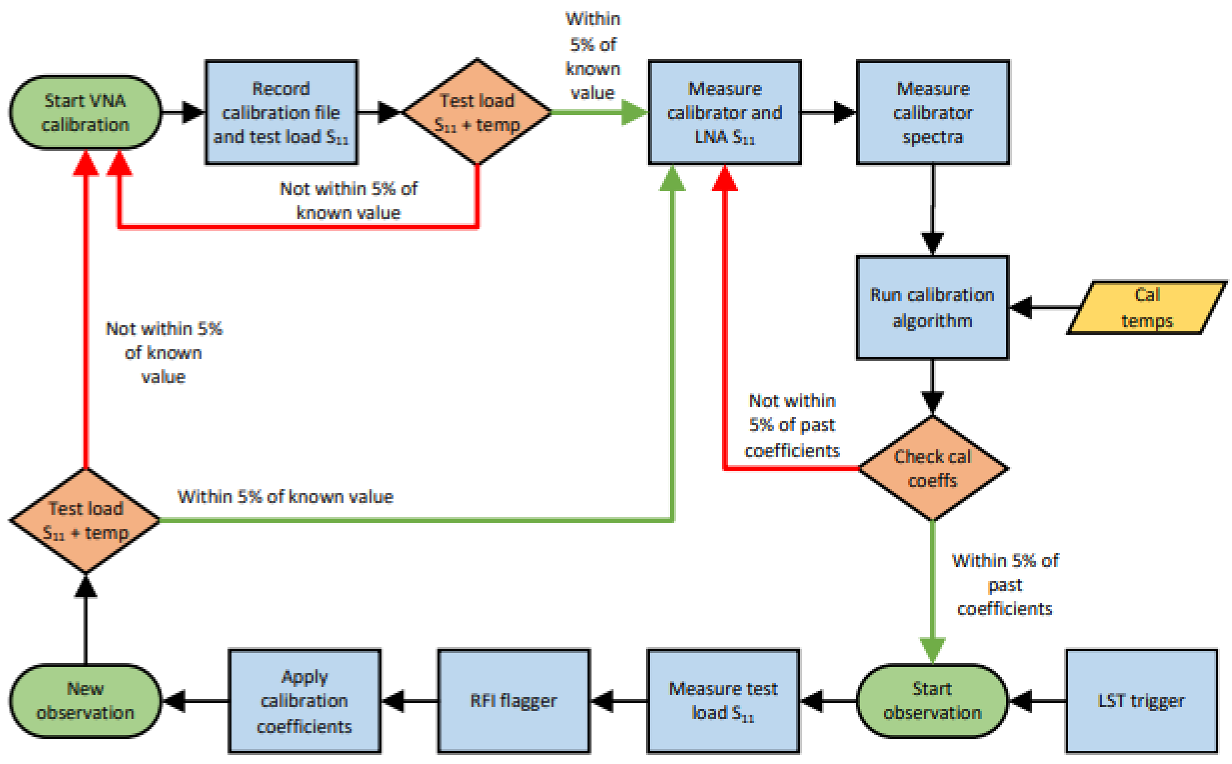
RF chain response

- Simulation by Nima
- LNA: measured, the other components are simulation based

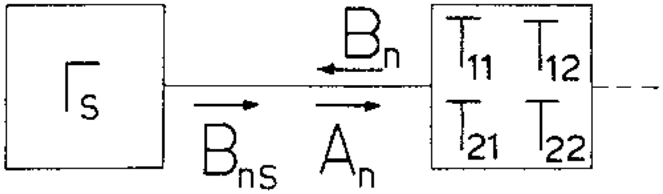


Cable current

- 10m cable is 10.1m; **model LBC195**
  2m cable is 2.02m; **model: not sure could be LMC195 or LBC195**
- **New cables: 2m and 10m LCOM200**


Start VNA calibration
Record calibration file and test load S11
Test load S11 + temp
Within 5% of known value
Measure calibrator and LNA S11
Measure calibrator spectra
Not within 5% of known value
Run calibration algorithm
Cal temps
Not within 5% of known value
Not within 5% of past coefficients
Check cal coeffs
Test load S11 + temp
Within 5% of known value
Within 5% of past coefficients
New observation
Apply calibration coefficients
RFI flagger
Measure test load S11
Start observation
LST trigger

- Noise waves from Meys paper
- Supposed to have a uncorrelated noise from receiver Tunc and describing the correlated part by Tsin and Tcos



(b)

Additional temp sensors

- There's a possibility to extend the 8

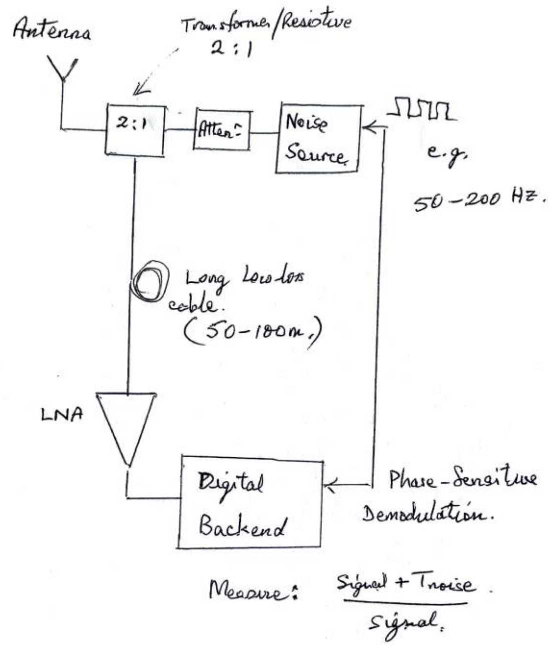
Fig. 9: The bottom and top layers of the stacked

Pros

1. Direct comparison of Antenna Power with a Noise source, using calibrated, passive components.
2. Using a long cable between the antenna and the LNA, the period of any standing waves (SWs) can be put outside the range of structure expected in the HI spectrum.
3. The SWs can either be fitted to a model or the spectrum convolved with a narrow bandstop filter. [Because the amplitude of the SWs will vary across the spectrum, fitting to a constant amplitude sine-wave is not appropriate.] Note that it is NOT necessary to know the phase of the SWs.
4. Measurements can be repeated with the 2:1 inputs interchanged if thought necessary.
5. Test measurements can easily be made with the Antenna replaced by alternative Noise sources for diagnostic purposes.

Cons

1. The effective system temperature is increased due to the loss in the 2:1 and the long cable. However the sky temperature is likely to be a significant factor in *any* receiving system.
2. The long cable will be bulky! However, it does mean that the active part of the receiving system can be a long way from the antenna (and the cable could also carry the drive signal for the noise source, if required).
3. There do not appear to be any requirements for temperature control anywhere in the system.
4. Because the calibration signal is relatively small e.g. ~10 to 20 K, a longer integration time will be required to reduce the noise level in the chosen spectral resolution bandwidth. These numbers need to be quantified !



Radically new ideas are also being looked at too, an idea by Paul Scott-> advantage very simple, but perhaps too simple …..