NWU LNA's for MFAA

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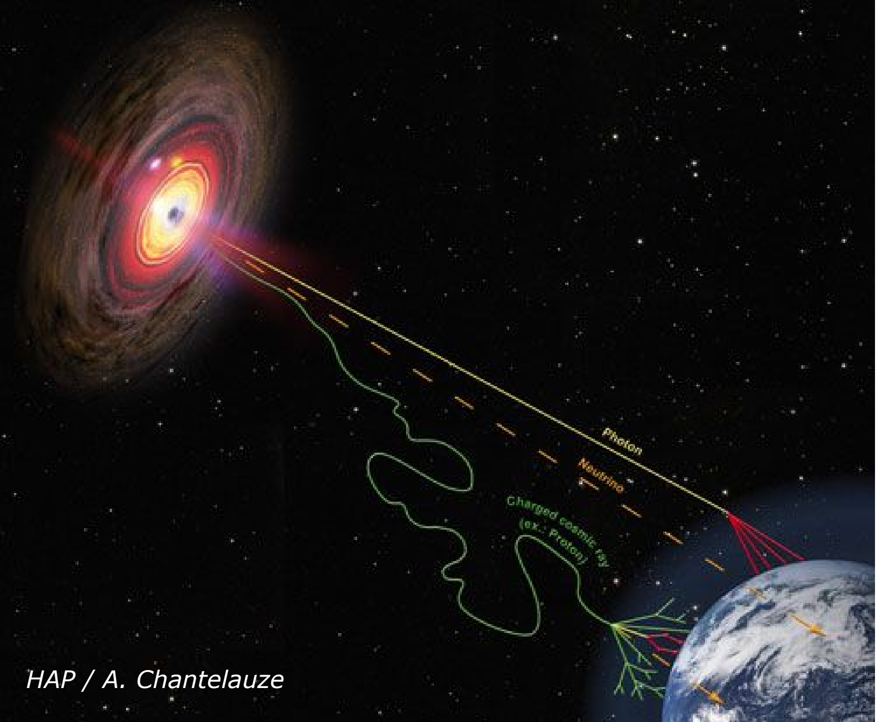
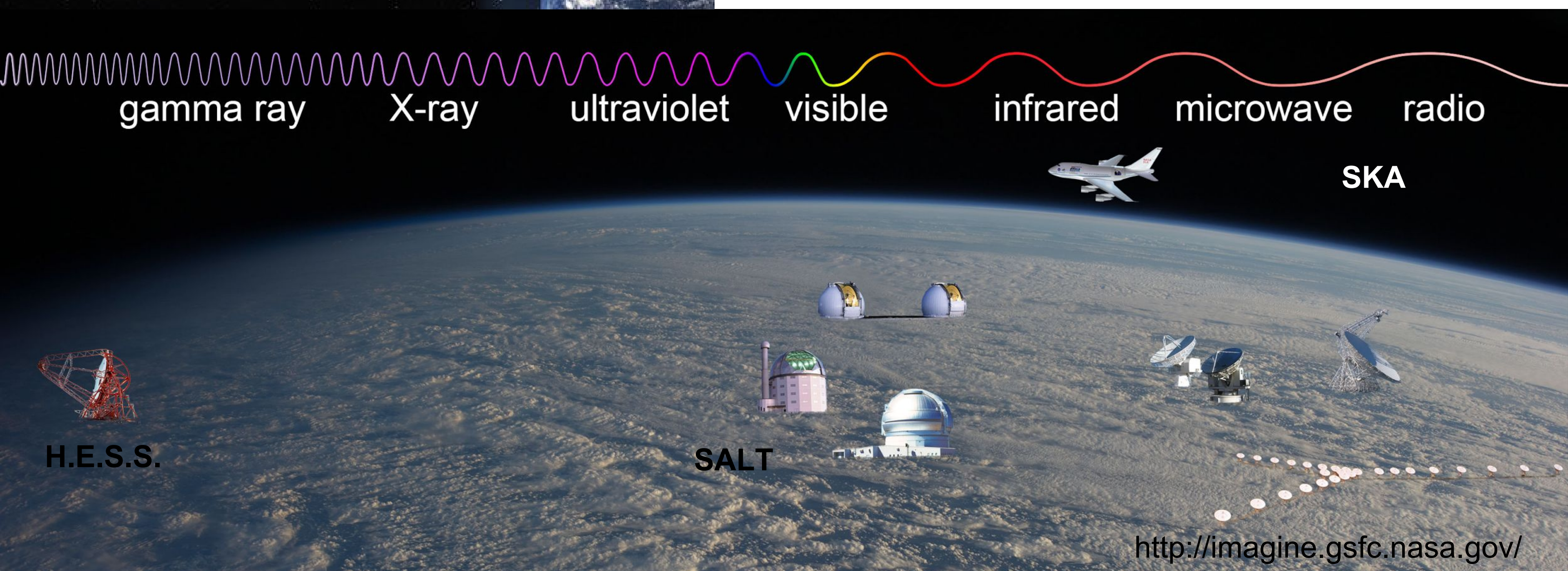
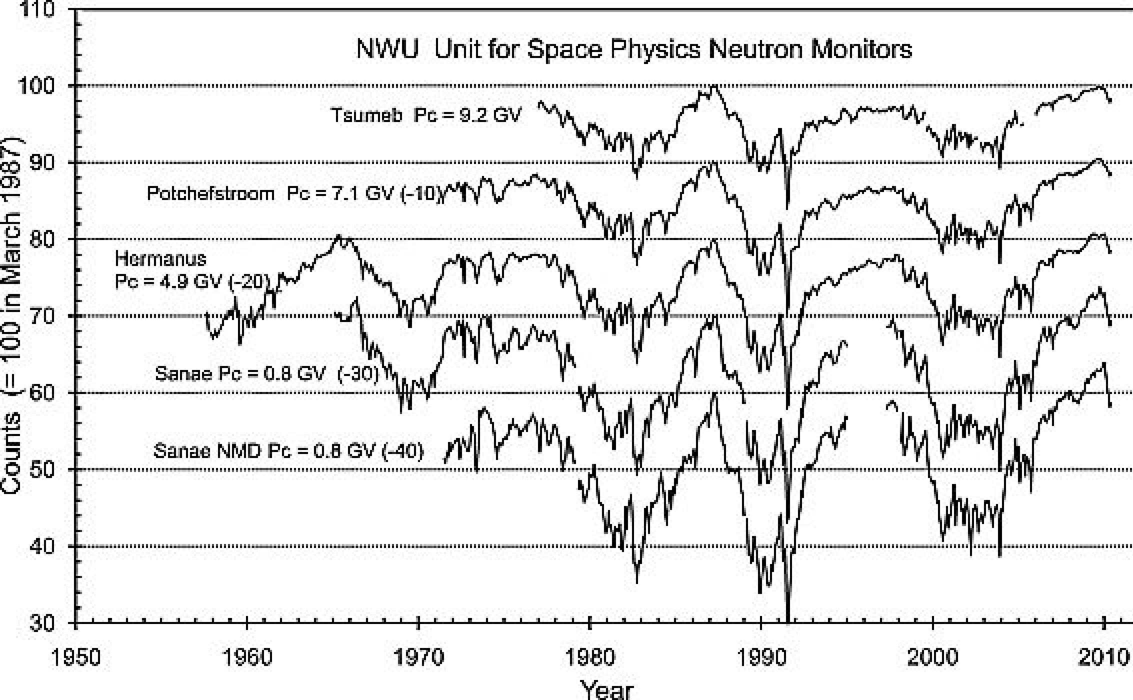
NWU background

High-energy astrophysics
- Gamma-ray astronomy
  - H.E.S.S. & CTA
- Cosmic-ray research
  - Neutron monitors





NWU background



Neutron monitors

Need room-temperature, pulse (broadband) LNAs

Gamma-ray telescope

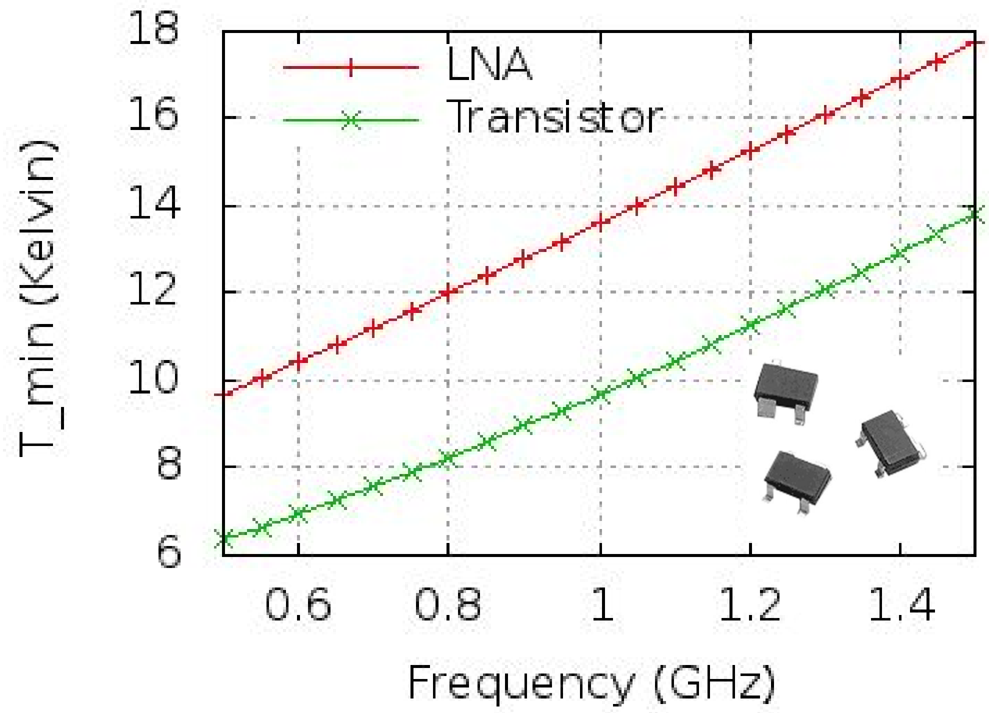
Need 1000x room-temperature, pulse (broadband) LNAs

MFAA LNA requirements

- Broadband: 0.4 - 1.5 GHz
- Low noise: <30 K
- Little power consumption: <50 mW
- Inexpensive
- Fully differential

Commercial HEMT: ATF 35143:

- Broadband: 0.5 - 1.5 GHz
- Low noise: <30 K
  - Tmin < 14K below 1.5 GHz!
- Little power consumption: <100 mW (for 30 dB gain)
- Inexpensive
- Fully differential



Commercial HEMT: ATF 35143:

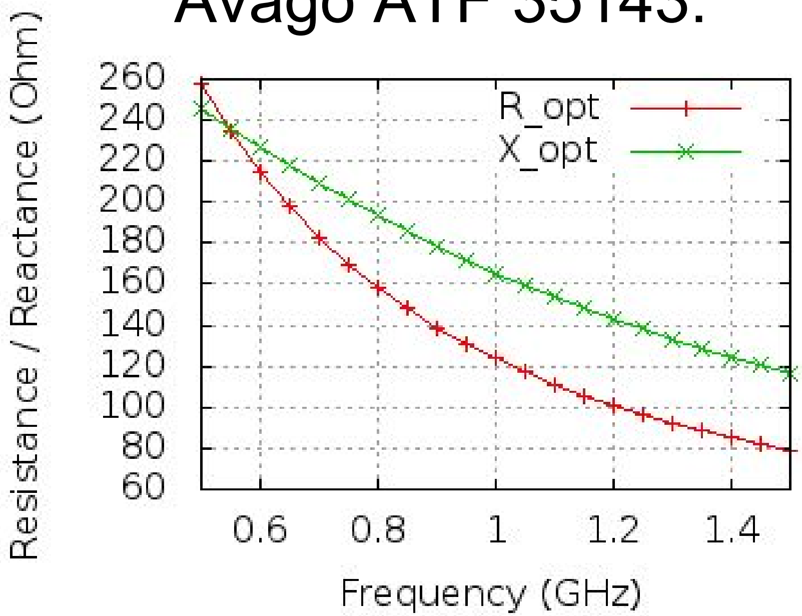
- Broadband: 0.5 - 1.5 GHz
- Low noise: <30 K
  - Tmin < 14K below 1.5 GHz!
- Little power consumption: <100 mW (for 30 dB gain)
  - 20mW / HEMT:
  - 2 HEMT = 30dB gain & 40 mW
- Inexpensive
  - <$1 / HEMT
- Fully differential
  - 4 HEMTS

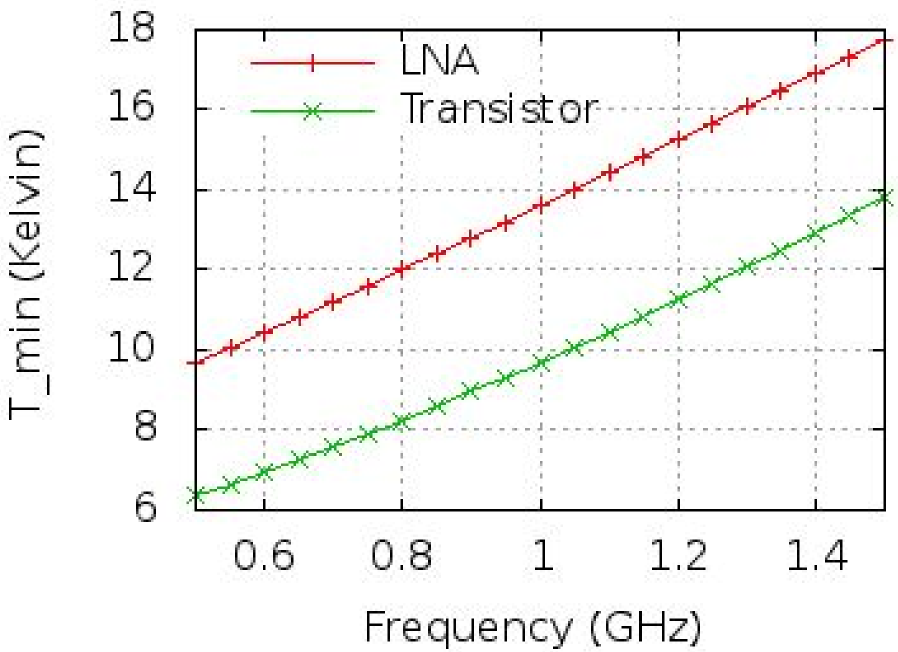
The Problem:

Very low Tmin only at the optimum impedance impedance, Zopt

Zopt is frequency dependent

Avago ATF 35143:



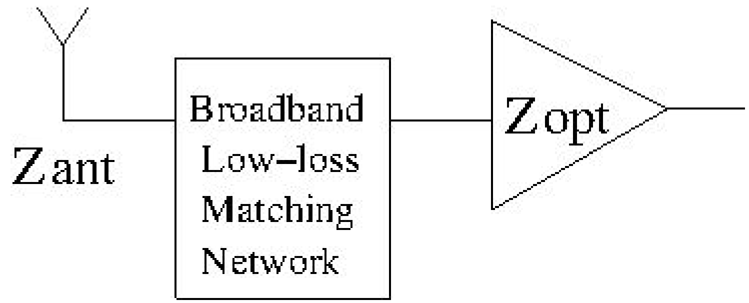


2 proposed solutions:

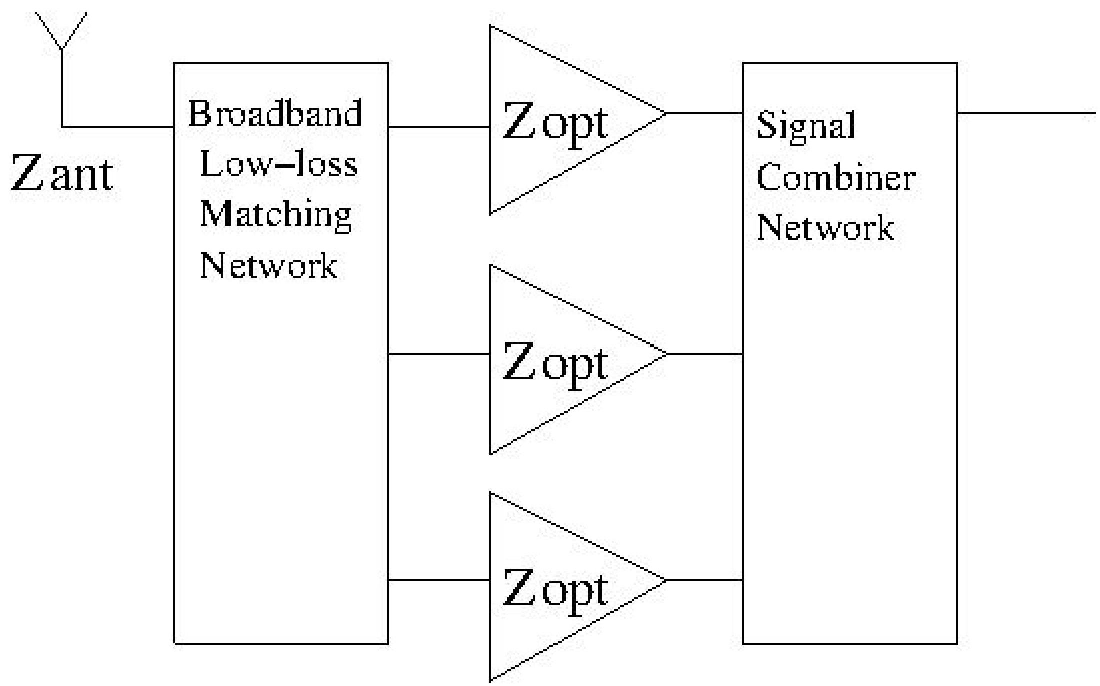
- Multipath amplifier
  - Low-loss matching technique to match antenna (Zant) to the optimum impedance (Zopt)
- Modify antenna
  - So that the antenna impedance is close to the optimum impedance, Zant=Zopt

1. Multipath amplifiers

Difficult to match Zant to Zopt over broadband with low loss:

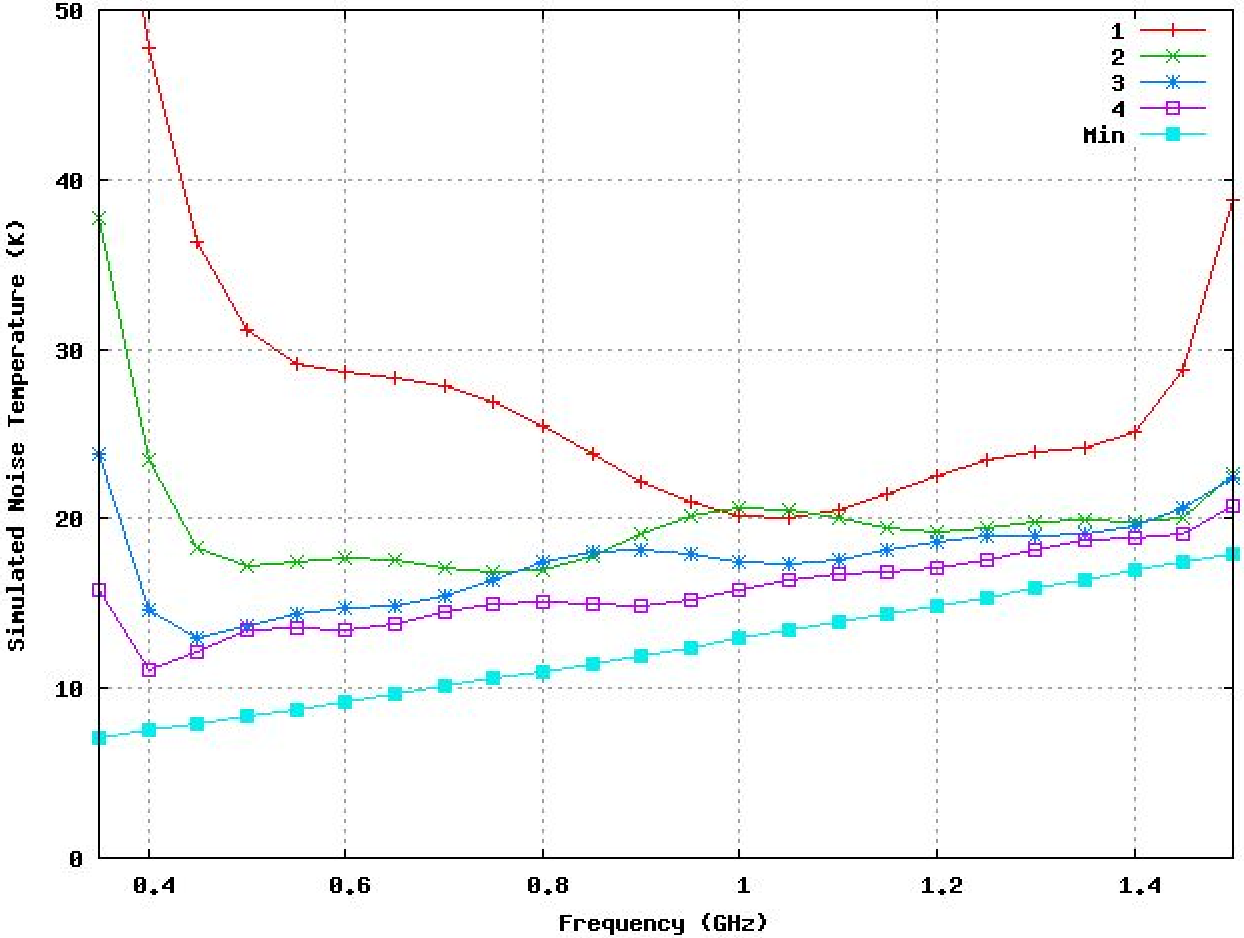


Much easier to match Zant to several amplifier's Zopt:

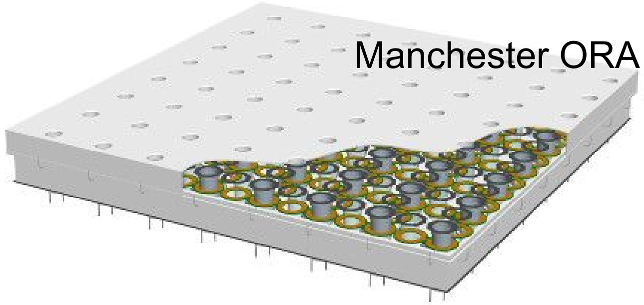


Multipath amplifier: Effect of the number of paths

Matching ATF35143's Zopt to 60 Ohm from 0.35 - 1.5 GHz:

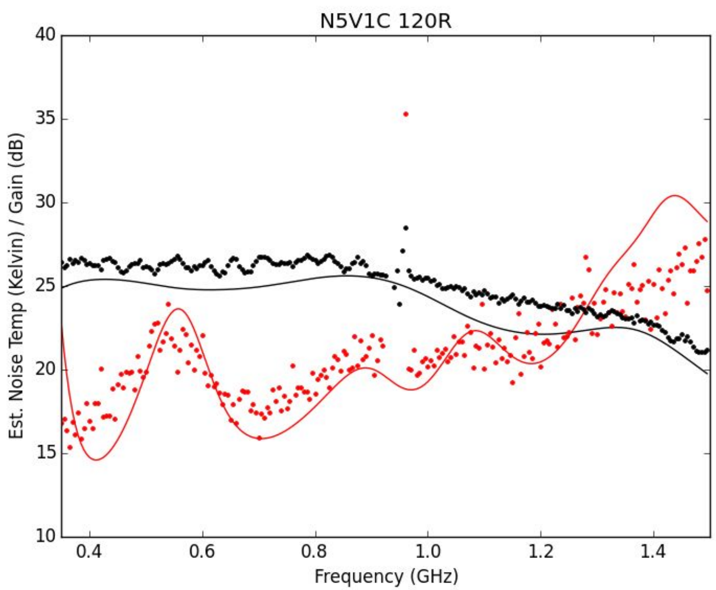


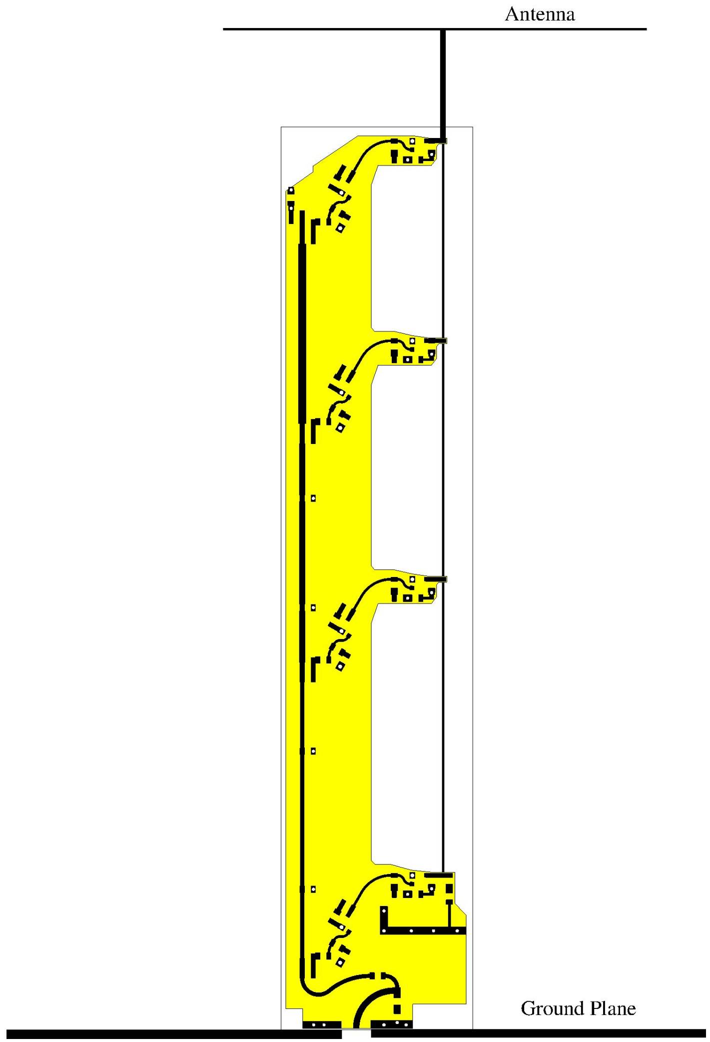
4-path LNA demonstrator



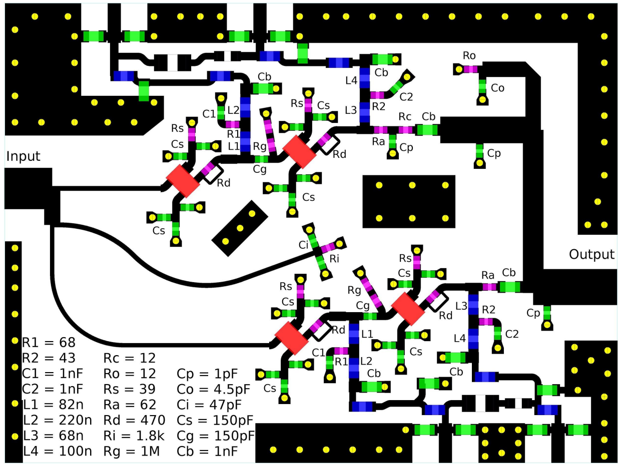
Fully Differential LNA

- Differential Input: 120 Ω
- Bandwidth: 0.35 - 1.5 GHz
- Measured noise temperature: 20-25K
- Power: 400 mW (16x ATF35143)



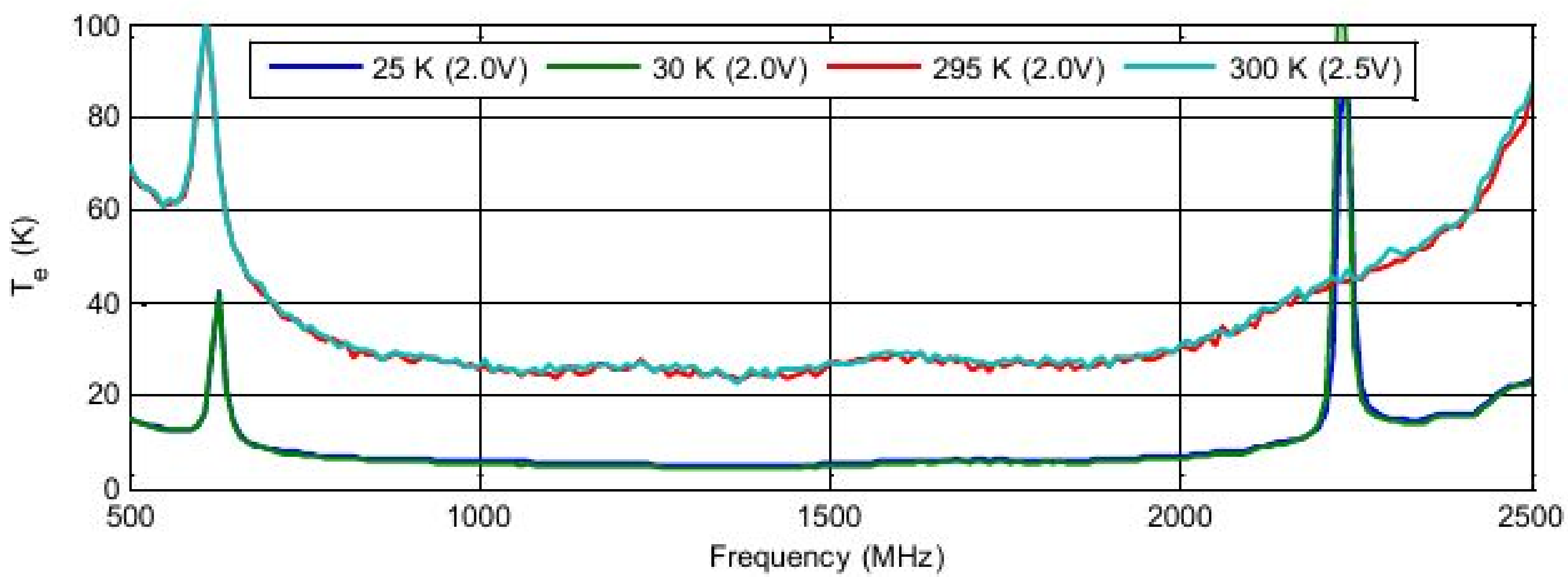


2-path LNA demonstrator



Single-ended LNA

- Input: 50 Ω (S_{11} < -10dB)
- Bandwidth: 0.8 - 2 GHz
- Measured NT: <30 K @ room temp.
- Power: 60 mW
- 4x ATF35143

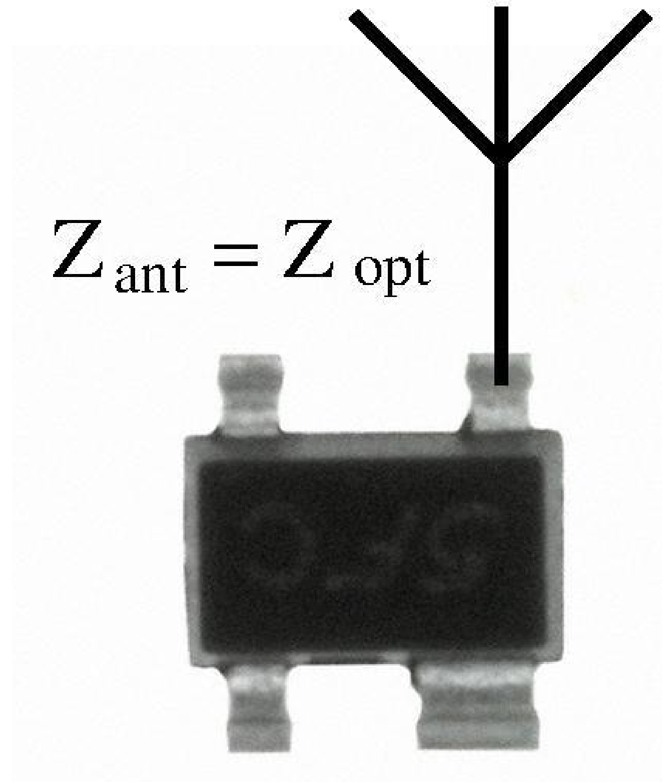


2. Design antenna having Z_{opt}

Antenna designed to have impedance close to Z_{opt}

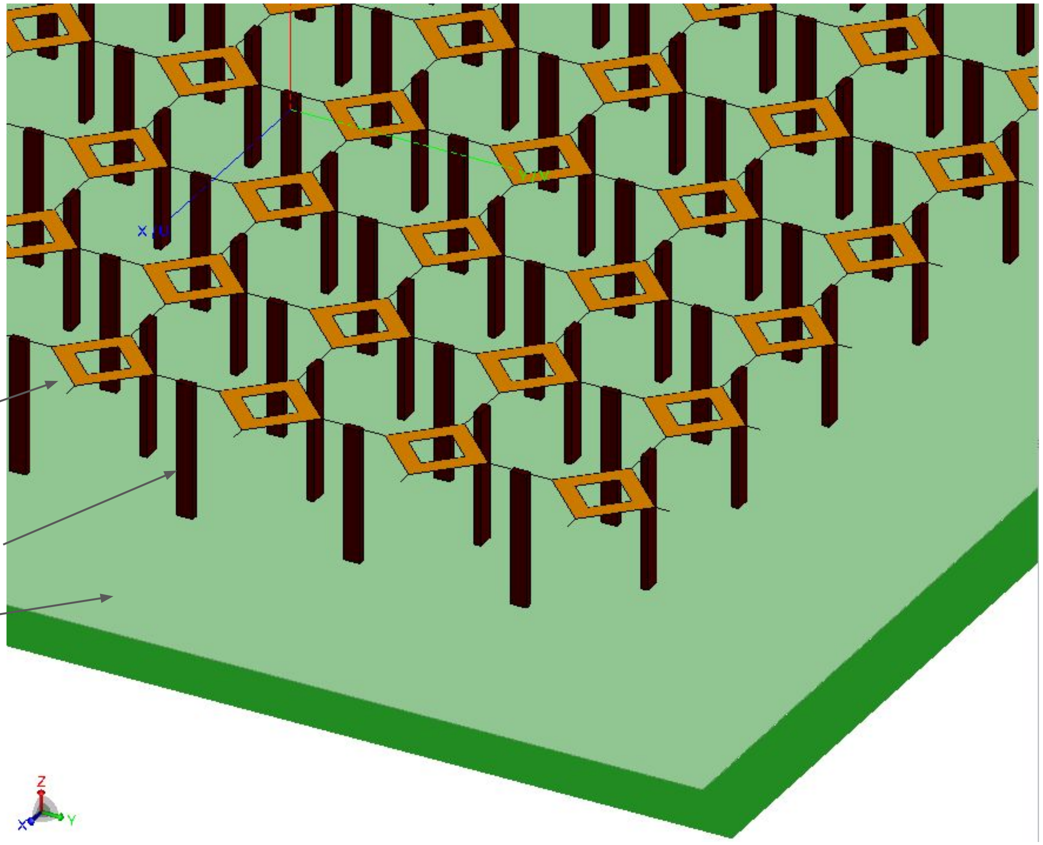
Only 1 amplification path::

- Reduce semiconductor cost
- Reduce power consumption
- Simpler

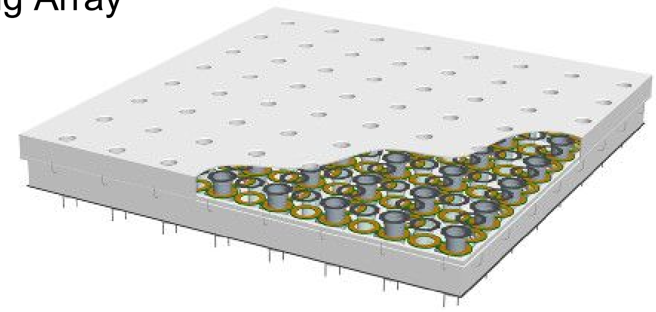


Apperture array example

- Construction
  - Copper wires and pads
  - Thin PCBs with LNA
  - Ground plane



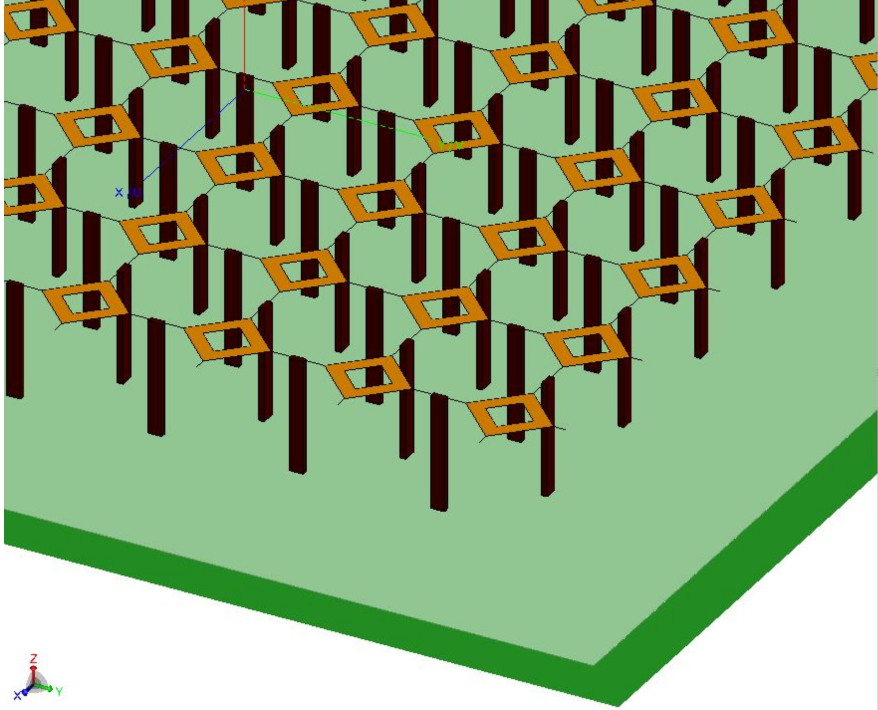
Based on Manchester's
Octal Ring Array

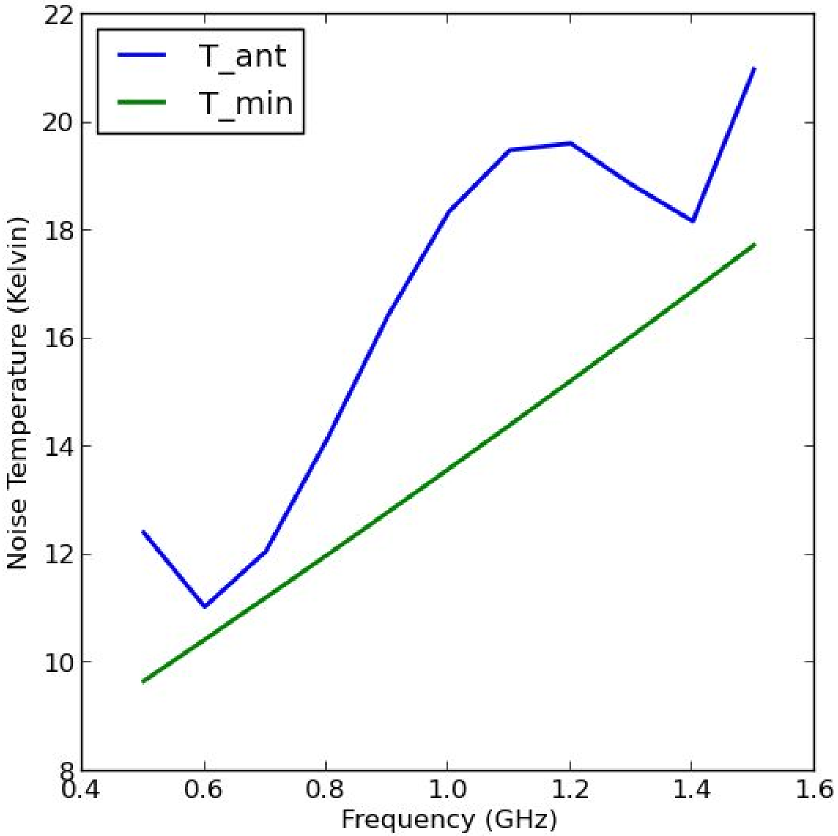


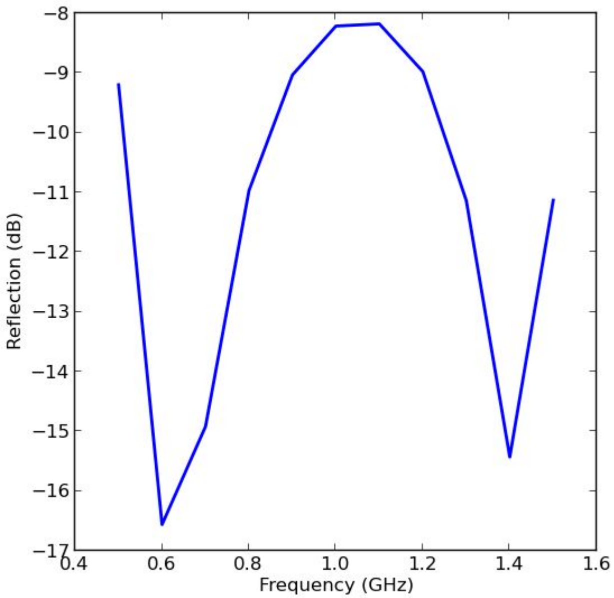
Apperture array example 1

- 12 cm between elements

  (Grating effect >45 degrees @ 1.5GHz)

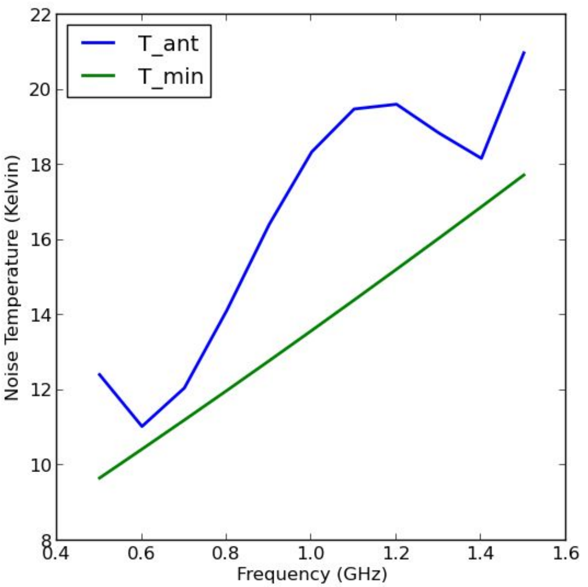


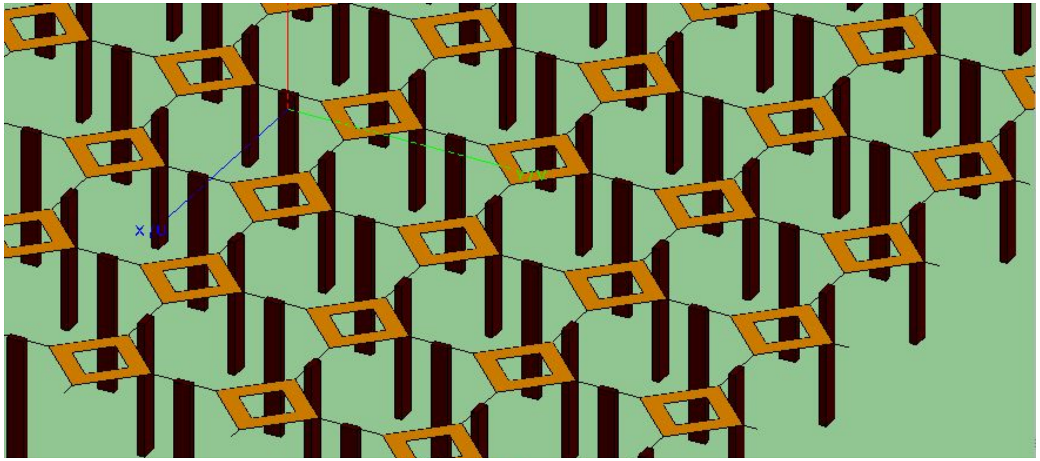




Apperture array example 1

- 0.5 - 1.5 GHz
- Noise Temp <30 K (LNA & antenna loss)
- 100mW (for 30 dB gain) / LNA
- Dual-polarised

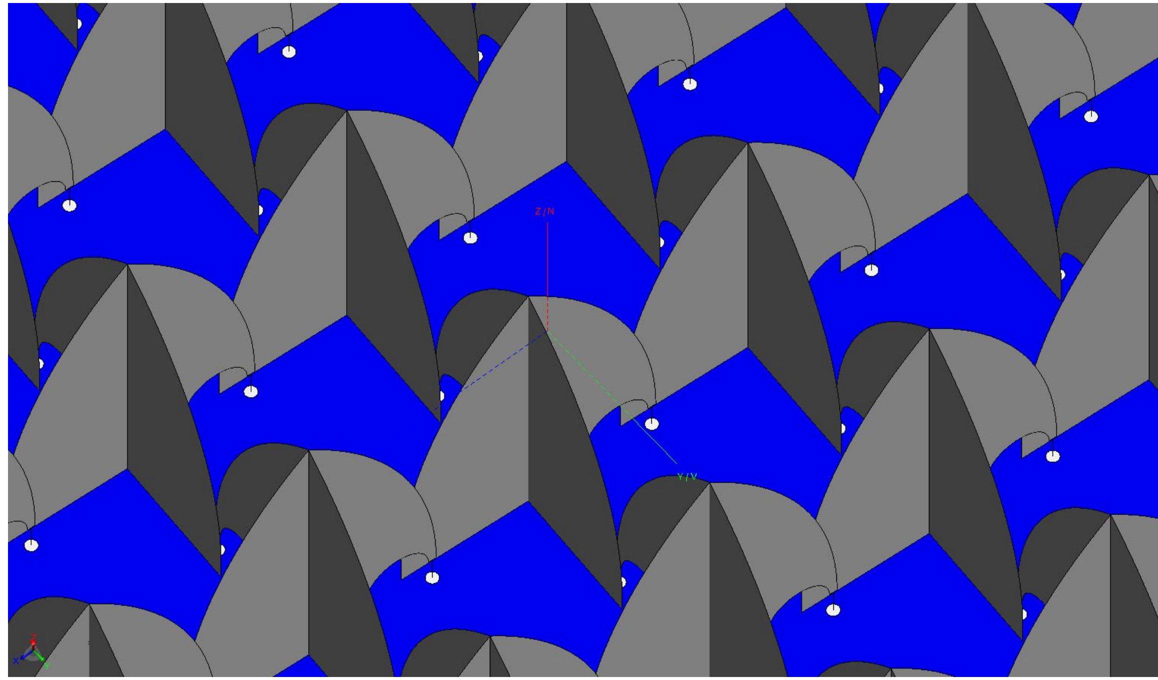




Apperture array example 2

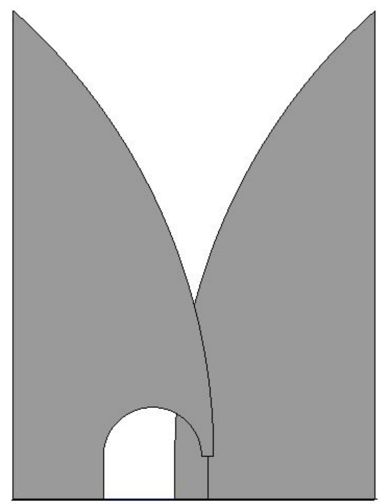
12 cm between elements

(Grating effect >45 degrees @ 1.5GHz)

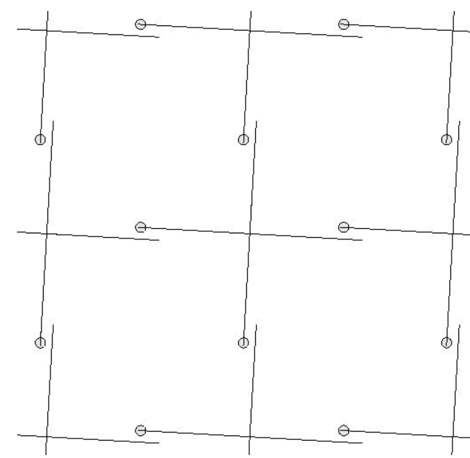


Based on ASTRON's design

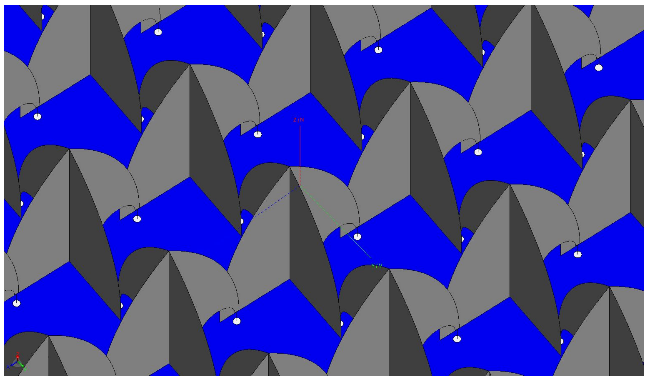
Side view

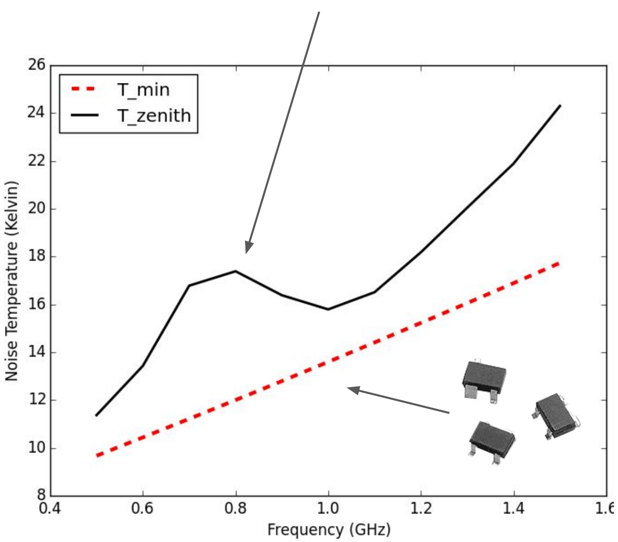


Top view

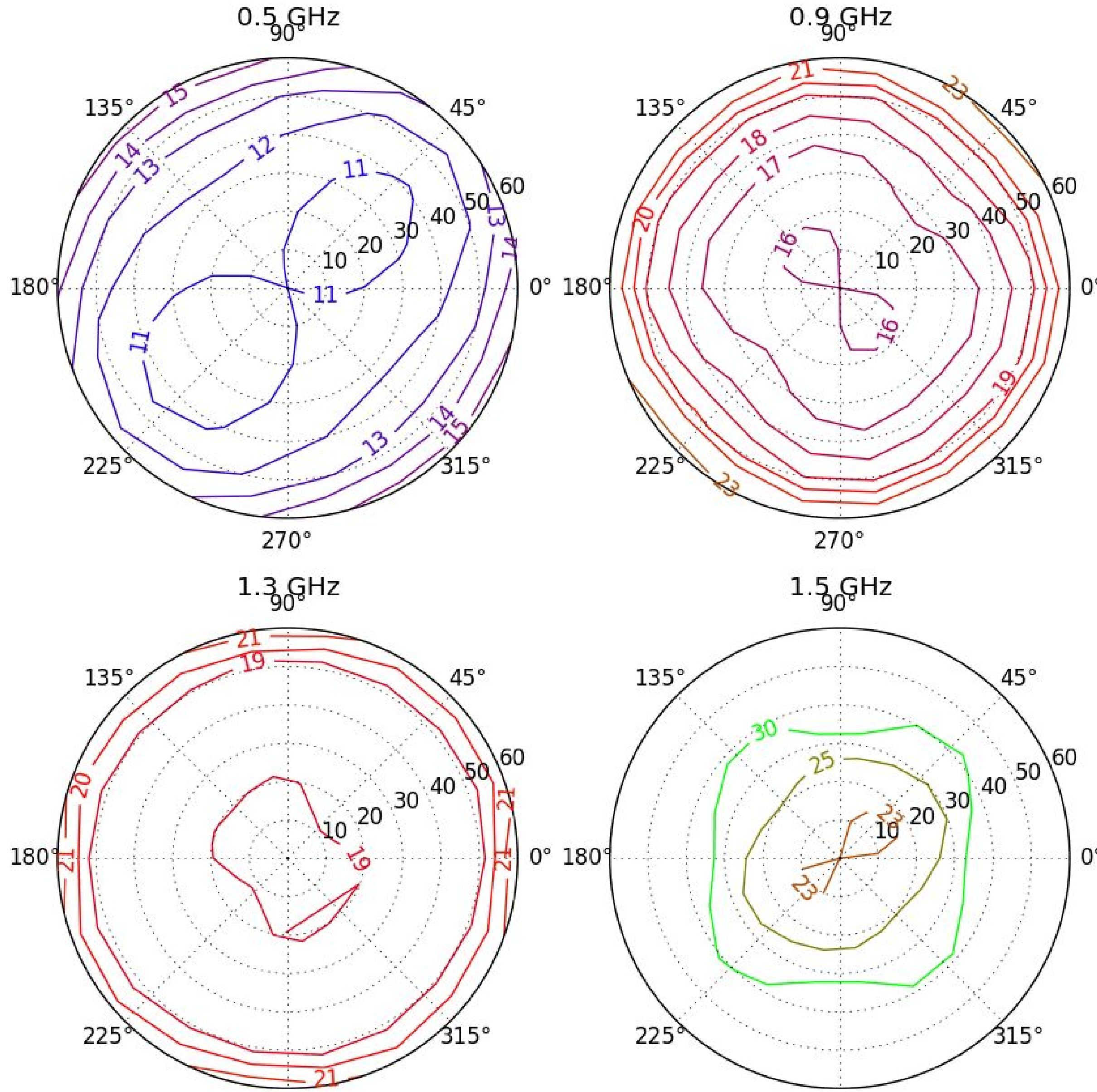


Apperture array example 2





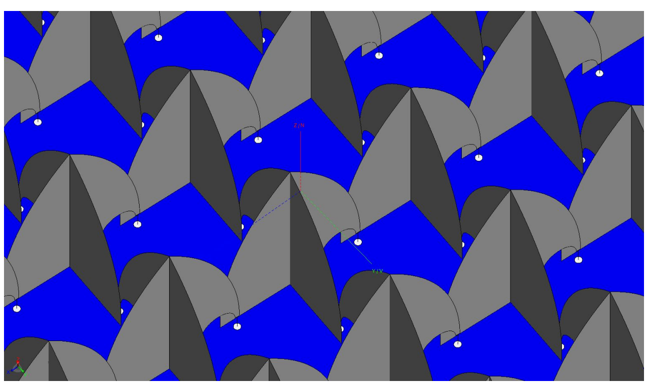
Receiver Noise Temperature (Kelvin)



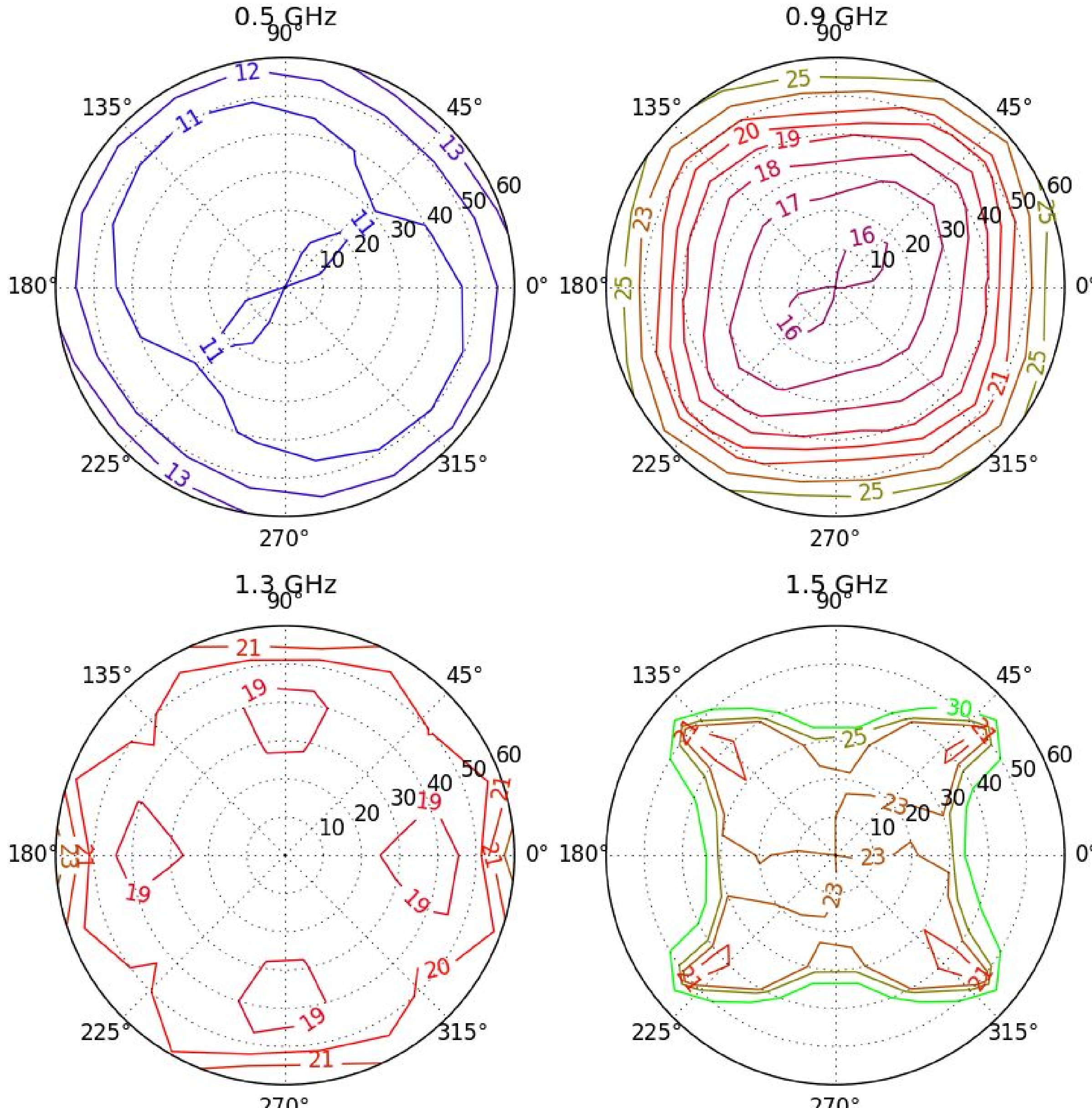
Parallel polarised

Apperture array example 2

- T_{rec} <30 K (Mostly <20K)
  - 0.5 - 1.5 GHz
  - 0-45° Zenith
- <50mW / LNA (for 25 dB gain)
- Single ended



Receiver Noise Temperature (Kelvin)



Perpendicular polarised

What about S_{11}?

Not important, but ...

Quite easy to design HEMT LNA to have Zin close to Zopt*.

A good match to Zopt* then also give a good match to Zin

Conclusion

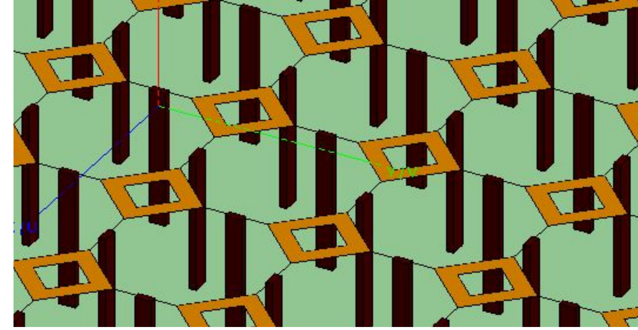
Using commercial HEMTs for LNAs may be a good and easy solution for MFAA.

Requires impedance matching:

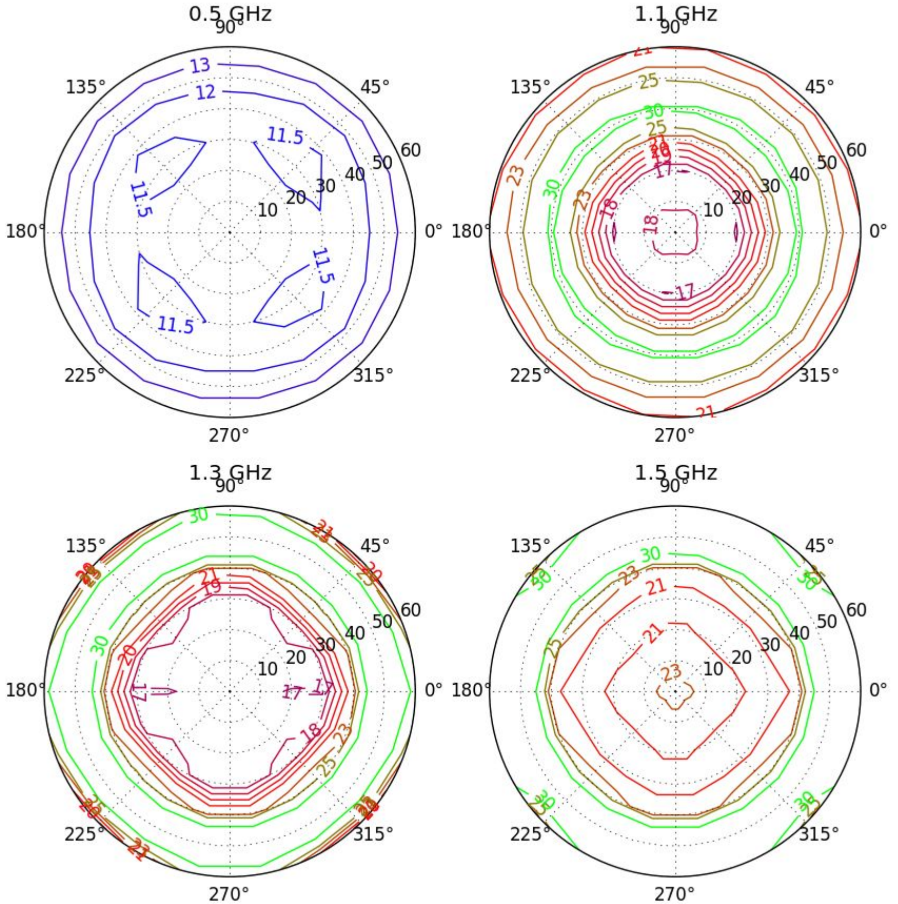
- By using a multipath amplifier
  - Advantage: Seperate LNA & antenna design
- By matching the antenna to the HEMT
  - Advantage:
    - Lower semiconductor cost
    - Lower power consumption
    - Simpler

Apperture array example 1

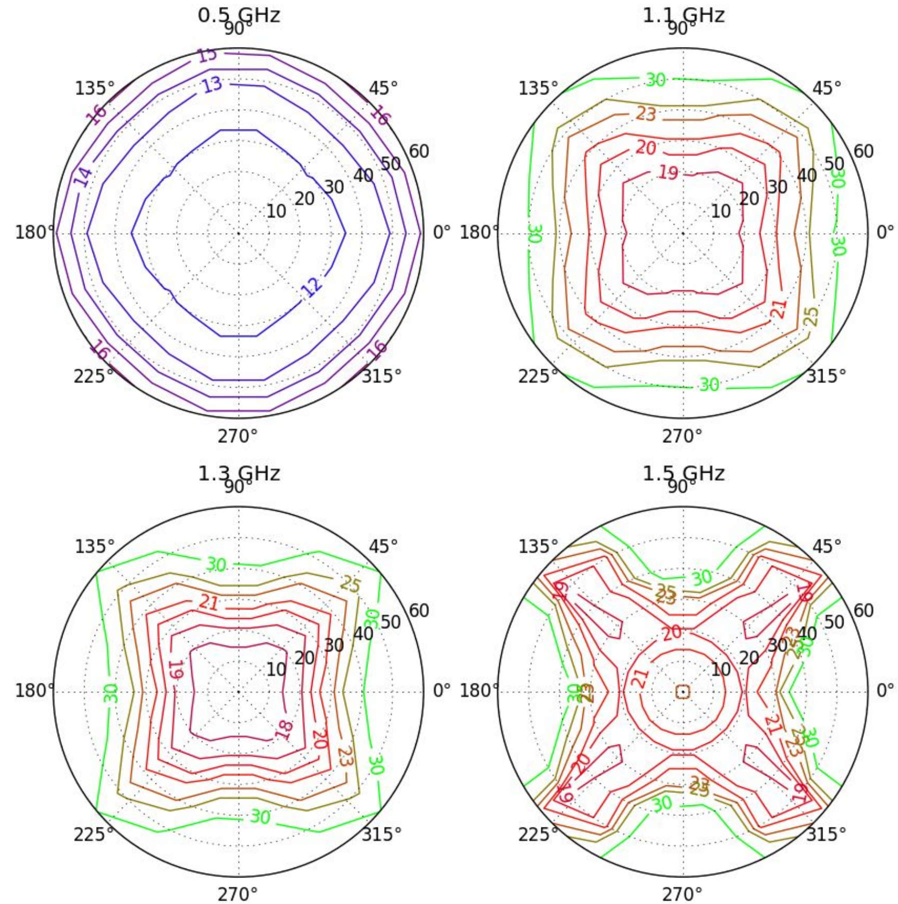
Receiver Noise Temperature (Kelvin)



Parallel polarised



Perpendicular polarised



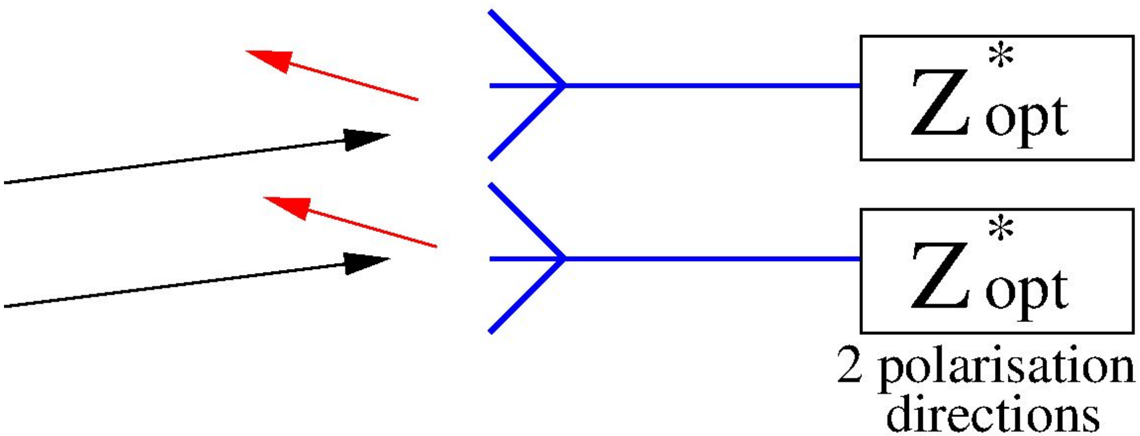
Receiver temperature

Load antenna with Z^*_{opt} (at each LNA)

Simulated incoming wave: P_{in} = power per array element

$$P_{in} = P_R + P_{loss} + P_{Zopt}$$

Measure absorbed power



P_{Zopt} : in load Z^*_{opt}

P_{loss}: in antenna metal

Receiver temperature

Load antenna with Z^*_{opt} (at each LNA)

$$\mathbf{T_{rec} = T_{min} + 2T_n(P_{in}/P_{Zopt}-1) + T_0\, P_{loss}/P_{in}}$$

T_0 - ambient temperature

T_{min} - amplifier minimum noise temperature

T_n - amplifier mismatch noise temperature ($\approx T_{min}$)

$T_n = 2\, R_n\, G_{opt}\, T_0$ (G_{opt} - optimum conductance, R_n noise resistance)

$$\mathbf{T_{rec} / A_{element} = T_{LNA+antenna} / A_{eff}}$$

Amplifier noise measurement: Procedure

3 Output power measurements

- P_s: Input shorted
- P_o: Input open
- P_t: Input terminated at room temperature T_R

Y-factor: $Y \equiv 2P_t / (P_s + P_o)$

Correction factor: $\alpha=1+S^2_{11}+2\mathrm{Re}(S_{11}) (P_s - P_o) / (P_s + P_o)$

$\alpha \approx 1$ when S_{11} small.

LNA Noise temperature: $\mathbf{T_{lna} \approx T_R /(2\alpha Y - 1)}$

Amplifier noise measurement: Simulated example