FRONTEND SIGNAL PROCESSING DESIGN FOR A CRYOGENIC PAF PROTOTYPE OF FAST

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OUTLINE

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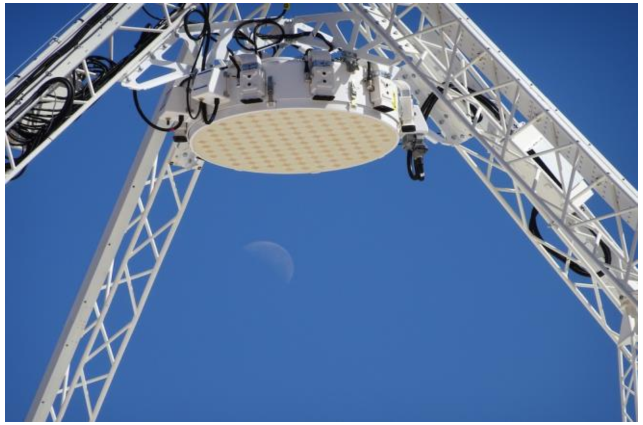
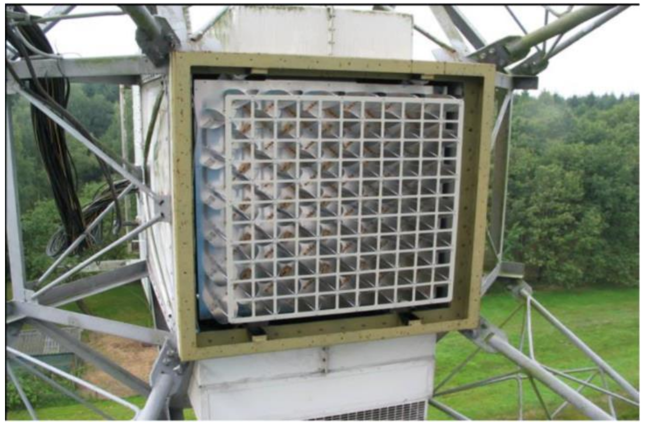
2. Frontend Signal Processing framework
3. Key Components Design and Test
4. Conclusion

1. INTRODUCTION

- Phased array feed (PAF) is quite a promising receiver technology for reflector antennas and has been developed for over 20 years. The advantages:
  - achieve continuous sky coverage in the telescope's field of view by sampling the electromagnetic field across the focal plane of the telescope and using digital beam forming.
  - make the telescope's gain close to or exceed those of traditional feeds.
  - realize a variety of observation modes flexibly.



ASKAP PAF by CSIRO



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1. INTRODUCTION

- the Five hundred meter Aperture Spherical Telescope (FAST) has fully operated in the early 2020
- Since the commission phase, the 19-horn receiver has been installed and conducting astronomical observations.
  - Due to gaps in the sky coverage of the adjacent horns, the FAST telescope needs multiple pointing to form continuous sky coverage, and the sensitivity of the outermost horns drops compared with that of the center feed.
  - By using PAF, it is expected to form continuous sky coverage, increase the sensitivity of each beam which will allow the FAST telescope to survey the sky 4-5 times more quickly. PAF can also achieve point-scanning calibration, compensate the position residuals of the feed cabin, and correct surface shape errors of the large dish, which will greatly improve the overall performance of the FAST telescope.

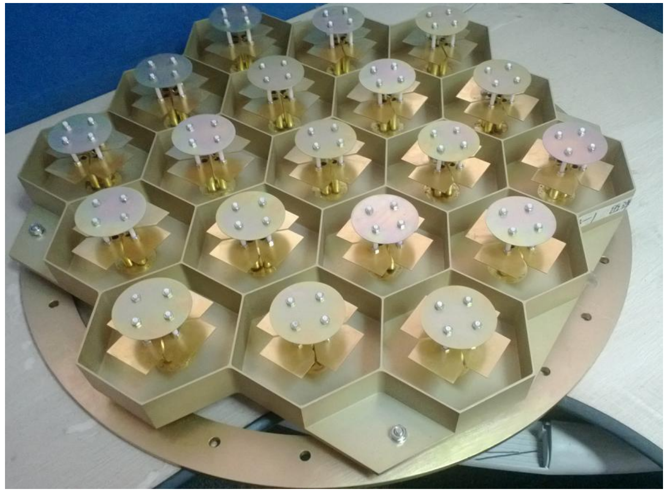
The world's largest single dish radio telescope FAST

19-horn receiver installed on FAST

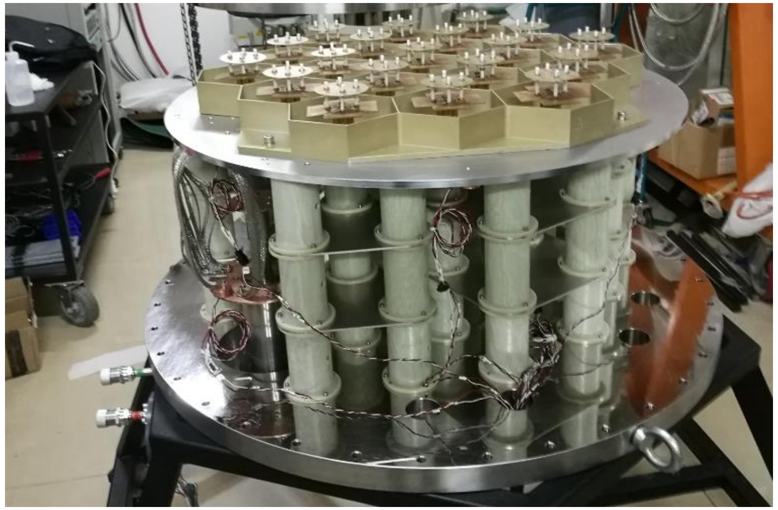
1. INTRODUCTION

We are working on an L-band cryogenic PAF prototype for the FAST which aims at acquiring better performance than the 19-horn receiver and exploring the potential to replace the 19-horn receiver in future.

- 19-element antenna array consisting of the hexagonal cavity-backed dipole was designed.
- Cryostat for the antenna array and low noise amplifiers was built and tested.



◂ The 19-element antenna array with hexagonal cavity-backed dipoles.



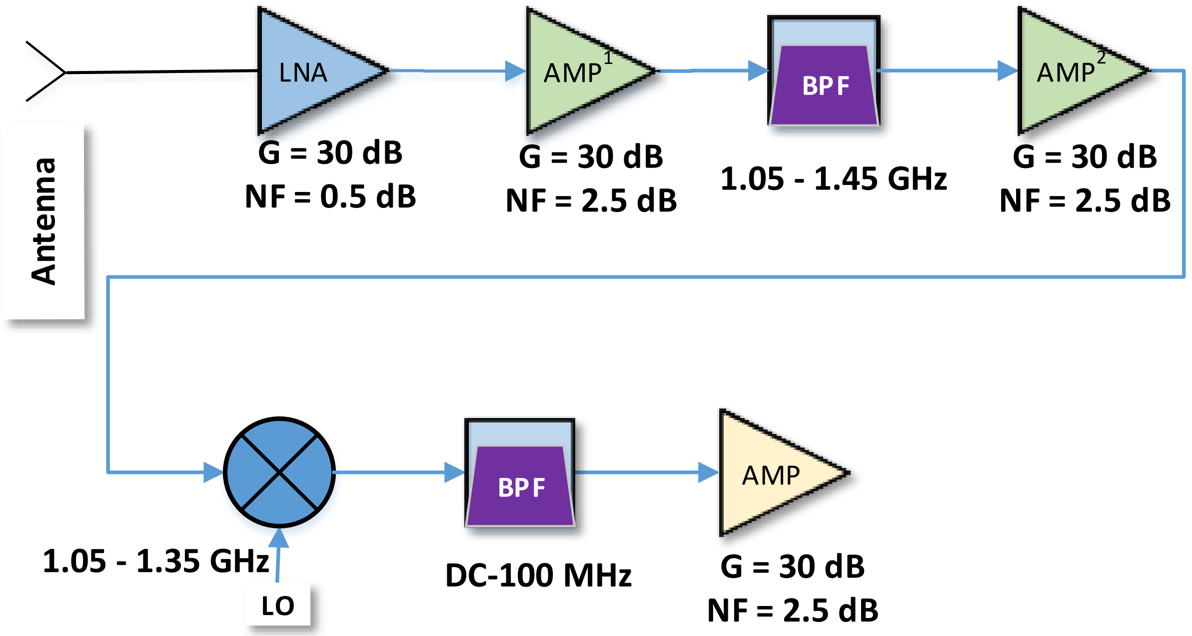
◂ Cryogenic test: the antenna array was installed in the dewar supported by G10 pillars.

- This paper describes our work on the frontend signal processing design for this 19-element PAF.

2. FRONTEND SIGNAL PROCESSING FRAMEWORK

Specifications

- Frequency coverage: 1.05 - 1.45 GHz
- Number of elements: 19
- Polarization: 2
- RF bandwidth: 400 MHz
- IF bandwidth: 100 MHz
- System noise figure: 0.5 dB
- System gain: about 120 dB, adjustable with attenuators

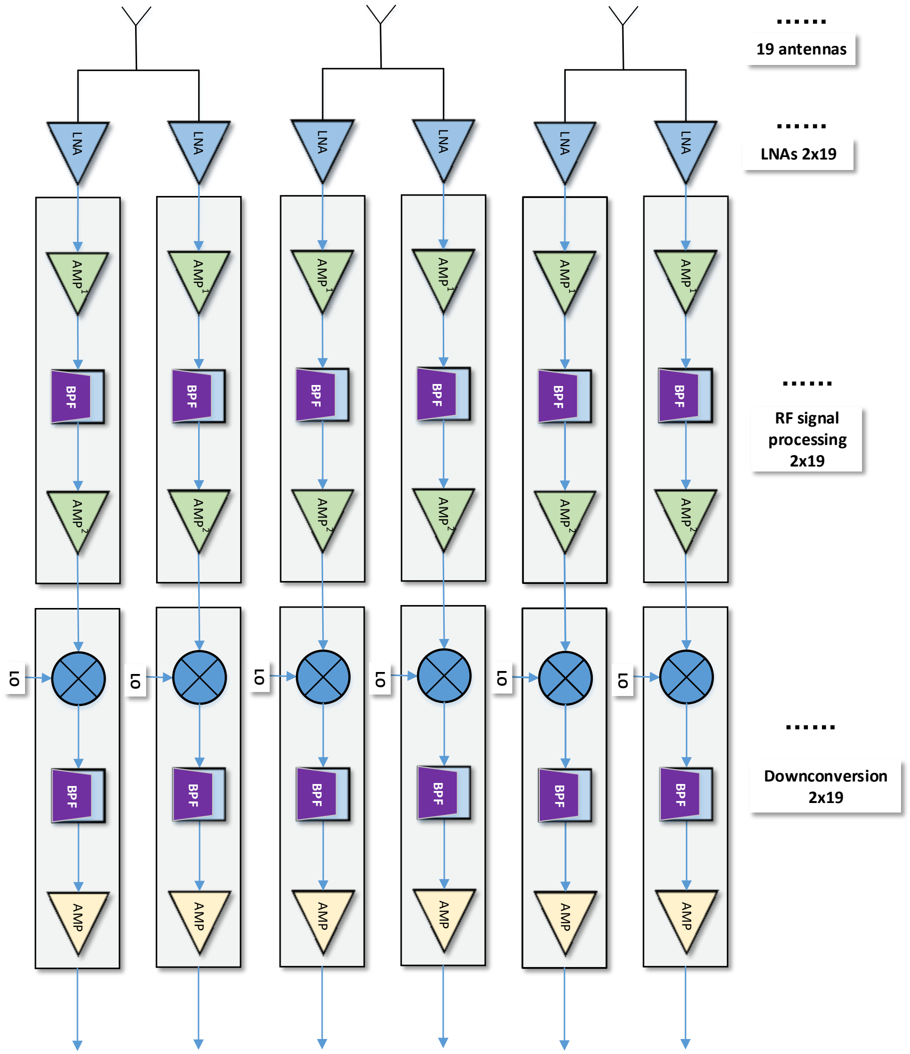


The frontend system composition and parameter allocation

2. FRONTEND SIGNAL PROCESSING FRAMEWORK

System integration

- Requirements: easy to produce, maintain, and operate
- The system is divided into three parts:
  - LNA: installed close to the antenna element, and both the LNAs and antennas are placed in the cryostat to be cooled to 15 – 20 K
  - RF signal processing: including band-pass filter, RF amplifiers, etc. which are integrated on one PCB and packaged in one box for every signal path
  - down conversion: including mixer, local oscillator and IF signal processing (filter, IF amplifier): packaged in one box for every signal path
- For every signal path, LNA, RF signal processing box and down conversion box are assembled in series.
- For the whole system, 38 RF signal processing boxes are installed parallel while 38 down conversion boxes are in parallel.

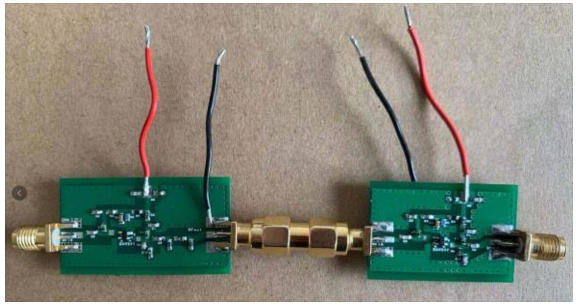


19-element PAF frontend signal paths framework

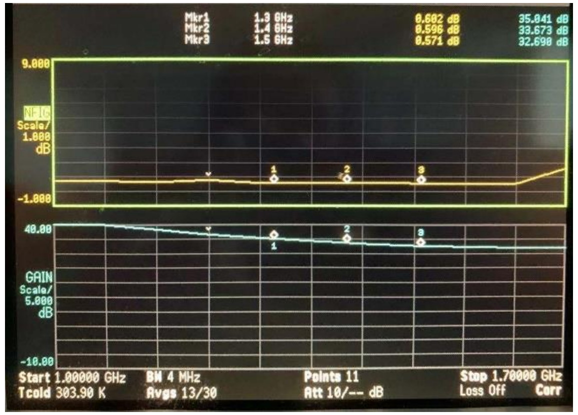
3. KEY COMPONENTS DESIGN AND TEST

Low noise amplifer

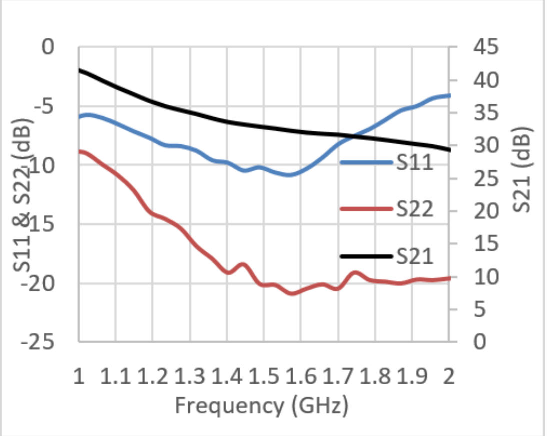
- As PAF is comprised of quite a large number of LNAs, costs, sizes, simple biasing, capabilities to be integrated to the antenna and possible filter, mass production, MTBF evaluation, etc., need to be considered.
- We selected commercial transistors with advantages of low noise, high gain, single power supply, simple matching network and biasing network, and small size.
- The noise figure is simulated as 0.27 dB at 1.05 GHz and 0.36 dB at 1.45 GHz. It measures 0.6 dB at 1.4 GHz. The current experiment board adopts FR4 material and ordinary electric devices are used. It next step high-quality boards and devices will be used to further reduce the noise.
- The S11 measures better than -6 dB and S22 is better than -10 dB in the operating frequency range.



◂ The experiment board of LNA



◂ The noise figure measurement of the LNA

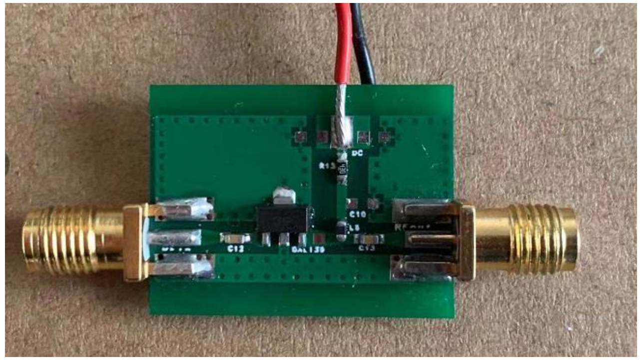


◂ S-parameter measurement results of the LNA

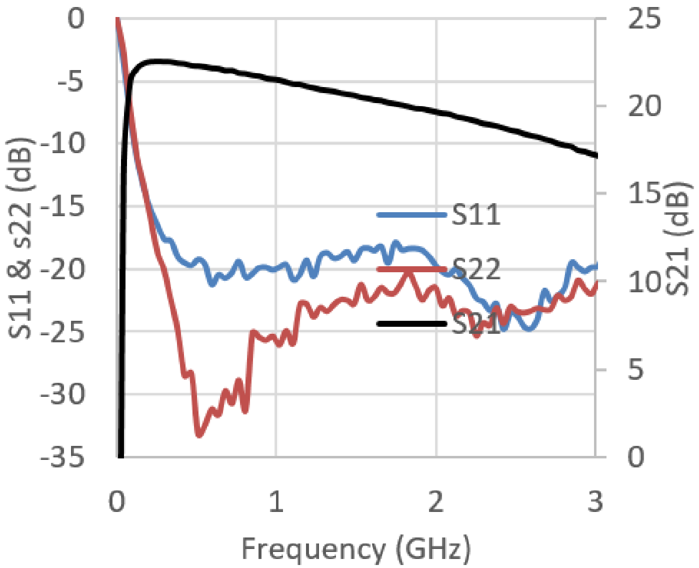
3. KEY COMPONENTS DESIGN AND TEST

RF Amplifier

- The experiment board consists of one stage transistor.
- The S11 measures better than -19 dB and the S22 better than -22 dB at 1.05 - 1.45 GHz.
- S21 is greater than 20 dB.
- The noise figure is about 2.5 dB at 1.4 GHz.
- The size of the board is 2.5 cm × 1.5 cm.



The experiment board of the RF amplifier



S-parameter measurement results of the RF amplifier

In the current state, we have preliminary design and test results about the LNA, RF amplifier and low-pass filter. Other parts including the bandpass filter, mixer, local oscillator are under development.

4. CONCLUSION

- The system design for the frontend signal processing of the FAST PAF prototype has been completed.
- The integration of the multiple signal paths has been preliminarily planed and need further consideration and implementation.
- Key components such as the LNA, RF amplifier, low-pass filter have been developed and measurement results are given.
- We will complete the prototype of the frontend signal path in next step and then integrate it to the backend and do functional debug in the lab.
- In the near future this PAF prototype will be assembled on a small telescope to do calibration test and experimental astronomical observations.

Thanks for your attention!