NATIONAL RADIO ASTRONOMY OBSERVATORY

Cryogenic Subsystem Concept

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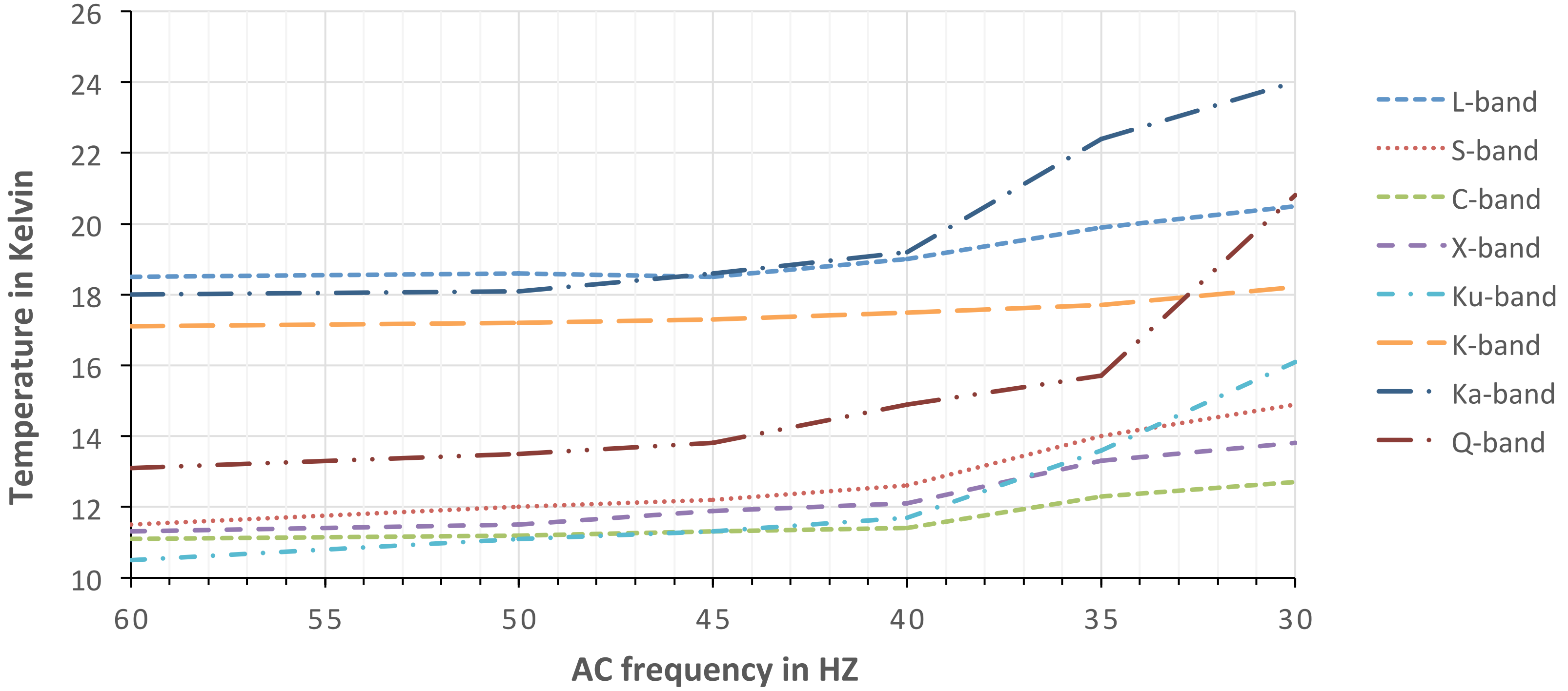
ngVLA

The Next Generation Very Large Array

Outline

- Results of the **V**ariable **F**requency **D**rive (VFD) experiment at the VLA
- Cryogenic concept
  - How varying the speed of a Gifford McMahon refrigerator can
    - Optimize performance
    - Reduce periodic maintenance
  - How varying the speed of a Scroll compressors can
    - Reduce power consumption
  - Application of this concept for ngVLA
  - Conclusions

VLA receivers with Multi layer Insulation run with VFD (2nd stage)



Lessons learned from the VFD experiment

- All VLA receivers can have their refrigerator running at lower speed and maintain adequate temperature (LNA temperature < 20°K)
- Adding **M**ulti **L**ayer **I**nsulation allows us to run the receivers colder at 40Hz than they were initially at 60Hz without MLI

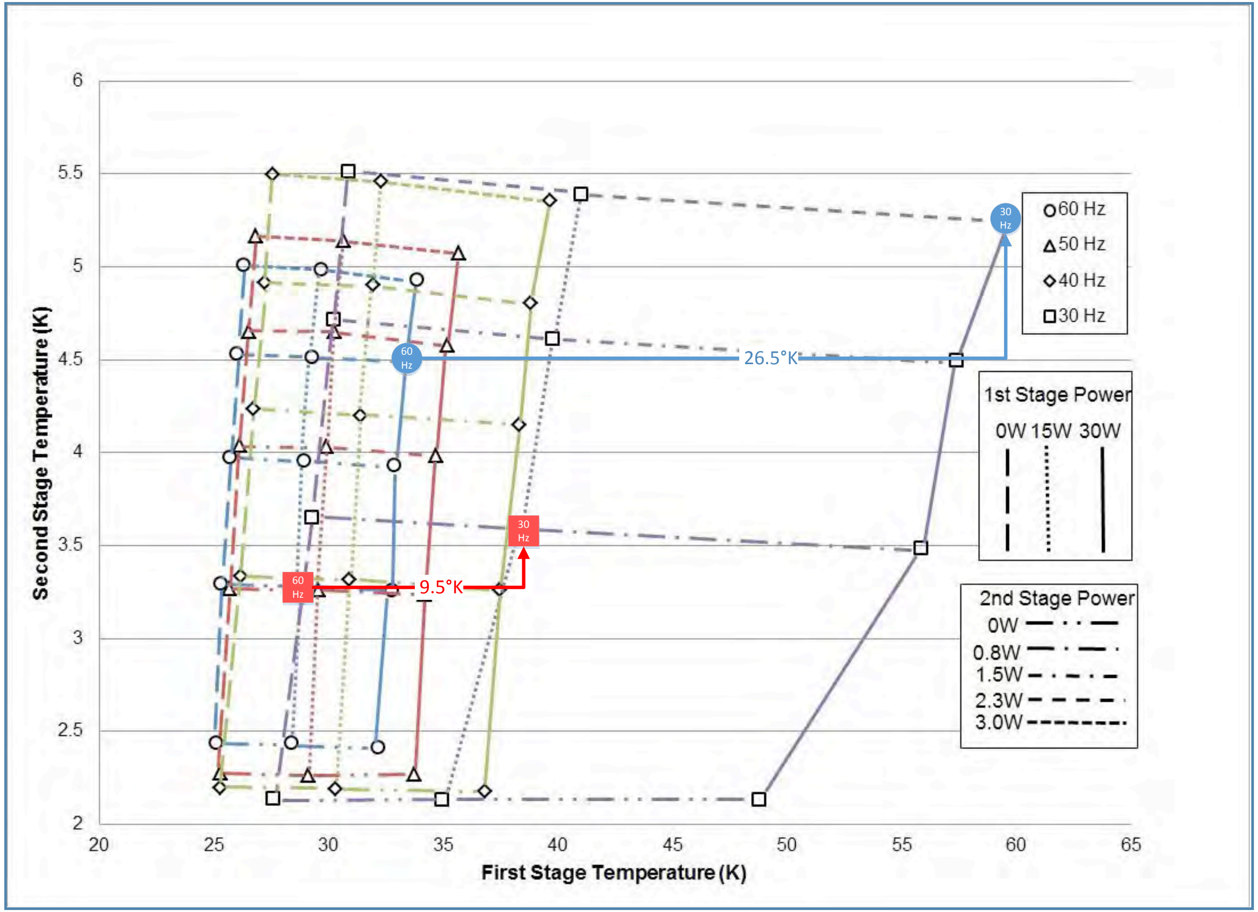
Present Gifford McMahon refrigerators

- Pros
  - NRAO has over 35 years experience with the technology
  - Temperature < 20K easily attainable
  - Cooling capacity fairly immune to orientation
  - Good serviceability
  - Being used in many different applications (research and industry)
    - Reasonable cost
    - Many manufacturers and models to choose from
- Cons
  - Not the most efficient thermo-cycle
  - Moving parts => periodic maintenance required
  - Generate vibrations

How to optimize GM refrigerator performance

- Run the refrigerator at variable speed
  - Adjustable cooling capacity
  - Cool below 20K only as needed
- Improve the refrigerator displacer efficiency
- Select the refrigerator based on the cooling capacity/flow relationship
  - Develop load maps at various operating frequencies
- Added benefit of a variable speed refrigerator
  - Speed can be increased to compensate for loss of efficiency due to seal wear and dust particle accumulation in regenerator from mechanical wear

Load map of a cold-head at different frequencies



Data provided by quantum Design

Example: Quantum Design GA1 refrigerator

	Heat load First stage 15W Second stage 0.8W		Heat load First stage 30W Second stage 2.3W	
Power Frequency in Hz	Temperature first Stage in Kelvin	Temperature Second stage in Kelvin	Temperature first Stage in Kelvin	Temperature Second stage in Kelvin
60	28.5	3.25	33	4.5
30	38	3.6	59.5	5.3
Delta 60-30	**9.5**	**0.35**	**26.5**	**0.9**

How to reduce the required maintenance

- Run the refrigerator at lower speed

Cold-head type	CTI 22 at 60Hz	CTI350 at 60HZ
Motor speed in rpm	200	72
MTBF in hours	6,132*	17,520*
MTBF in Year	0.70*	2.00*
MTBF in number of revolutions	1226,400*	1261,440*

Ratio of the motor speed **2.78**

Ratio of the MTBF **2.86**

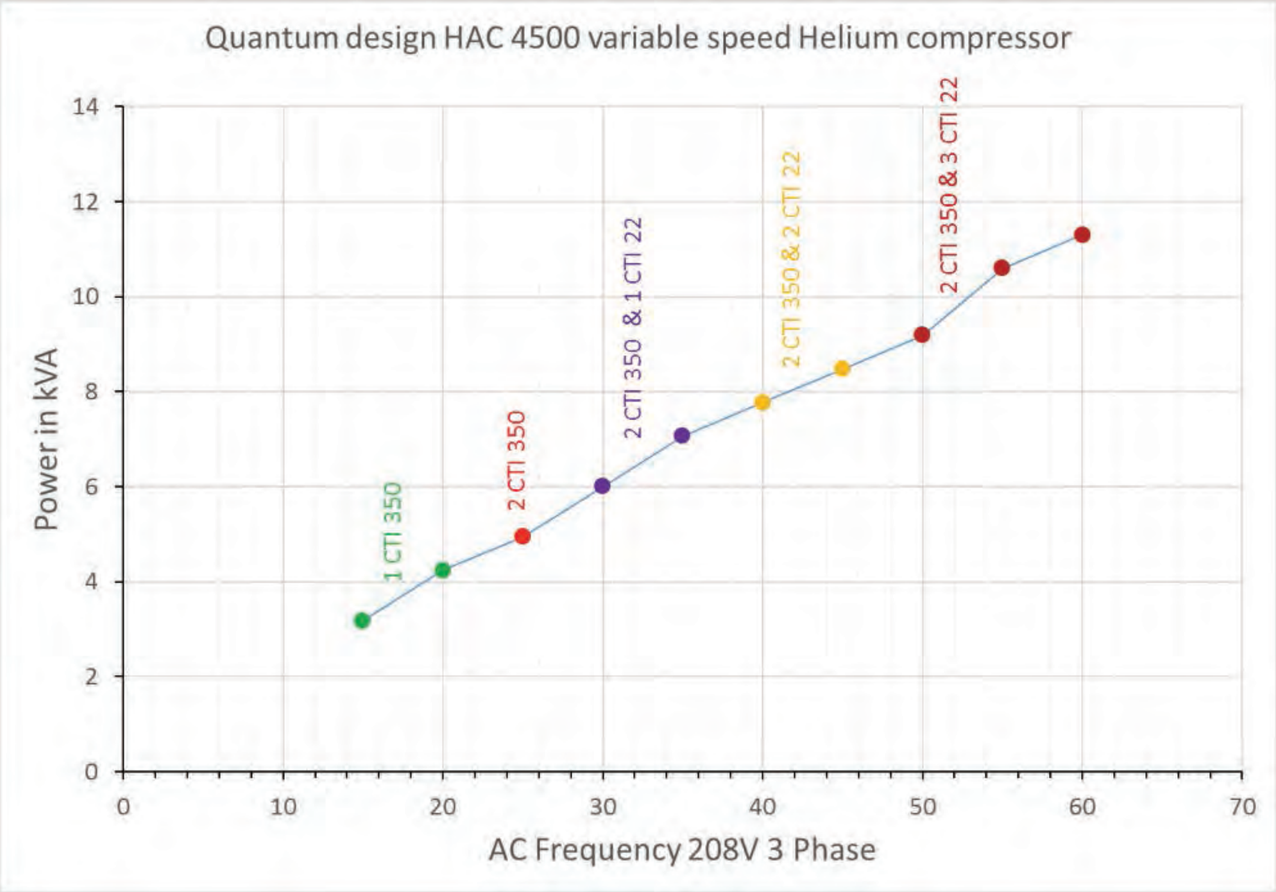
* VLA data

Why use an Helium Scroll compressor

- Pros
  - Well established technology
  - Proven reliability
  - Variable speed capsules already available
  - Large enough capacity to run a single compressor/antenna
- Requirements
  - Efficient oil/Helium separation is extremely important
  - Periodic maintenance required
    - Adsorber replacement (30,000hours / 3-4years)
    - Heat exchanger cleaning

Variable-speed Scroll compressor

- Pros
  - Lower the power consumption by only generating the required flow
  - Minimize start up current by slowly increasing the speed
  - Help start the compressor in cold weather condition
  - Extended lifetime
- Cons
  - Added cost
  - Added electrical circuit complexity
  - Generates RFI and will require appropriate shielding
  - Adjustable heat rejection required (multi-speed cooling fan)


Quantum design HAC 4500 variable speed Helium compressor
Power in kVA
AC Frequency 208V 3 Phase
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
1 CTI 350
2 CTI 350
2 CTI 350 & 1 CTI 22
2 CTI 350 & 2 CTI 22
2 CTI 350 & 3 CTI 22

Other design parameters of importance

- Careful design of the cryostat(s) to minimize heat load and out-gassing
- **M**ulti **L**ayer **I**nsulation is a must
- Minimize pressure drop in the lines between compressor and refrigerators
- In multi-cryostat configuration, develop a “standby mode” where the temperature of a cryostat is allowed to rise to 30K when not in use (cryo-pumping still active)
- In case of a multi-band cryostat, power down unused frequency bands to reduce thermal loading

	Current VLA configuration	ngVLA 1.2-116GHz configuration	ngVLA 11-116GHz configuration
Number of cryostats	9	3	1
Number of 25m Antennas	27	155	155
Number/type of cold-heads per antenna	2 x CTI22, 6 x CTI350 1 x CT1050	2 x CTI350, 1 x CTI 1050	1 x CTI350
Number of cold-heads on the array	243	465	155
Variable speed drive	No	Yes	Yes
Cumulative Helium flow (scfm)	121	40*	10*
Number of Helium compressors	3	1	1
Variable speed drive	No	Yes	Yes
Cumulative electrical power consumption (kWh)	**18**	**5**	**3**
Annual electrical cost per antenna	$17,350 **	$4,800 **	$2,900 **
Annual electrical cost for the array	**$470,000**	**$750,000**	**$450,000**

*Assumes cold-heads are run at 40Hz instead of 60Hz as in the VLA case

** kWh in New Mexico 11 cents

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Number of cold-heads on the array	243	465	155
Variable speed drive	No	Yes	Yes
Normalized MTBF per antenna (CTI350 =1)	2 x 1/3, 6 x 1, 1	3 x 3/2*	3/2*
Expected number of failure	351	310	103
Normalized annual maintenance cost	1	0.88	0.29
Annual maintenance cost	**100%**	**88%**	**29%**

*Assumes cold-heads are run at 40Hz instead of 60Hz as in the VLA case
Annual MTBF = number of refrigerator / number of failure

Conclusions

- Operation budget for ngVLA should not exceed twice the current VLA budget. For the cryogenics it is within reach.

  - 155 antenna (25m) 1.2GHz to 116GHz
    - Annual energy cost 1.6 time the VLA
    - Annual maintenance cost same as VLA
  - 155 antenna (25m) 11GHz to 116GHz
    - Annual energy cost same as VLA
    - Annual maintenance cost 1/3 of the VLA