Cold inertance tube for 4 K Stirling type pulse tube cryocoolers

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Outline

1. Motivation
2. Calculation Model
3. Results and Discussion
4. Summary

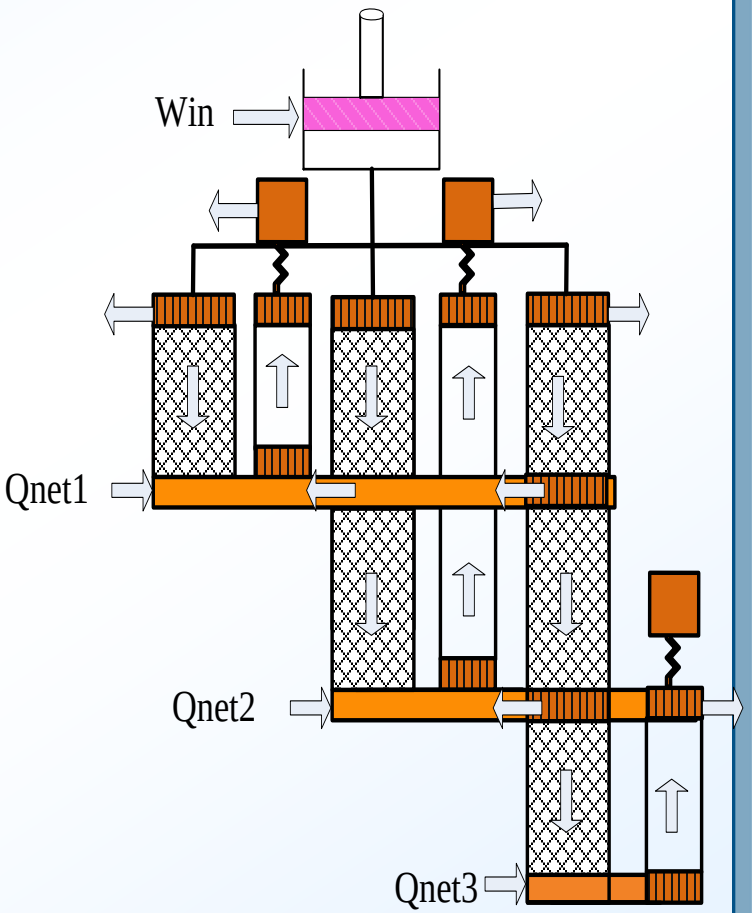
4 K Applications

Application Field	Cases	Cooling Power@4 K
Space Exploration	Mid-Long Wave（1.5-1000 μm）Infrared Sensors	10-500mW
	Precoolers for Space Microcalorimeter	10-50mW
	Precoolers for Space Thermal radiometer	10-50mW
Military Detection	Very long wave infrared sensors For Mid courese missile	100-200mW
Low Temperature Superconductivity	Superconducting Quantum Interference Device (SQUID)	10-100mW
	Magnetically Levitated Train	5-10W
	Superconducting Magnetic Energy Storage (SMES)	1W-1kW
	Accelerators&Fusions	1-100kW
	High Speed Communications (HSC)	100mW
Medical Examination	Magnetic Resonance Imaging (MRI)	0.5-3W

4 K Pulse Tube Cryocoolers

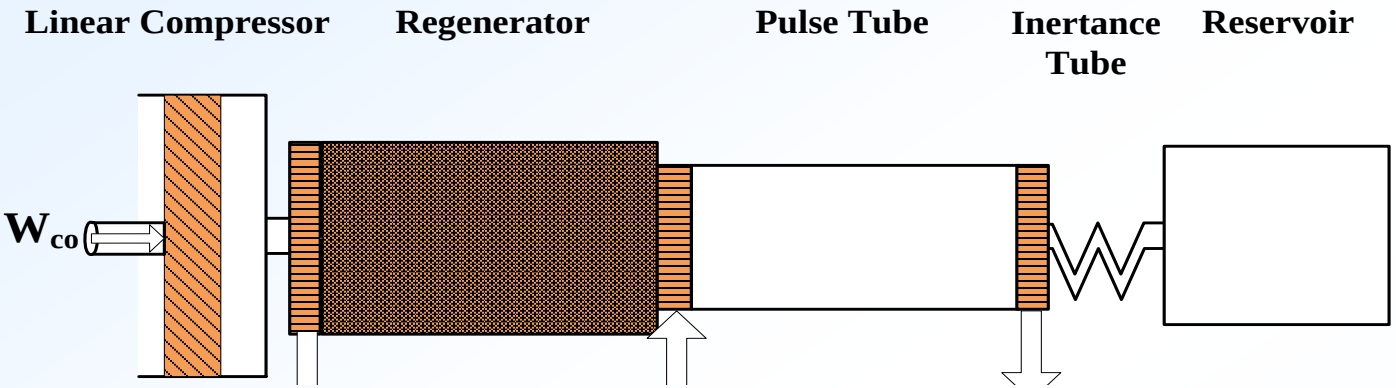
4 K Stirling type
Pulse Tube Cryocooler (SPTC) (30Hz)

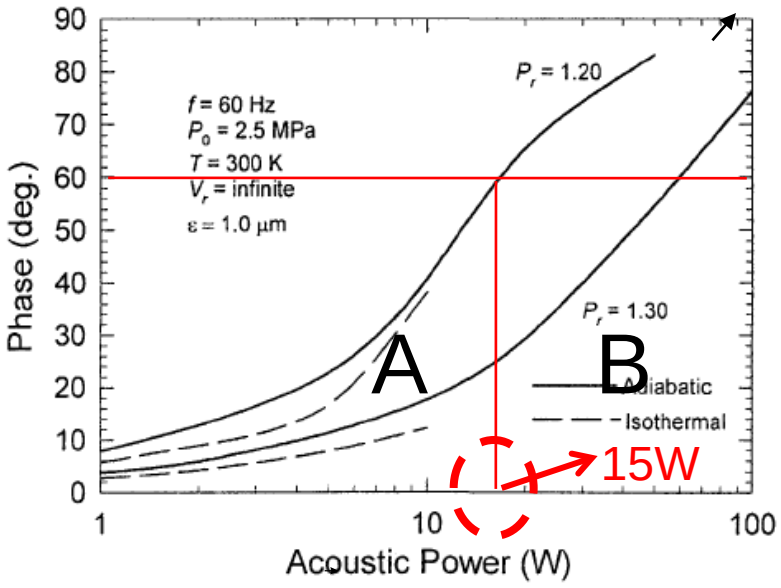
–Compact structure
–Light weight
–High reliability
–Potentially high efficiency
(Linear compressor, 80%)
–5y MTTF, no maintenance

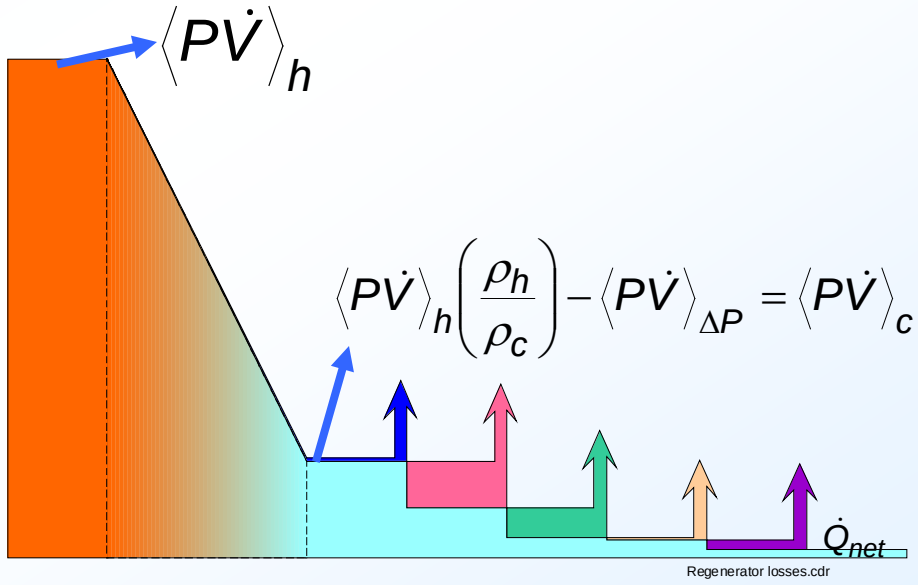


Stirling type Pulse Tube

Phase shifters for Stirling type Pulse Tube Cryocooler

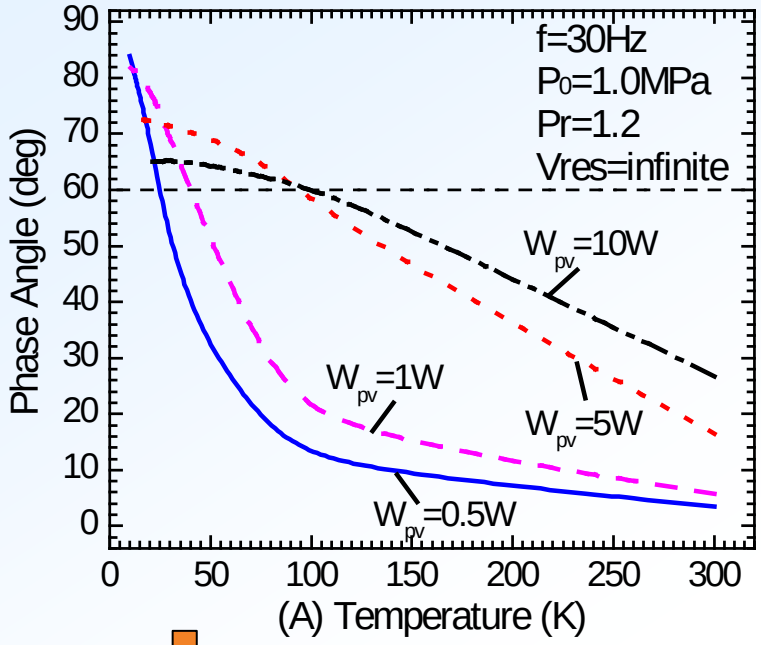


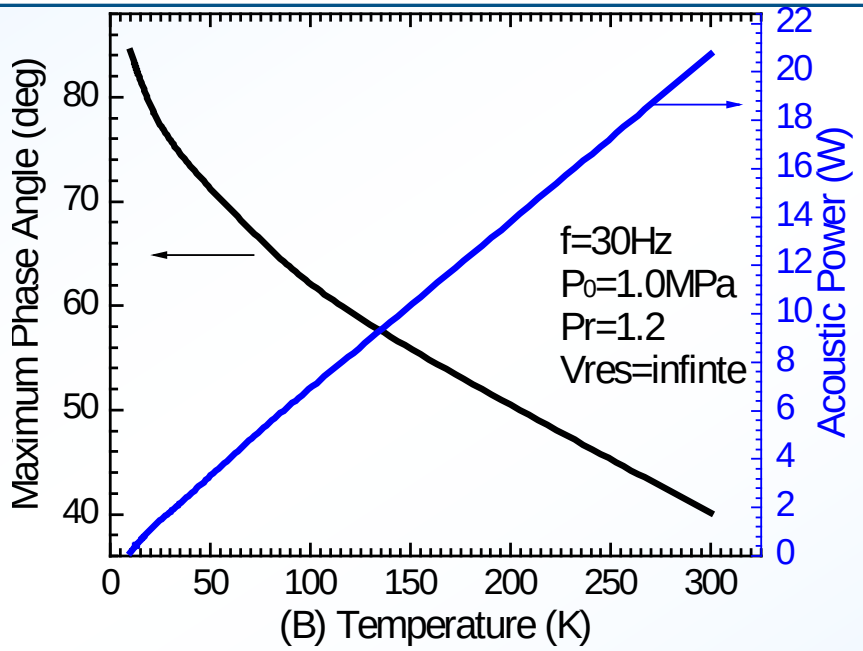


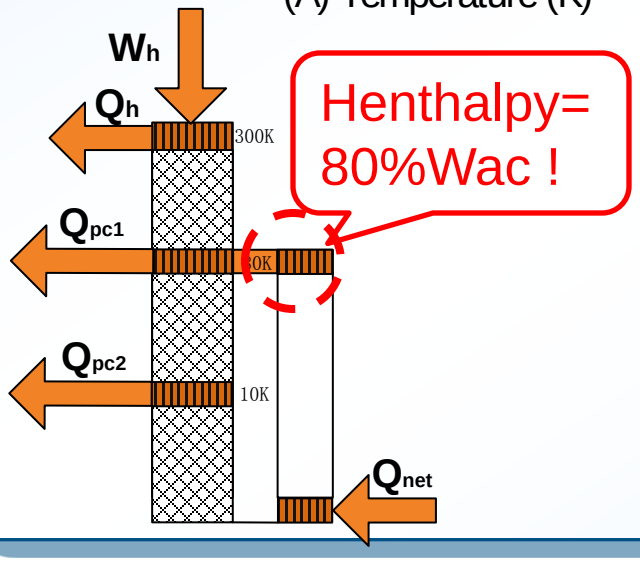


Radebaugh R., Lewis M., Luo E.C., et al. Inertance tube optimization for pulse tube refrigerators[C]. Advances in Cryogenic Engineering. New York: AIP, 2006, 51: 59-67

Cold Inertance Tube







Henthalpy= 80%Wac !

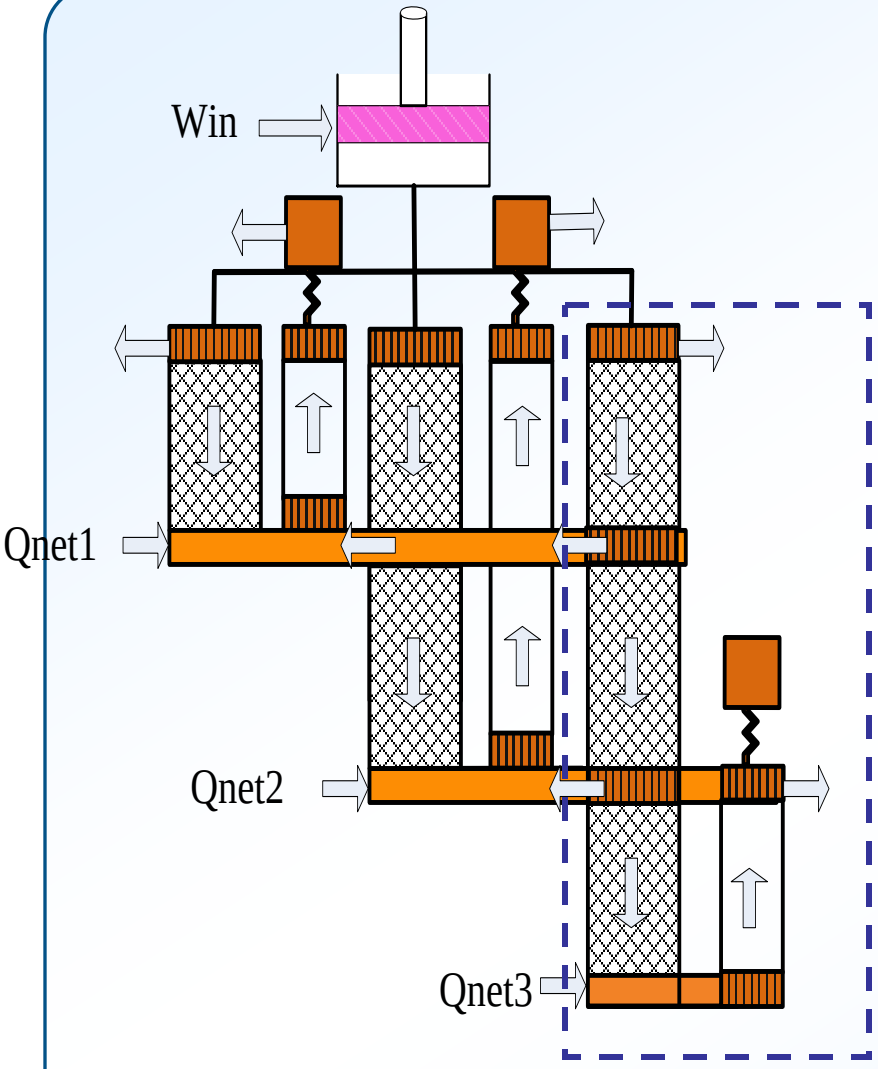
Advantage

Large phase shift with small acoustic power

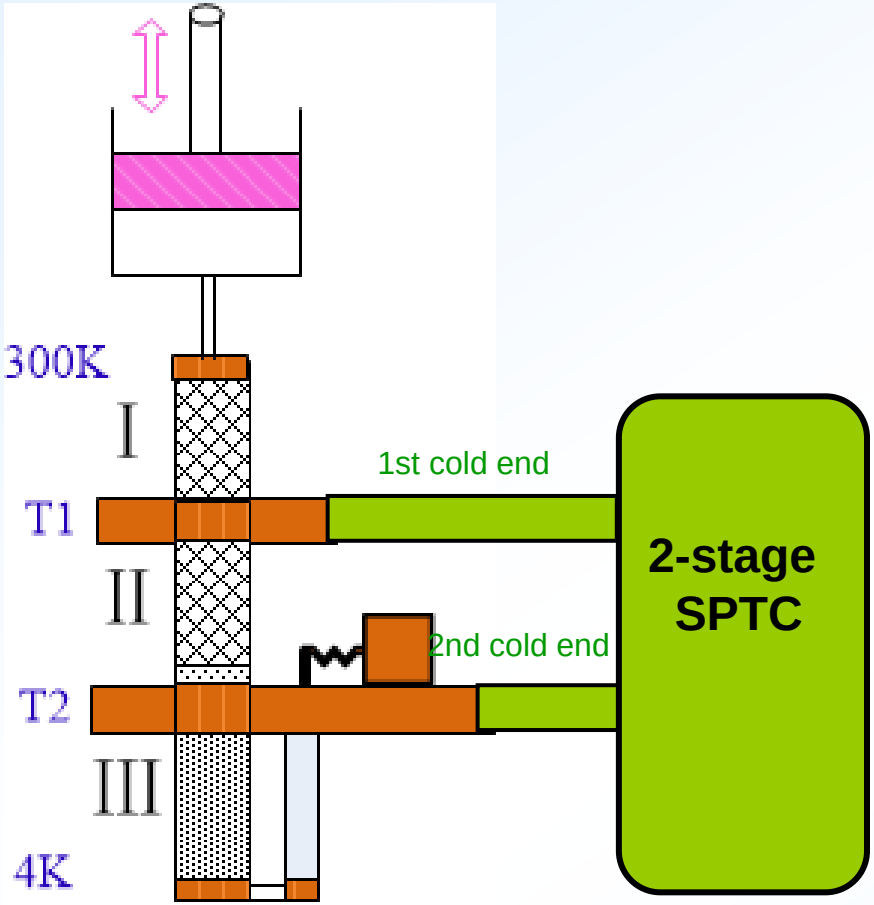
Disadvantage:

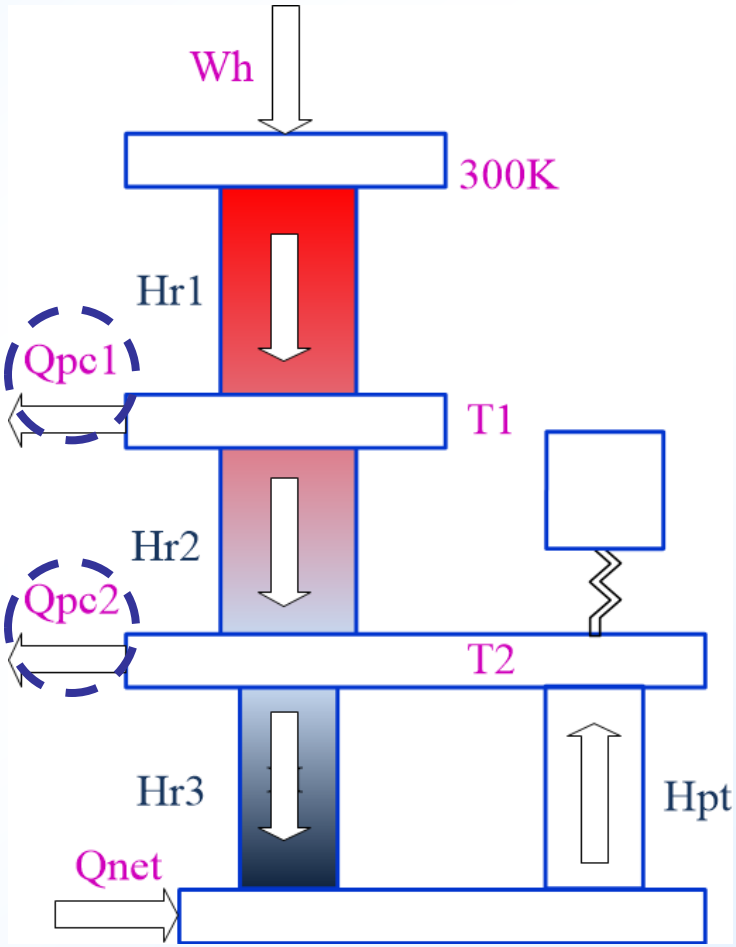
Additional heat load to the regenerator

Calculation Model



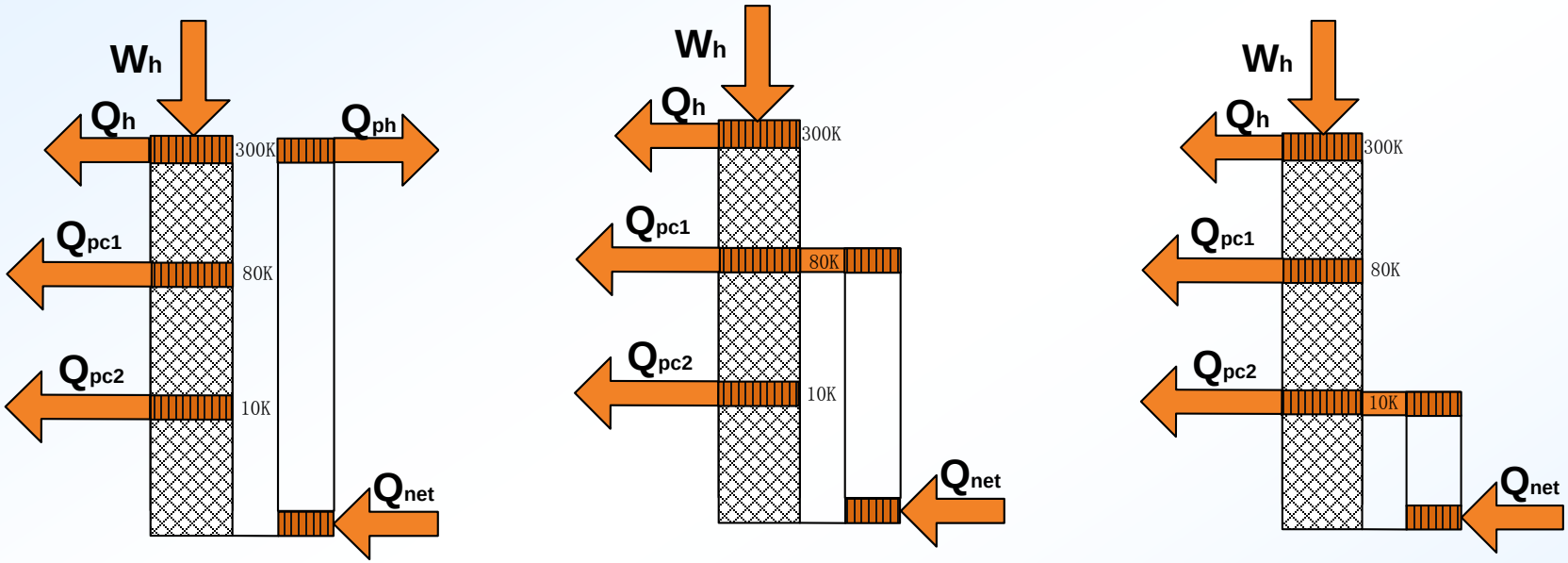
Calculation Model





When should a cold inertance tube be used?

The decrease of Qreg > <H>pt∝<Wpv>c



(a) 300 K inertance tube (b) 80 K inertance tube (c) 10 inertance tube K

Acoustic power at cold end

0.1W, 0.5W, 1W, 5W

?

Temperature of Inertance Tube

300K,80K,10K

Calculating Parameters with REGEN 3.3

Main parameters used in the numerical calculation for the 4K SPTC with inertance tube.

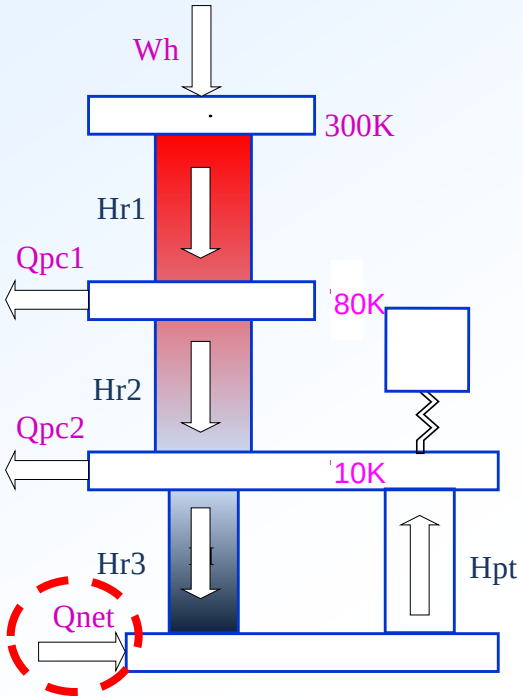
regenerator	Tc（K）	Th（K）	0.1W		0.5W		1W		5W		L (mm)
			Ag（cm^2）	mc（g/s）	Ag（cm^2）	mc（g/s）	Ag（cm^2）	mc（g/s）	Ag（cm^2）	mc（g/s）	
I	80	300	0.37108	-	1.8554	-	3.7108	-	18.554	-	30
II	10	80	0.37108	-	1.8554	-	3.7108	-	18.554	-	25
III	4	10	0.22998	0.3	1.1499	1.5	2.2998	3	11.499	15	30

The size of the 4K Stirling type pulse tube cryocooler is magnefied by a fixed ratio (Ag/mc=0.3cm2-g/s)

Ag-cross section area of gas helium mc-mass flow at cold end

Effect of temperature of inertance tube on performance of 4K SPTC

a



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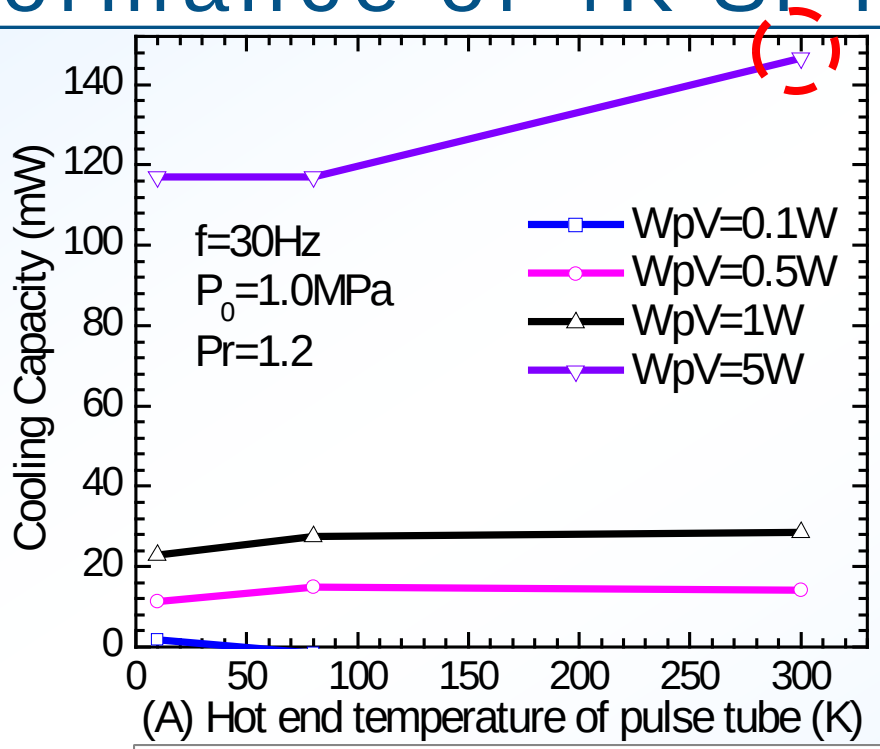

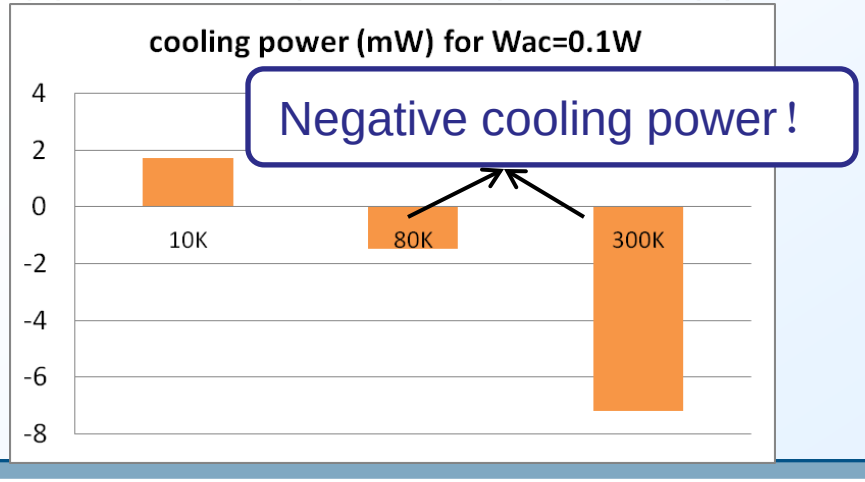

Effect of temperature of inertance tube on performance of 4K SPTC

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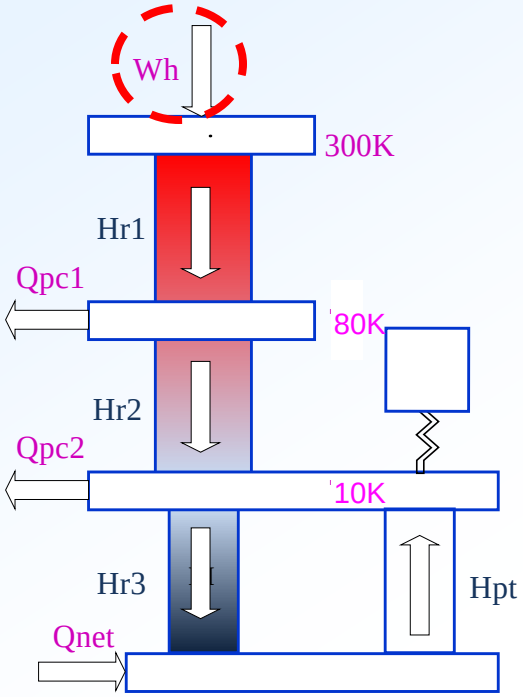

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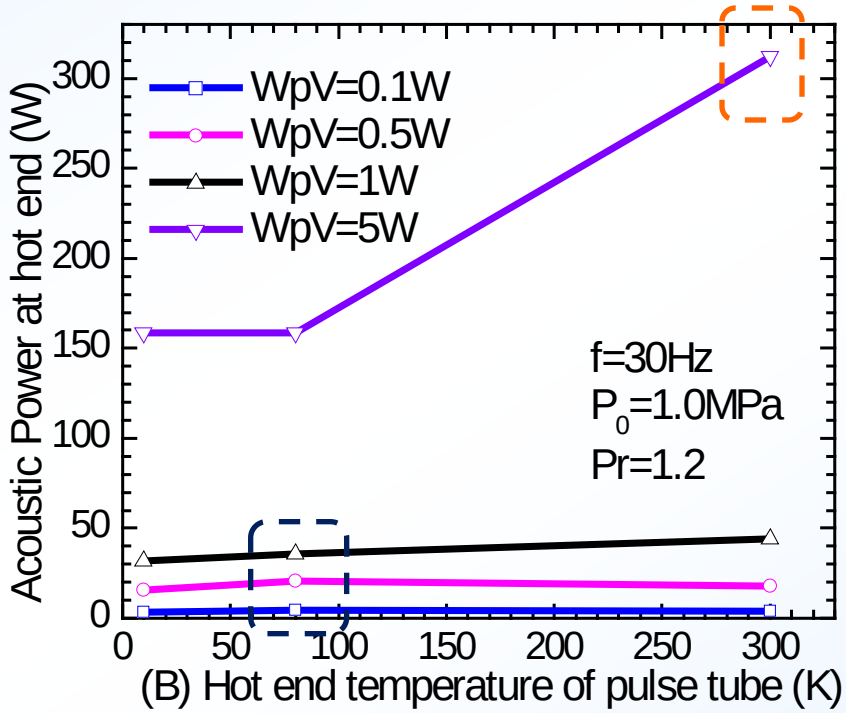
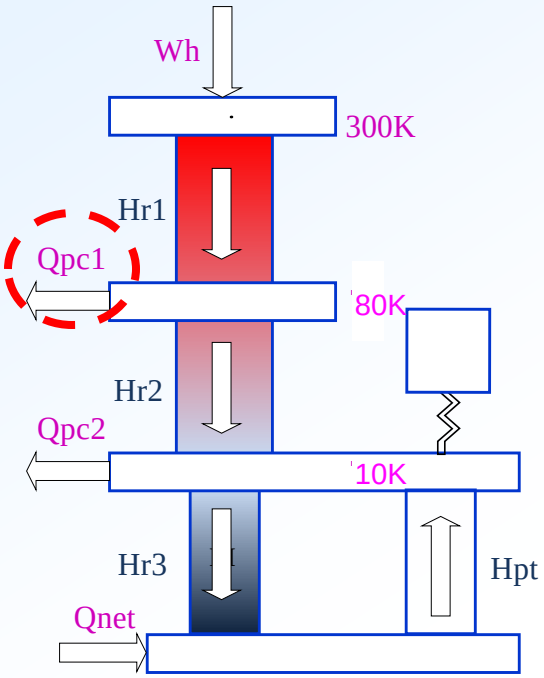
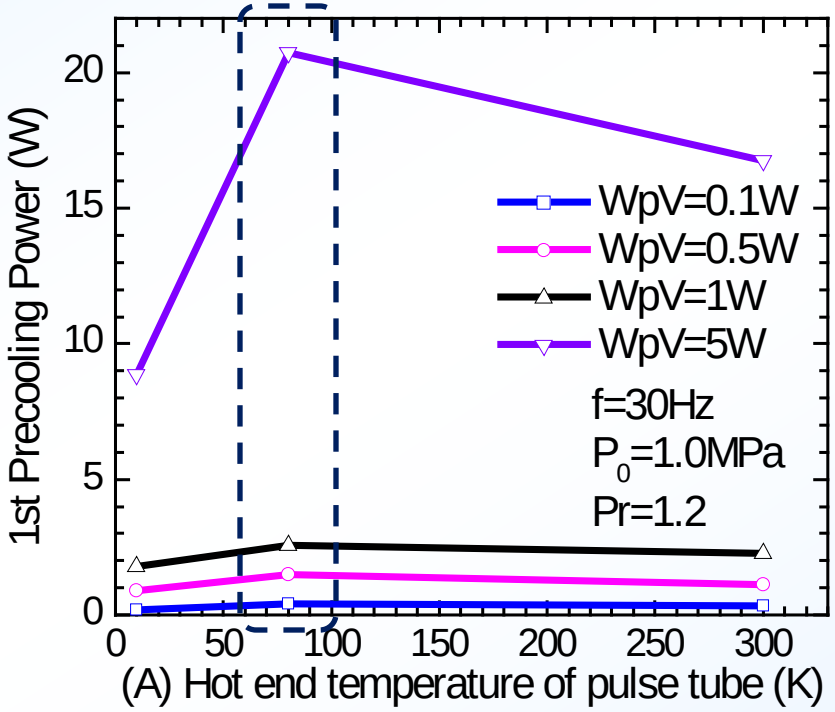


Effect of temperature of inertance tube on precooling powers

a b



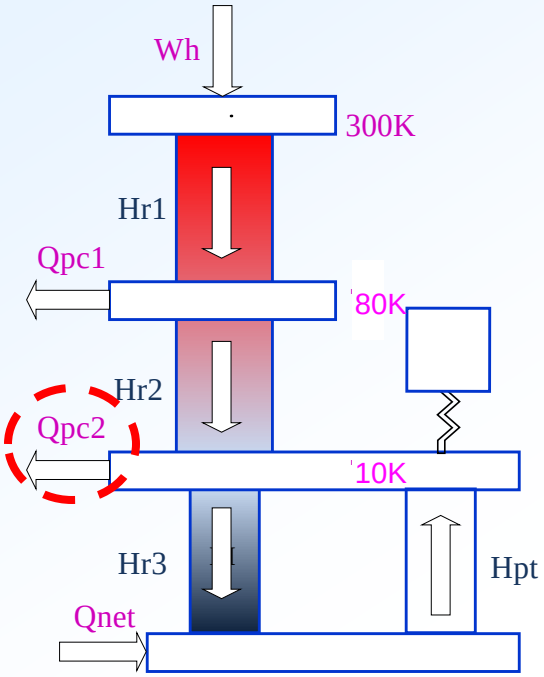


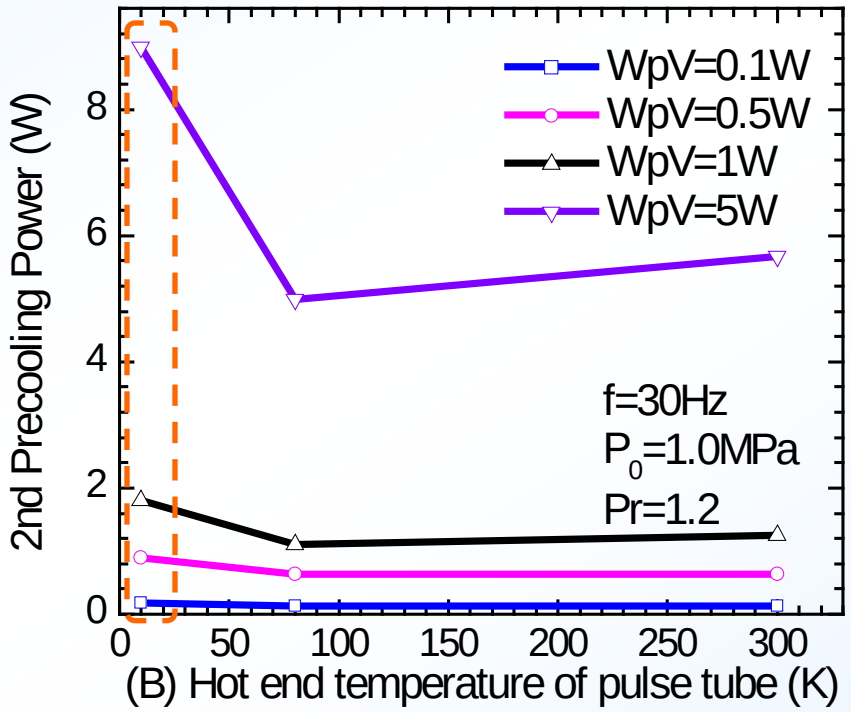
First precooling power: $Q_{pc1}=H_{r1}-H_{r2}$

The enthalpy in the pulse tube is dissipated to the 80K precooler

Effect of temperature of inertance tube on precooling powers

a b

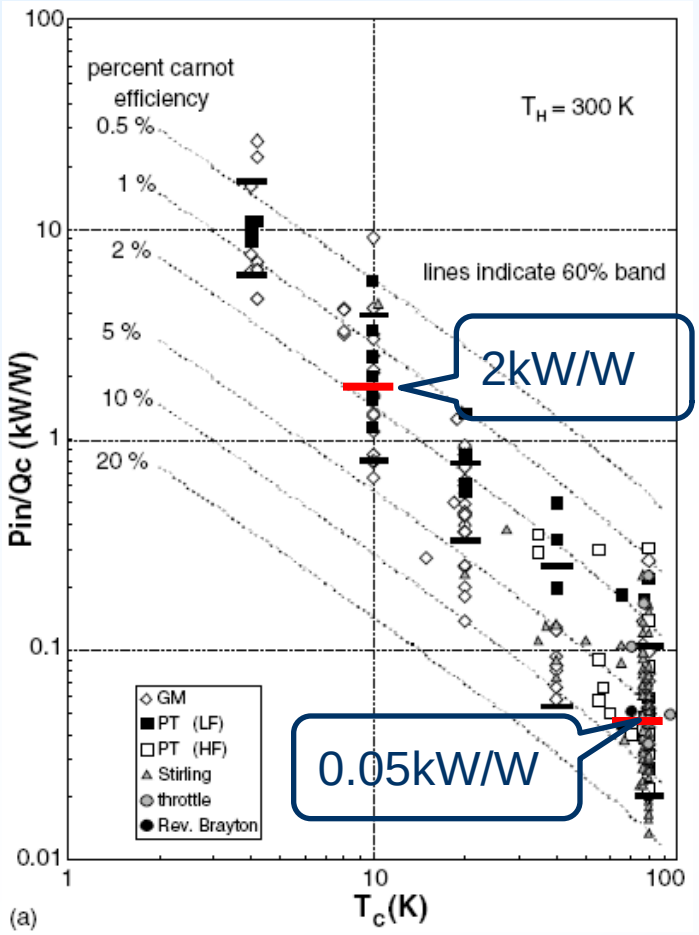




Second precooling power: $Q_{pc2}=H_{r2}-H_{r3}$

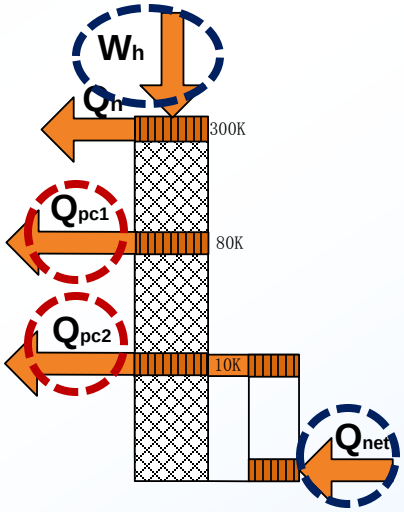
Evaluation of the 4K SPTC system with precooling

How to evaluate the whole system with a precooler?



Qpc1 ⇨ Wpc1

Qpc2 ⇨ Wpc2



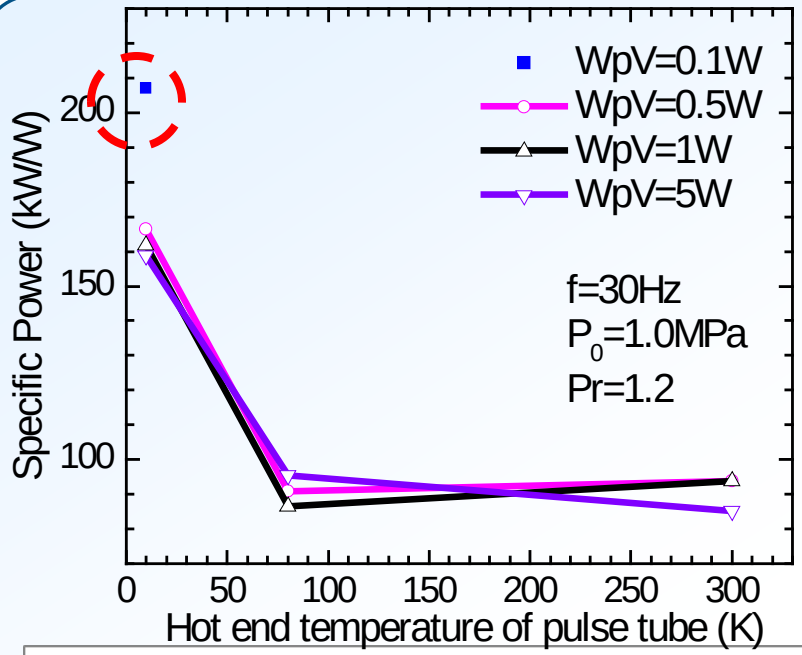
Transforming the precooling power into Compressor input power by specific power

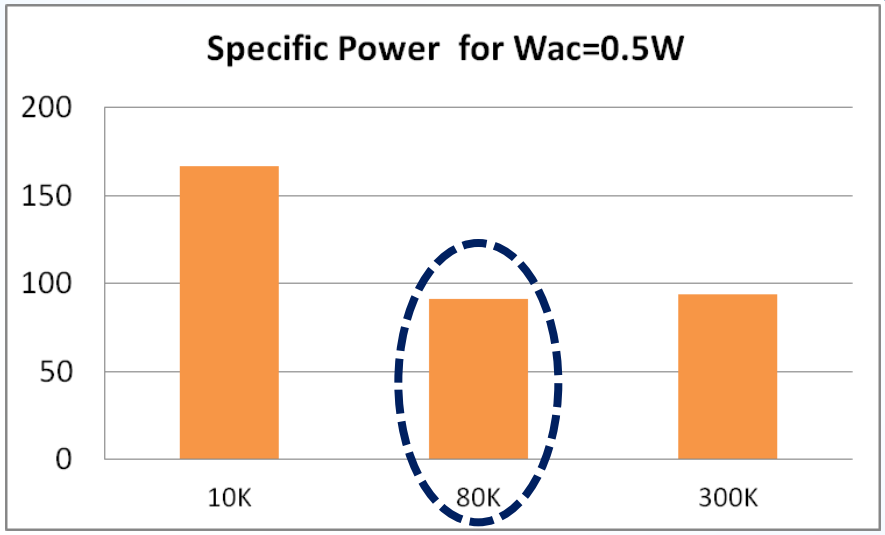
$$COP = \frac{Q_{net}}{W_{tot}} = \frac{Q_{net}}{W_{precooling} + W_{sptc}} = \frac{Q_{net}}{W_{precooling1} + W_{precooling1} + W_{sptc}}$$

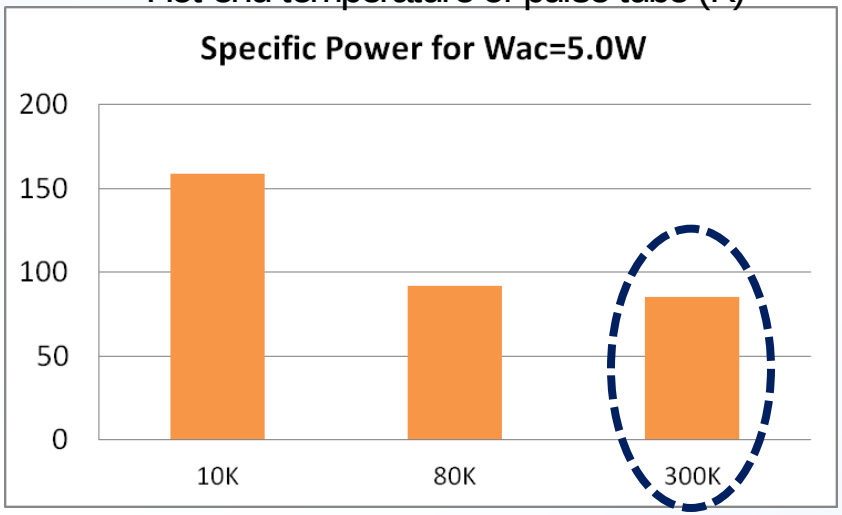
$$= \frac{Q_{net}}{50 \times Q_{precooling1} + 2000 \times Q_{precooling1} + W_{sptc}}$$

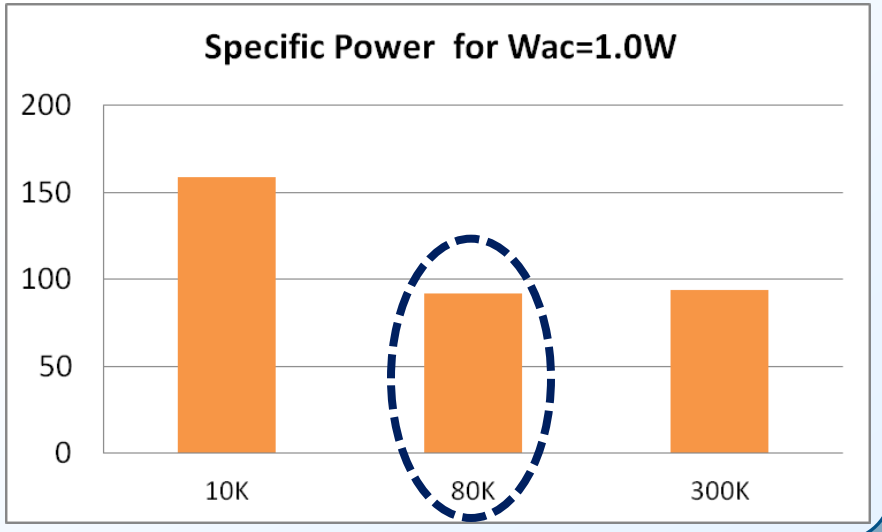
ter Brake, H.J.M., Wiegerinck, G.F.M., Low-power cryocooler survey. Cryogenics, 2002. 42(11): p. 705-718

Effect of temperature of inertance tube on specific power of 4 K SPTC system









Summary

- A 4K SPTC with inertance tube at different temperature regions with different acoustic powers at the cold end is calculated.
- 10K cold inertance tube should be used for a 4K SPTC when Wac at the cold end is about 0.1W.
- 80K cold inertance tube would be a good choice when Wac is in the range of about 0.5W-1W.
- 300K inertance tube gives the maximum efficiency when Wac=5W.

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Thank You!