

时分复用SQUID室温电子学

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第二十一届全国核电子学与核探测技术学术年会



目录

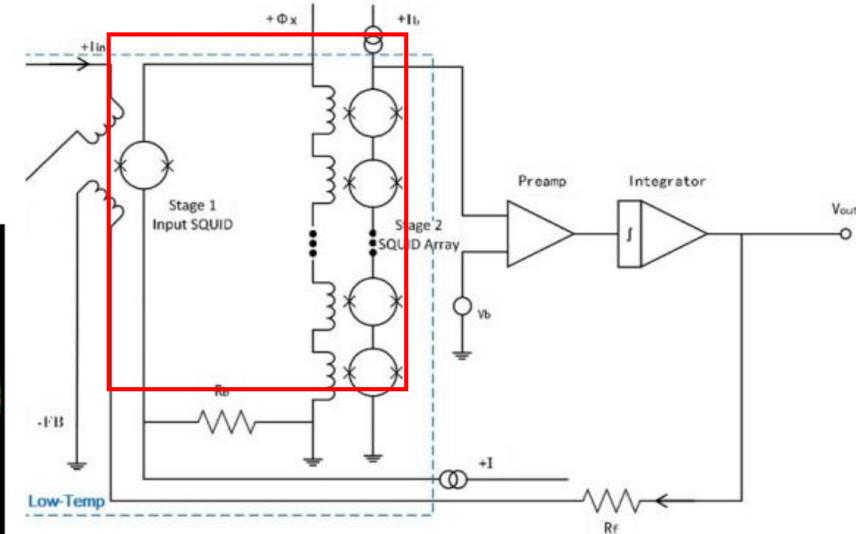
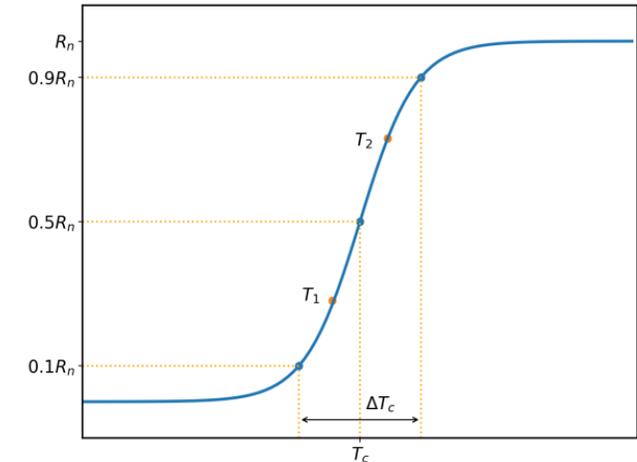
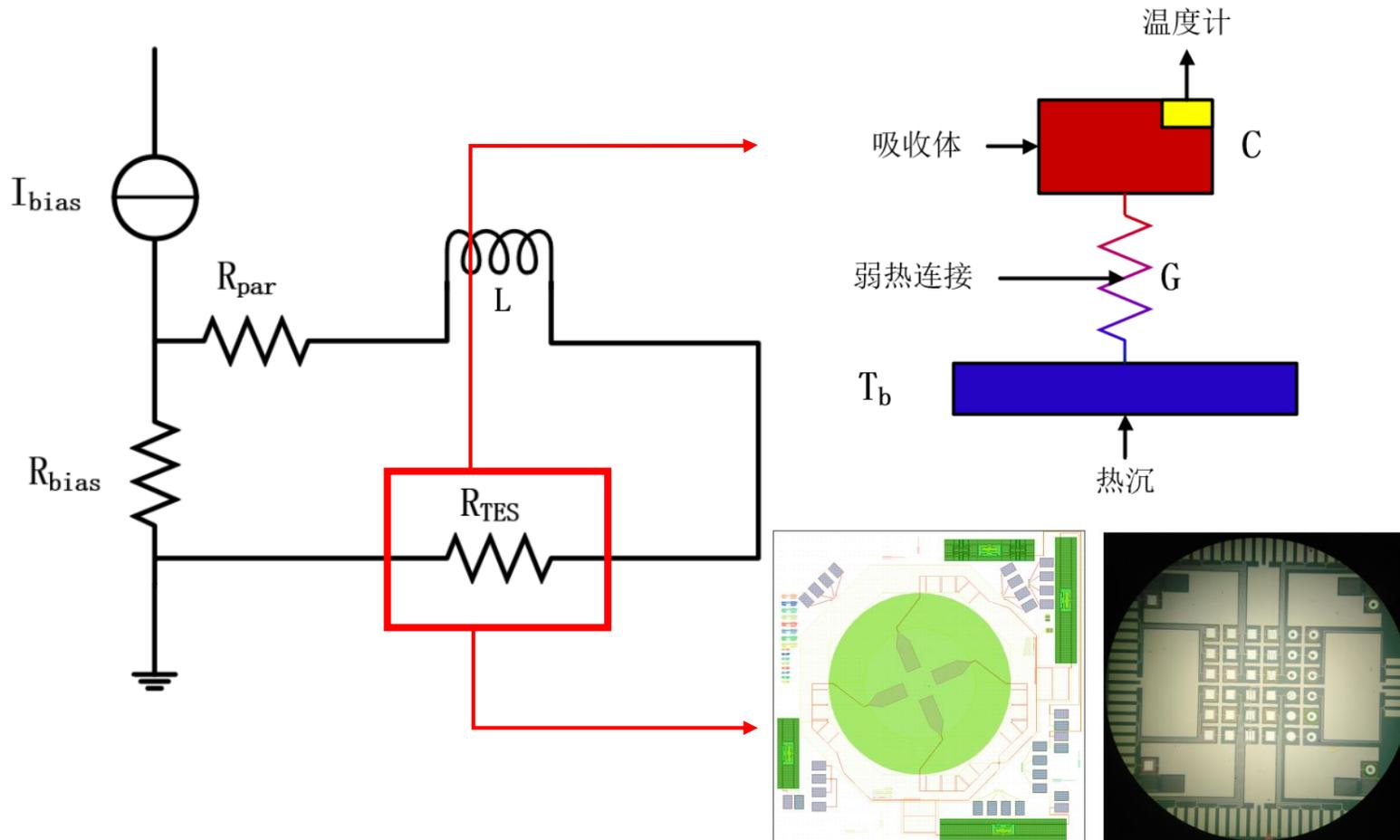
- 背景简介
- 两级SQUID电子学架构
- 时分复用SQUID电子学
- 状态进展
- 总结与展望

背景简介

◆ Transition-Edge Sensor (TES) 广泛用于

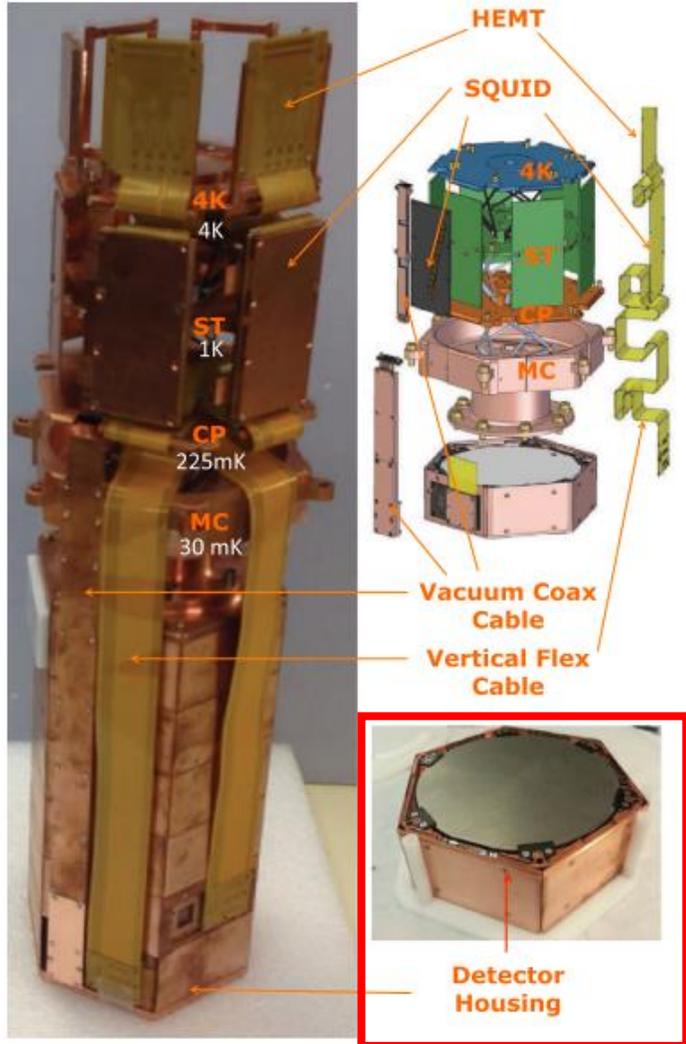
❖ 同步辐射/自由电子激光线站、微波背景辐射探测、暗物质/轴子/中微子探测

◆ Superconducting QUantum Interference Devices (SQUID) 低噪放大



背景简介

◆ TES Arrays & Microwave Multiplexing The *SuperCDMS* SNOLAB engineering tower



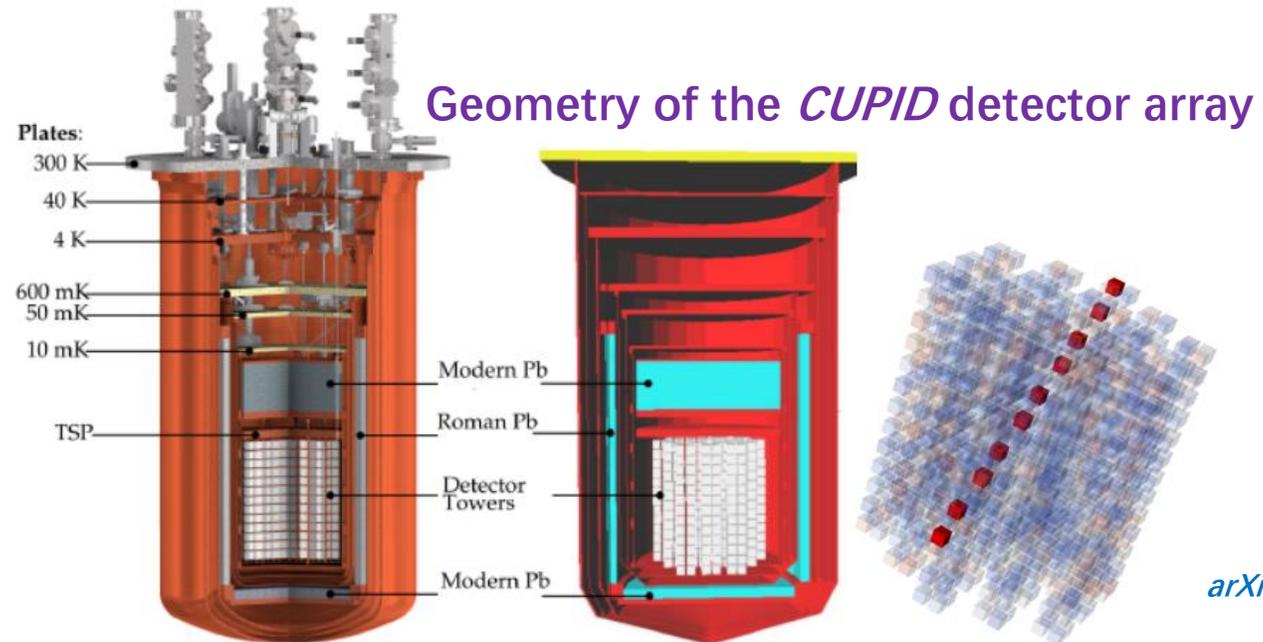
Al Kenany, S., et al. *J Low Temp Phys* 167 (2012): 1167-1172

NLS beamline U7A/*NLS-II*,,,,,, X-ray spectrometers

Abstract Time-division multiplexing (TDM) is a mature scheme for the readout of arrays of transition-edge sensors (TESs). TDM is based on superconducting-quantum-interference-device (SQUID) current amplifiers. Multiple spectrometers based on gamma-ray and X-ray microcalorimeters have been operated with TDM readout, each at the scale of 200 sensors per spectrometer, as has several astrophysical cameras with thousands of sub-mm or microwave bolometers. Here we present the details of two different versions of our TDM system designed to read out X-ray TESs. The first has

更多gamma、X射线谱仪集成TDM复用电子学

Dorise, William B., et al. J Low Temp Phys 184 (2016): 389-395.



Geometry of the *CUPID* detector array

arXiv:1907.09376v1

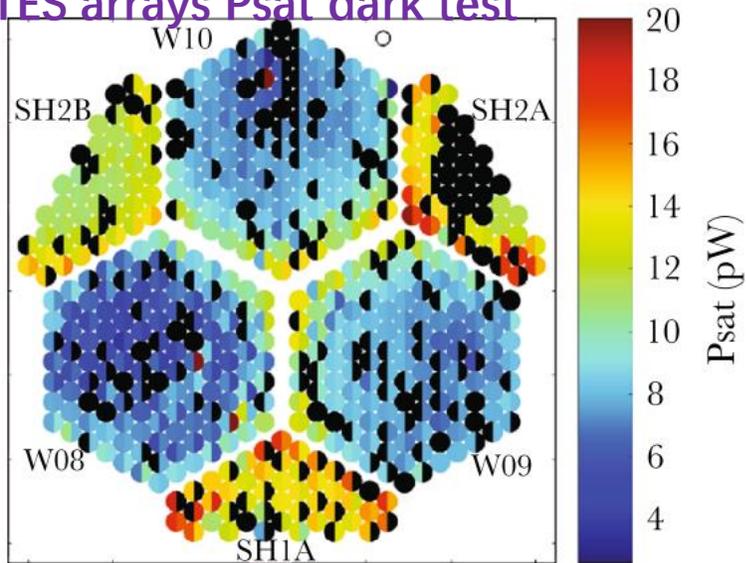
背景简介

◆ TES Arrays & Microwave Multiplexing

BICEP2 focal plane TES arrays



ACTPol TES arrays Psat dark test



Grace, E.A et al J Low Temp Phys 176, 705-711 (2014)

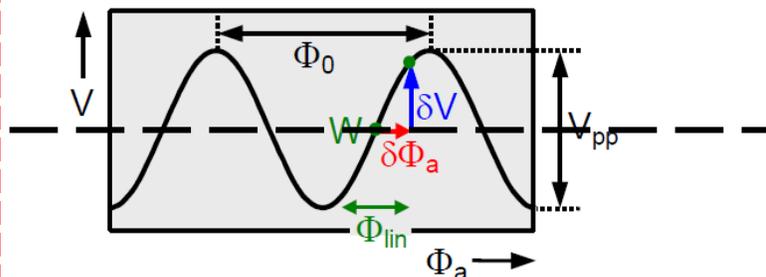
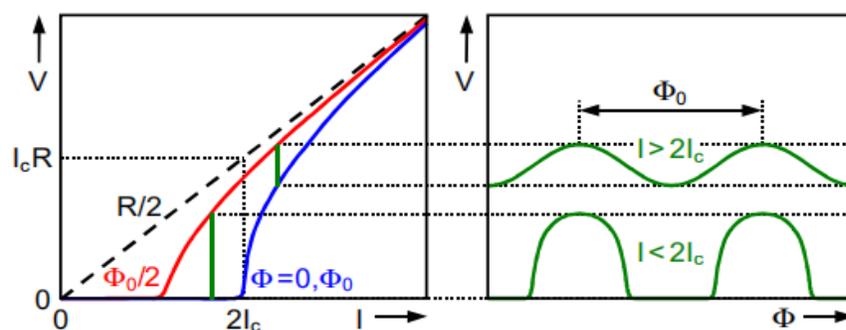
Cross section of the AliCPT-1 telescope



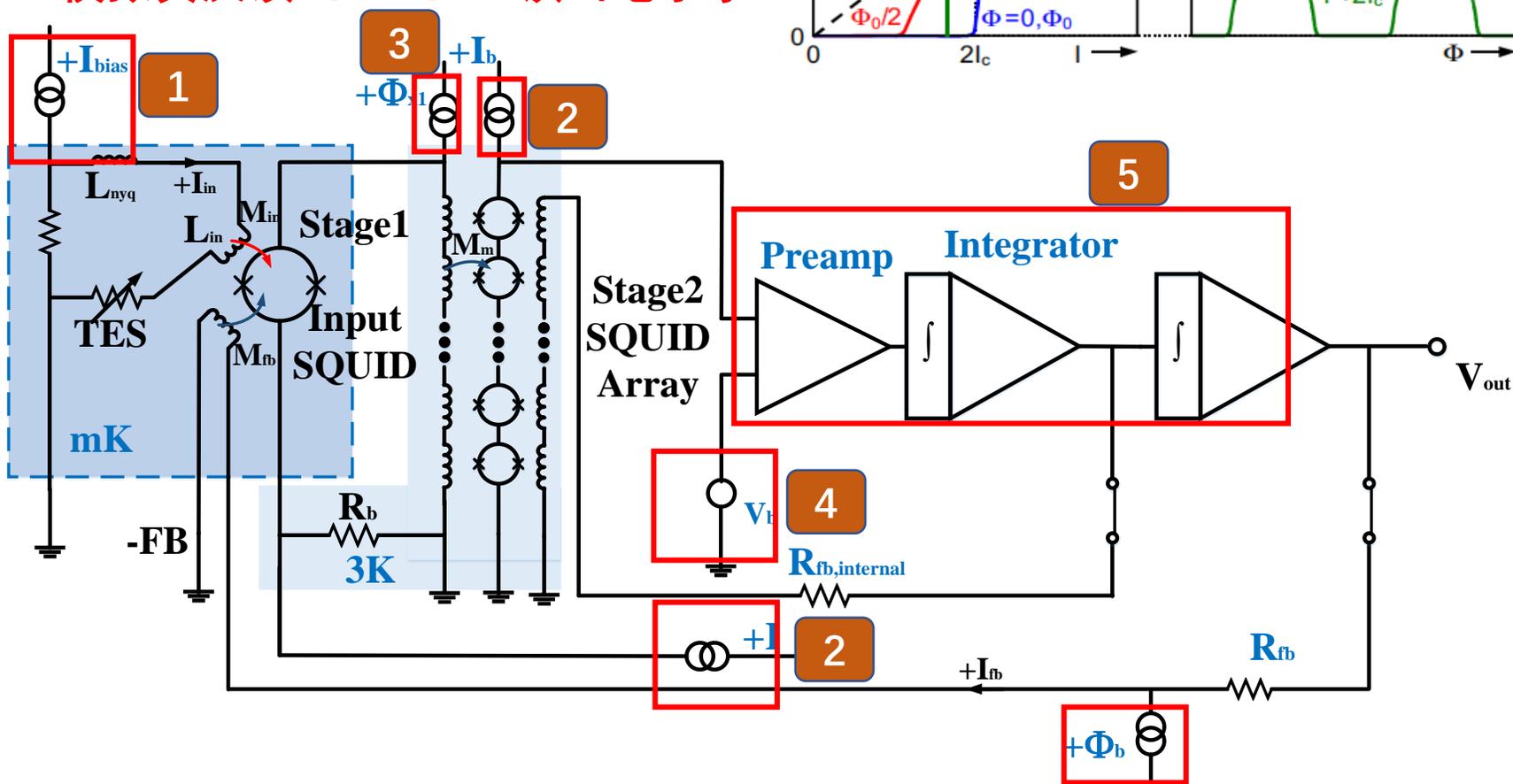
两级SQUID电子学架构

- ◆ TES/SQUID DC/AC/Flux 偏置
- ◆ 噪声 pA/\sqrt{Hz} 量级
- ◆ 模拟负反馈 (AFB) + 读出电子学

通过调节输入直流偏置，找到最佳工作区域



Flux偏置，使得锁定在线性度最好的位置



室温电子学系统

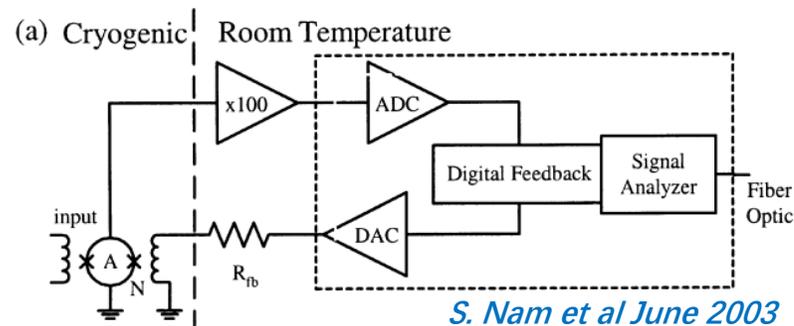
TES bias	1
SQUID/S-Arrays bias	2
SQUID/S-Arrays Flux offset	3
Amplifier DC offset	4
AFB	5
DAQ	

时分复用SQUID电子学

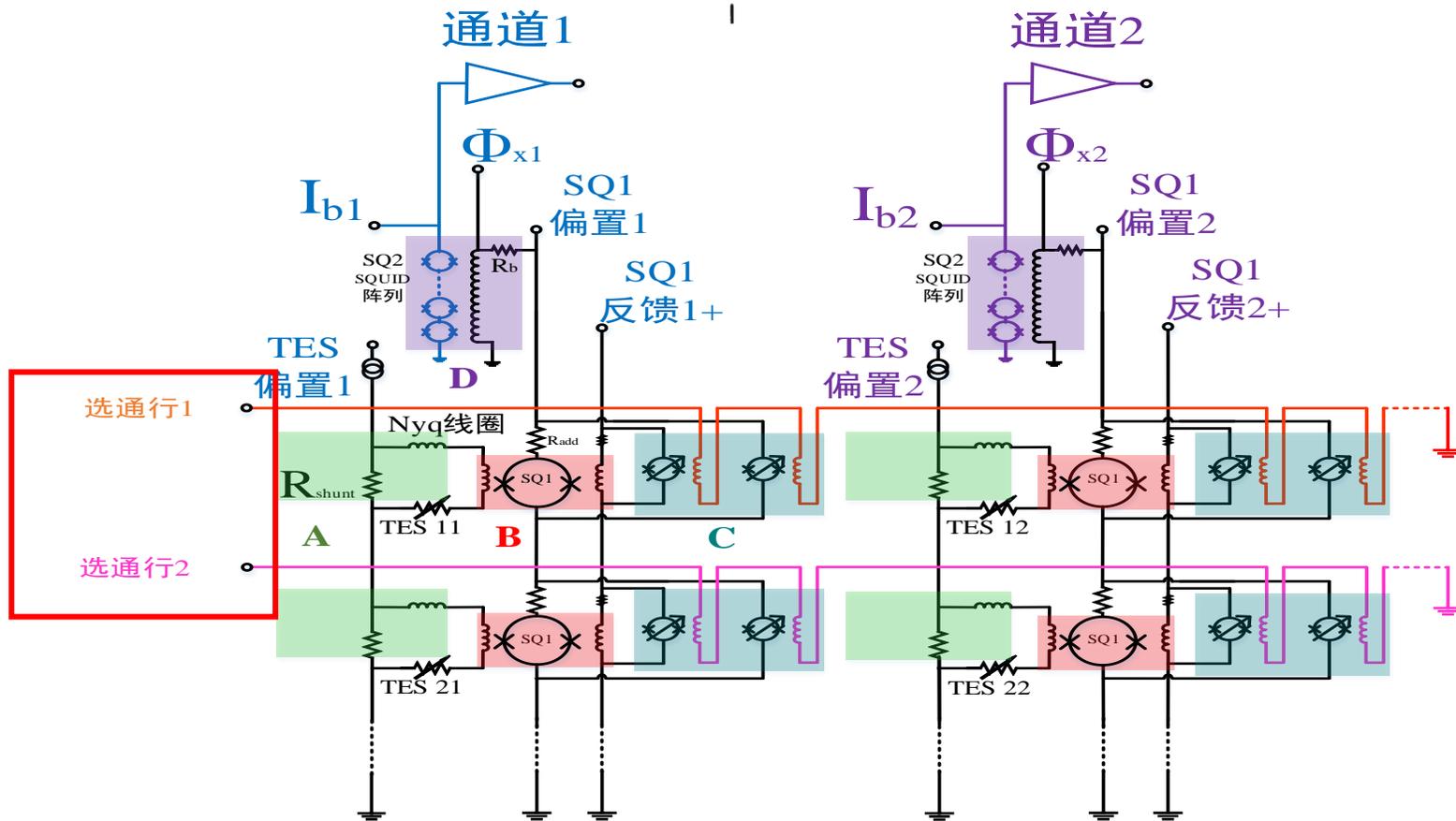
◆ Time-Division Multiplexing SQUID (TDM)

◆ 选通逻辑，复用比 20:1

◆ 数字负反馈 (DFB) + 读出电子学

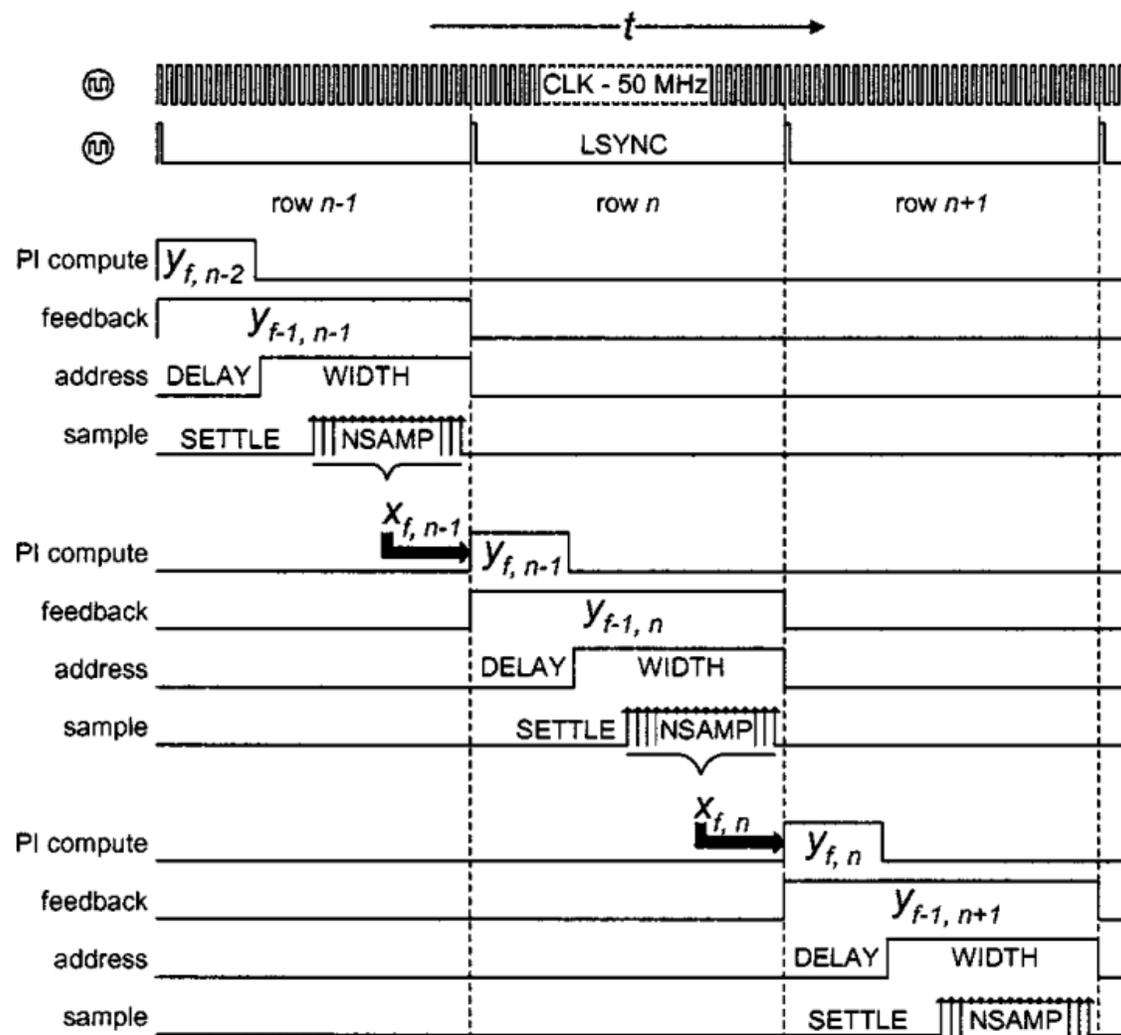
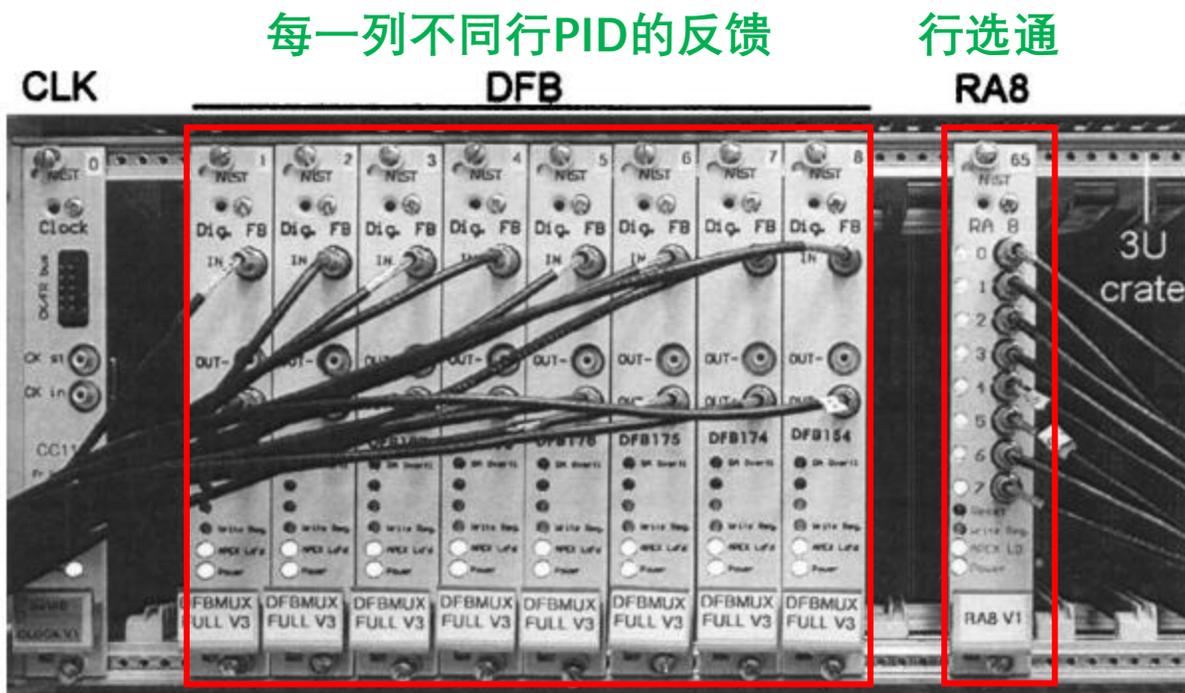


室温电子学系统
TES bias
SQUID/S-Arrays bias
SQUID/S-Arrays Flux offset
Amplifier DC offset
DFB/DAQ
Multiplex (Mux) logic
Time SYNC



时分复用SQUID电子学

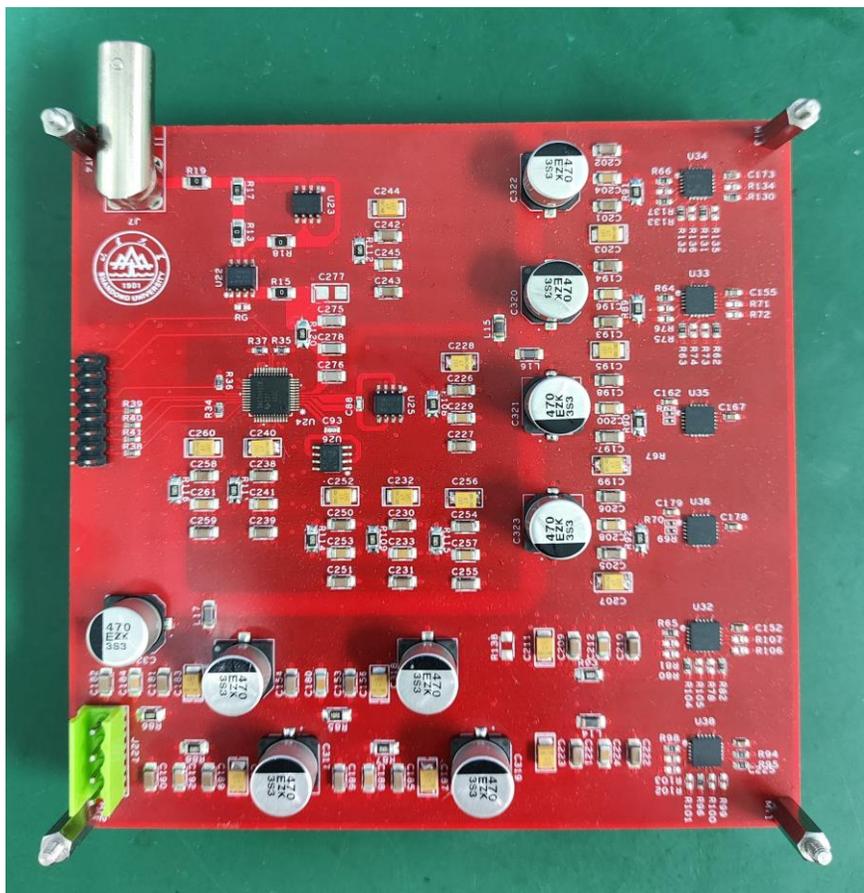
- ◆ 时分复用SQUID (TDM)
- ◆ 选通逻辑
- ◆ 数字负反馈 (DFB) + 读出电子学



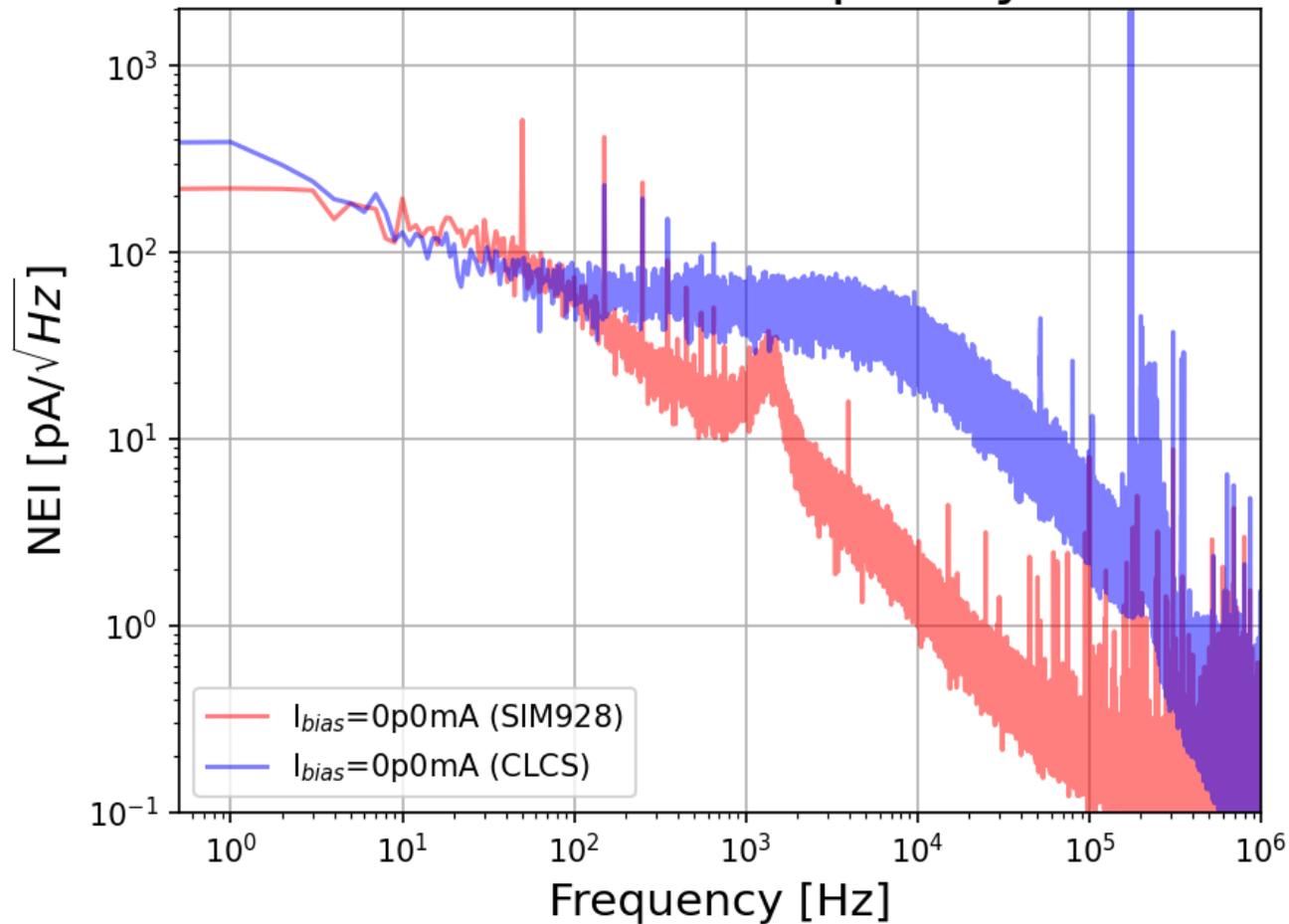
Review of Scientific Instruments 74, 4500 (2003)

可配置低噪声电流源 (CLCS)

◆ TES/SQUID 可配置低噪声直流源

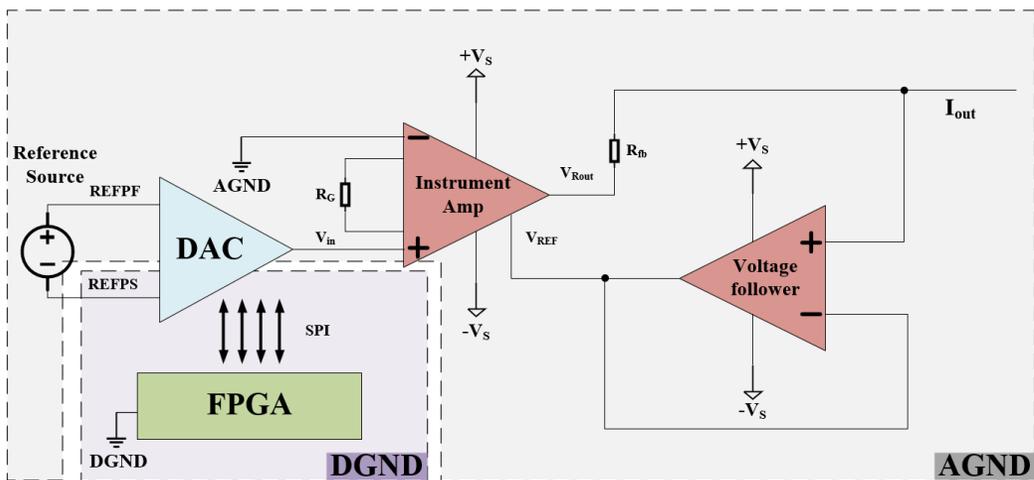


Bias Source Noise (Frequency Domain)

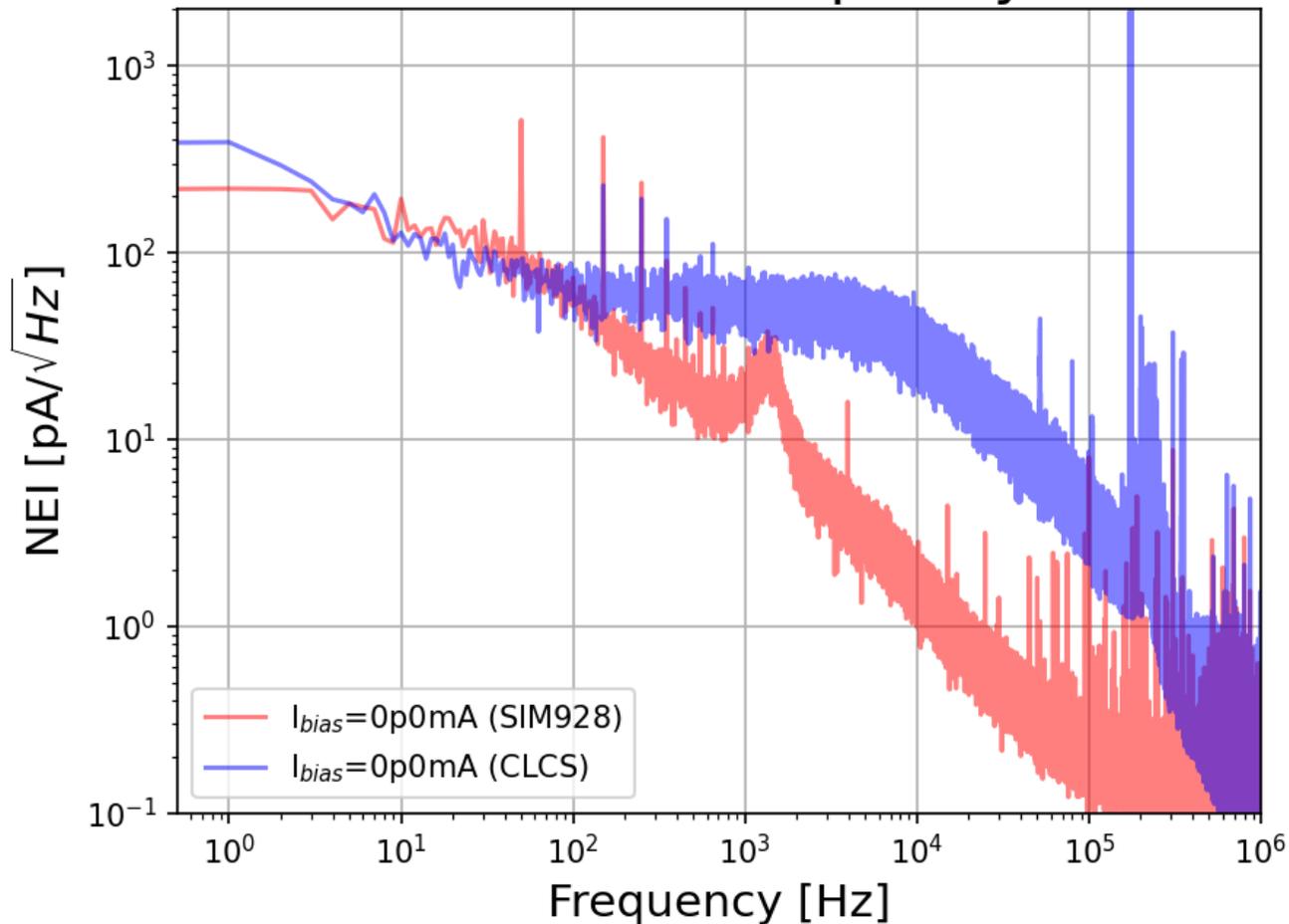


可配置低噪声电流源 (CLCS)

◆ TES/SQUID 可配置低噪声直流源

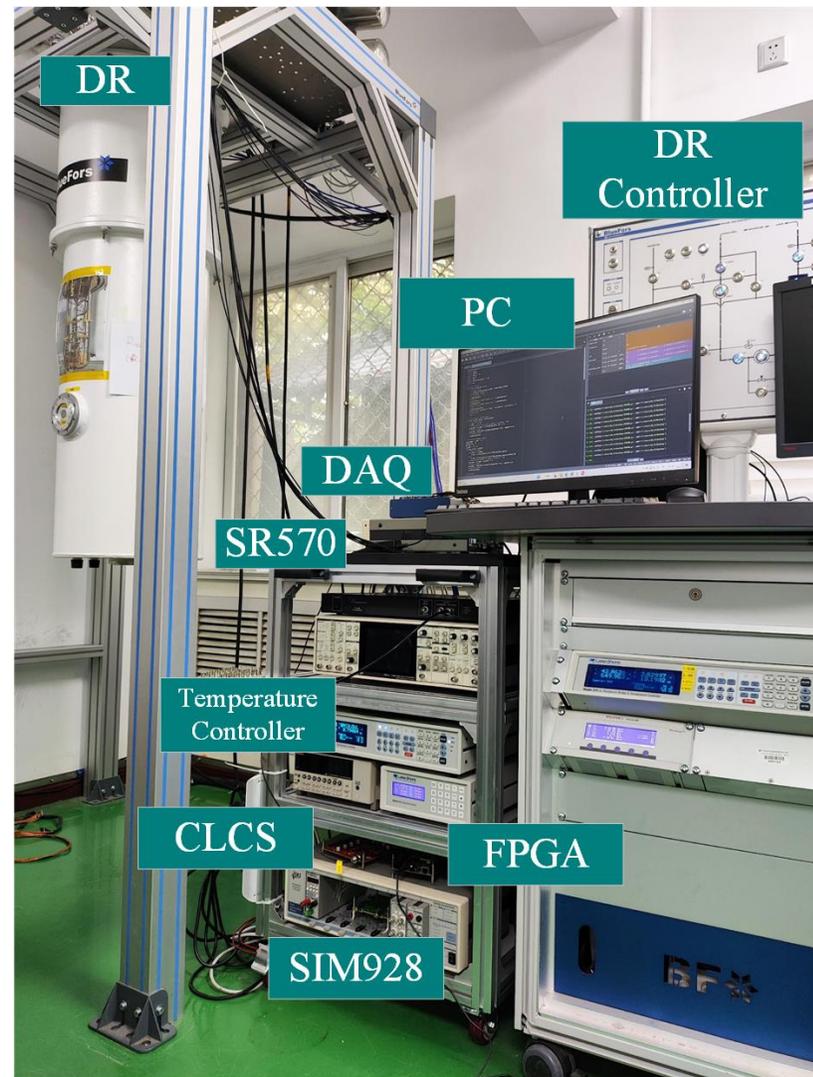
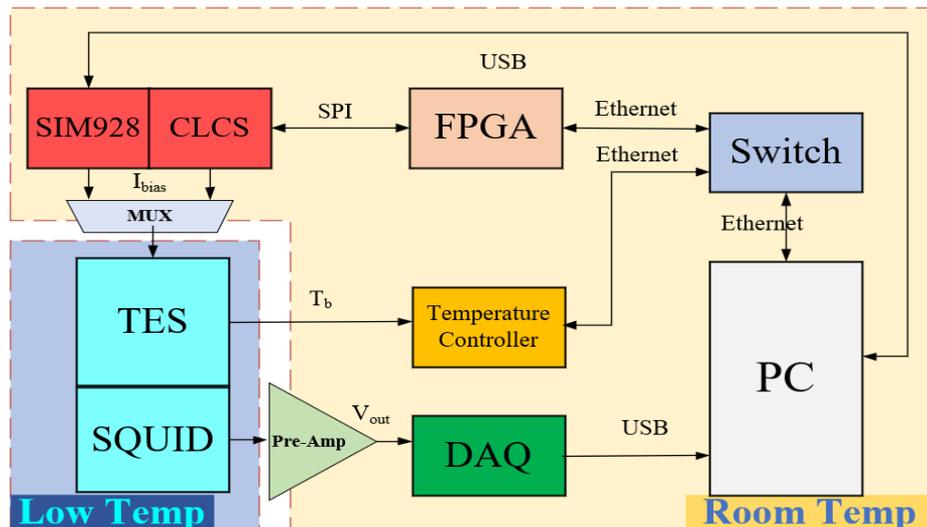
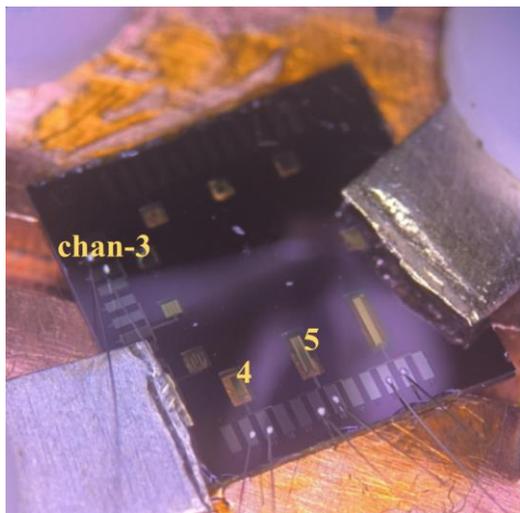


Bias Source Noise (Frequency Domain)

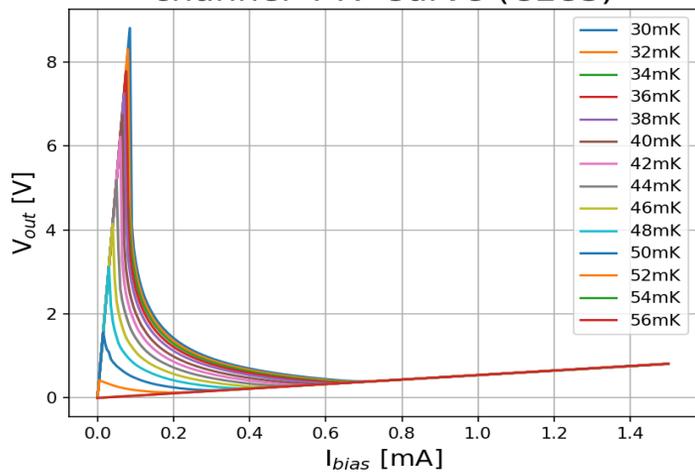


可配置低噪声电流源 (CLCS)

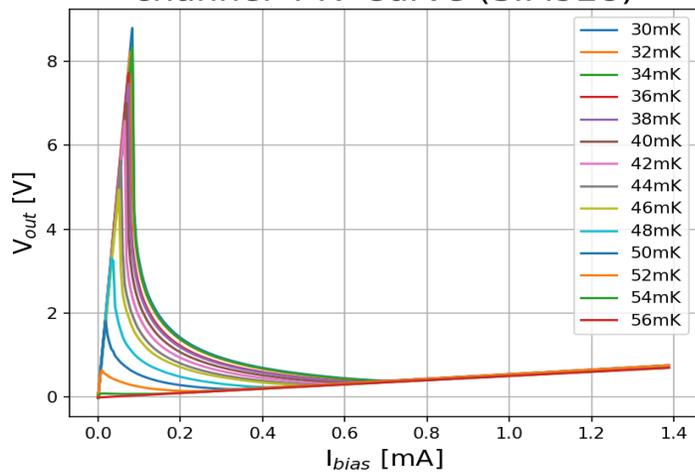
◆借助TES测试实用性表现



channel 4 IV Curve (CLCS)

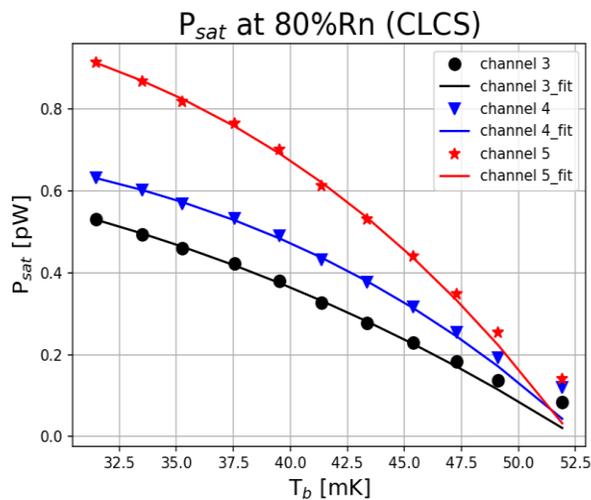
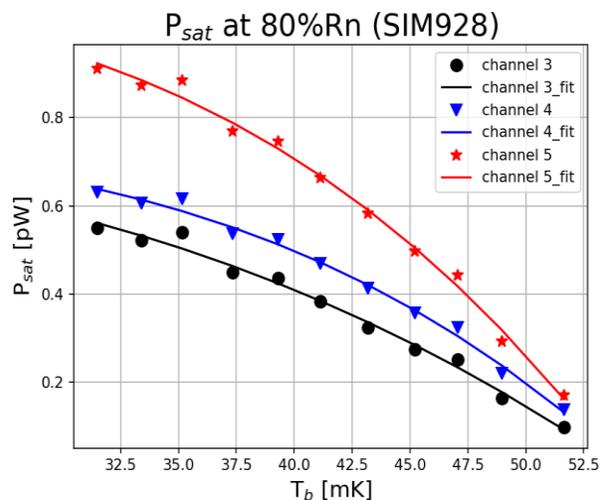
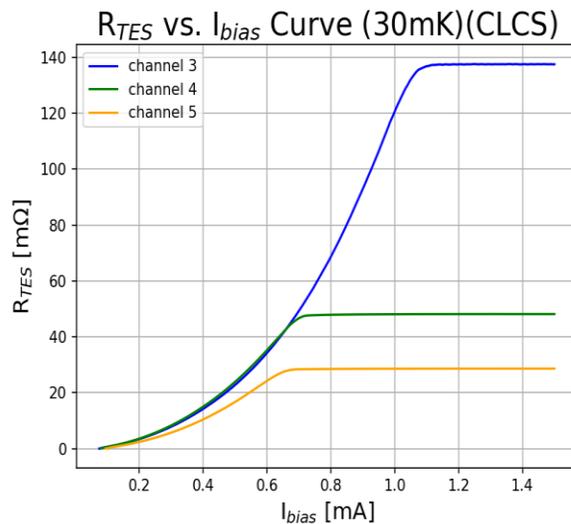
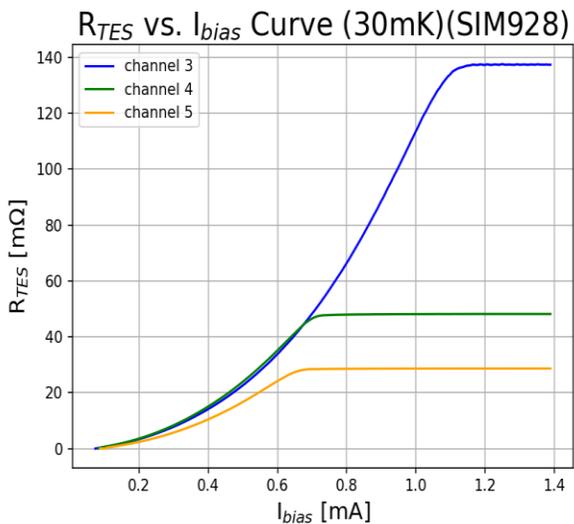


channel 4 IV Curve (SIM928)



可配置低噪声电流源 (CLCS)

◆借助TES测试实用性表现



$$P_{sat} = K (T_c^n - T_{bath}^n)$$

$$G = \frac{dP_{sat}}{dT_c} = nKT_c^{n-1}$$

SIM928	Channel 3	Channel 4	Channel 5
Gain (V/A)	105950.94	105841.68	105583.24
Rn (mΩ)	137.42	48.18	28.66
G [pW/K]	36.192	48.662	69.701
n	2.699	3.575	3.456
Tc [mK]	54.309	54.551	54.108

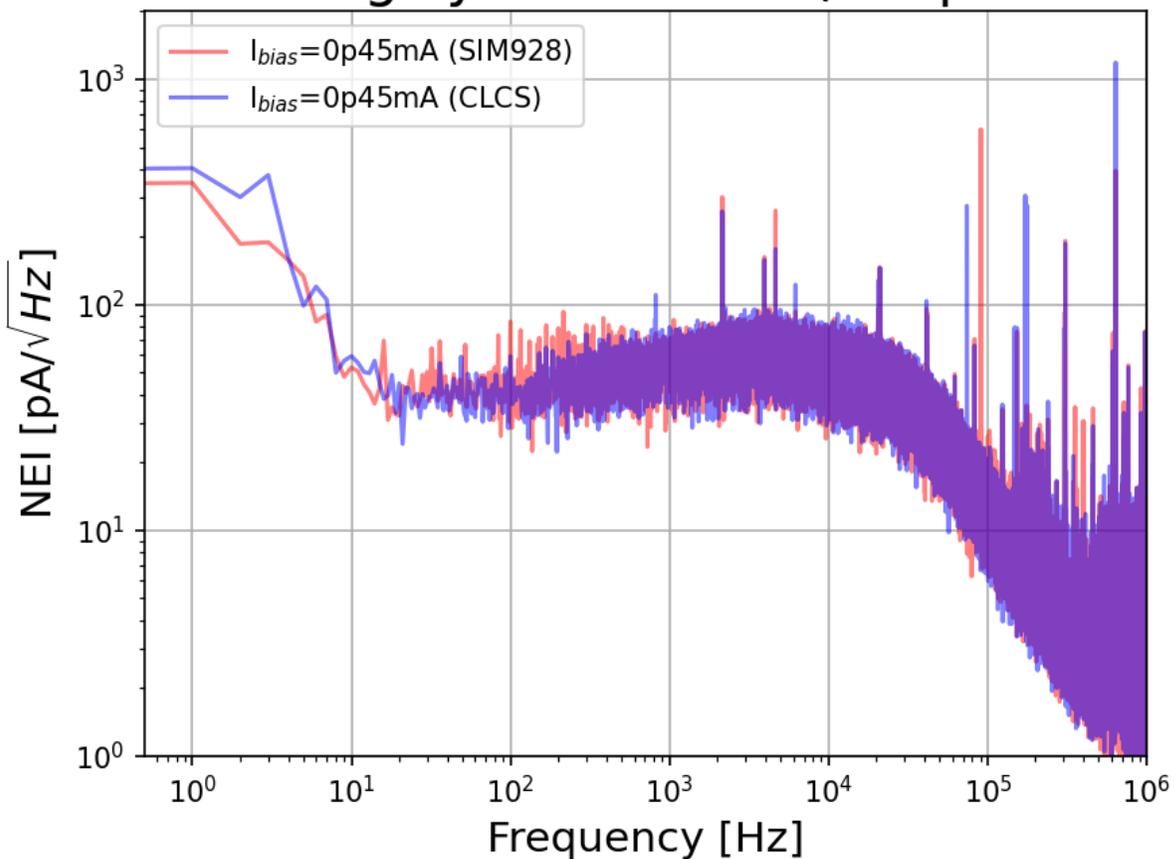
CLCS	Channel 3	Channel 4	Channel 5
Gain (V/A)	103843.93	103692.65	103428.36
Rn (mΩ)	136.87	48.13	28.63
G [pW/K]	35.347	51.005	74.506
n	2.559	3.604	3.585
Tc [mK]	52.517	52.787	52.357

可配置低噪声电流源 (CLCS)

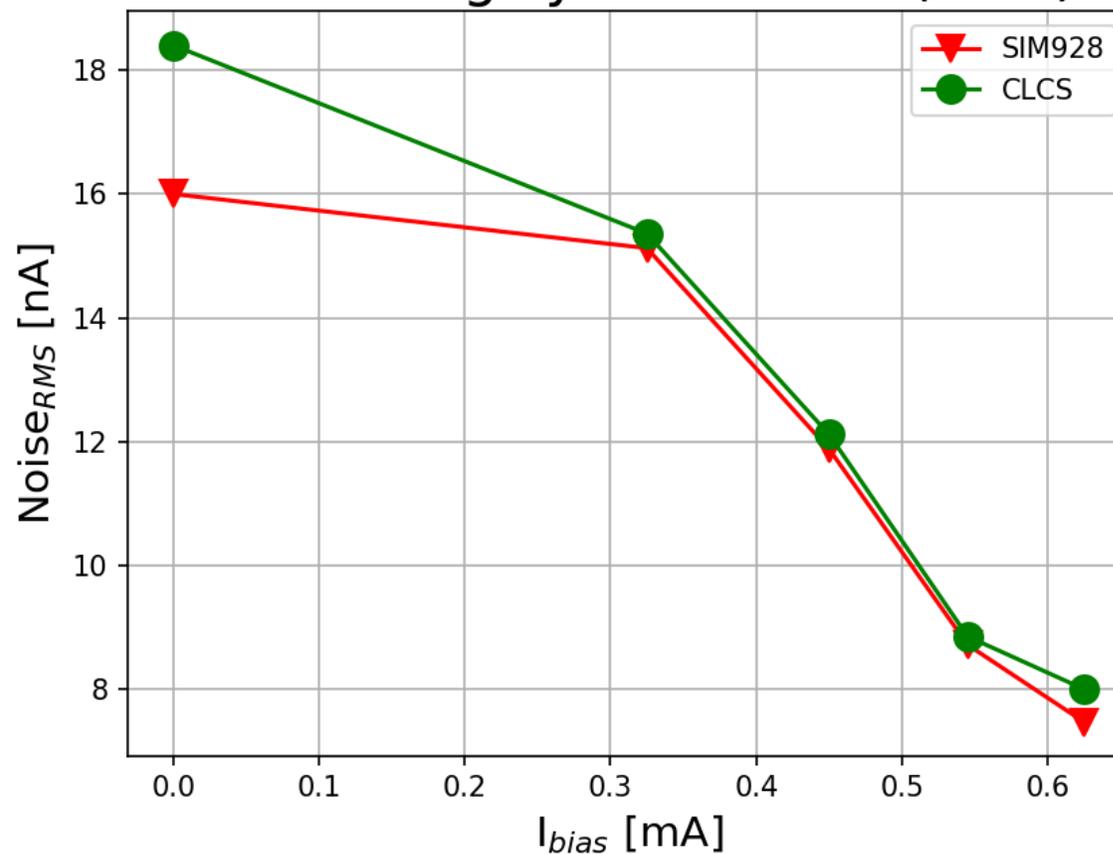
◆借助TES测试实用性表现

Noise测试

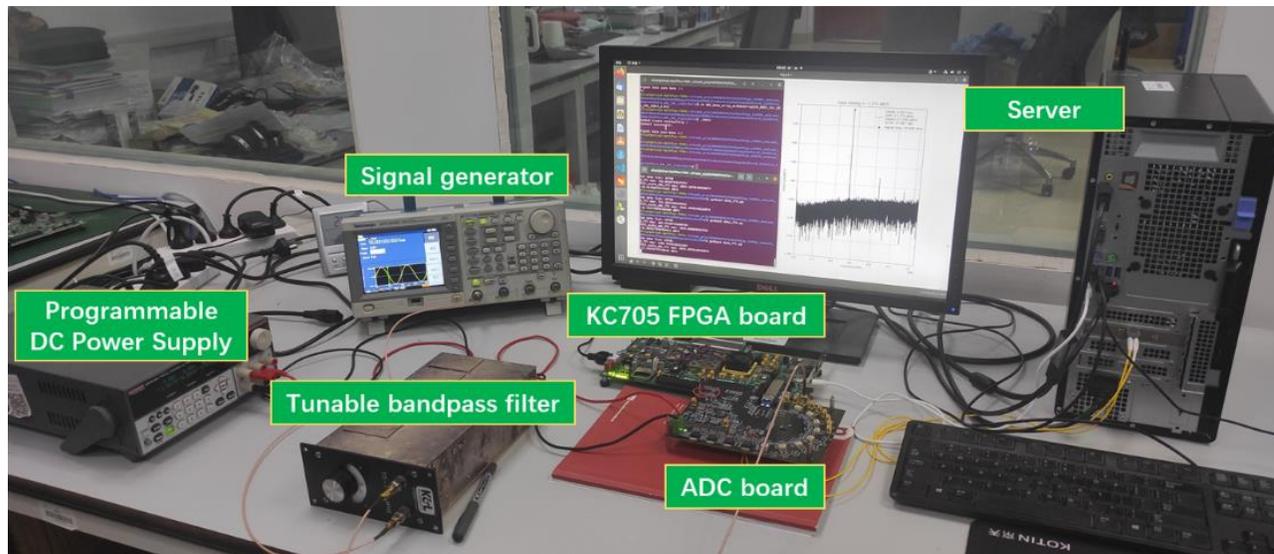
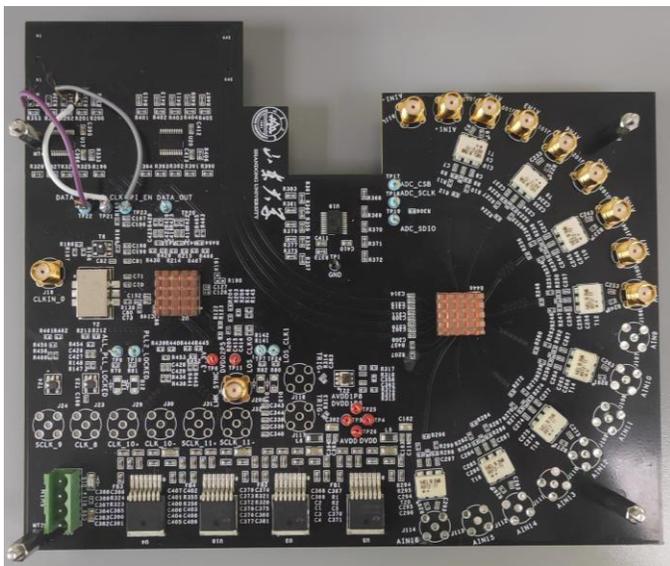
TES testing system Noise (Freq Domain)



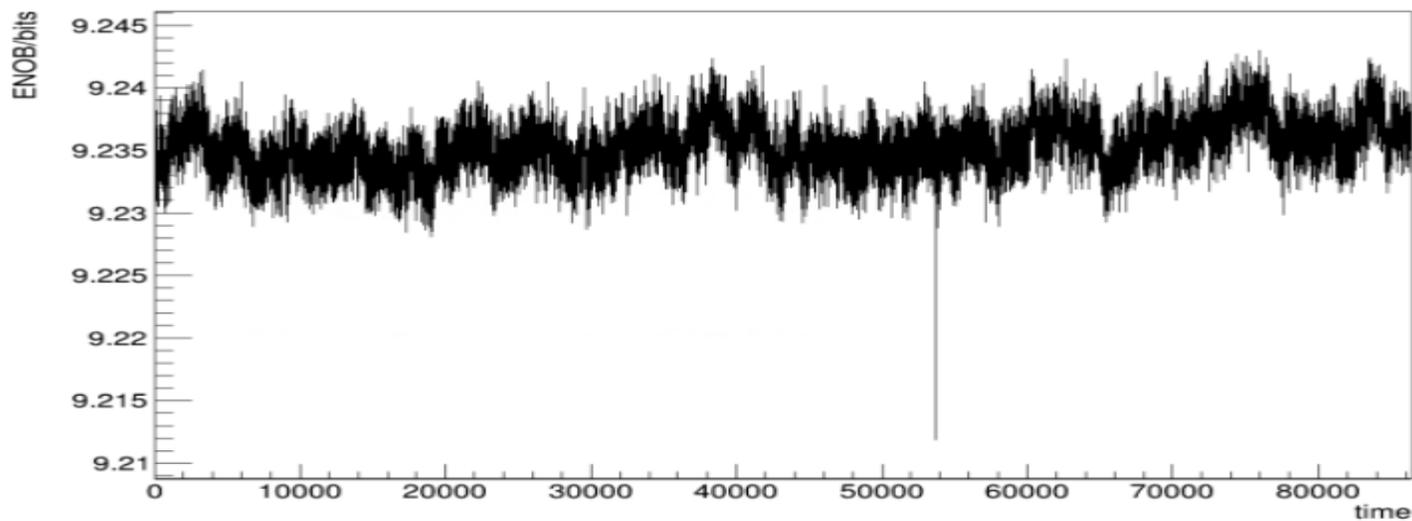
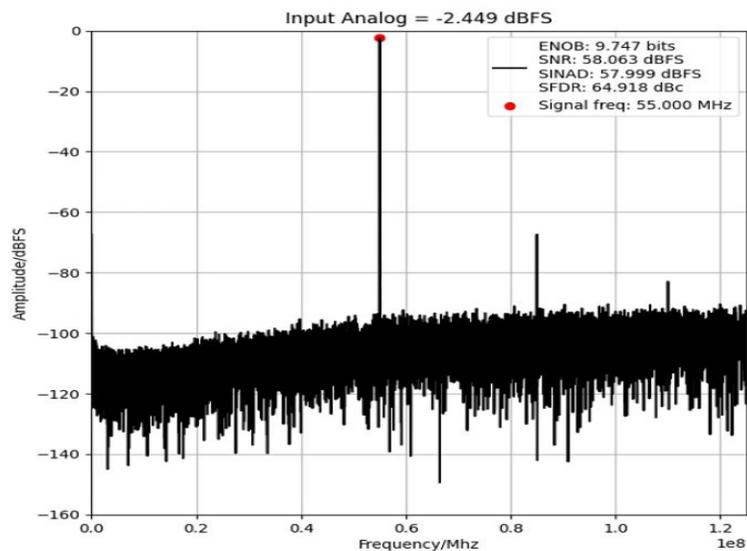
TES testing system Noise (RMS)



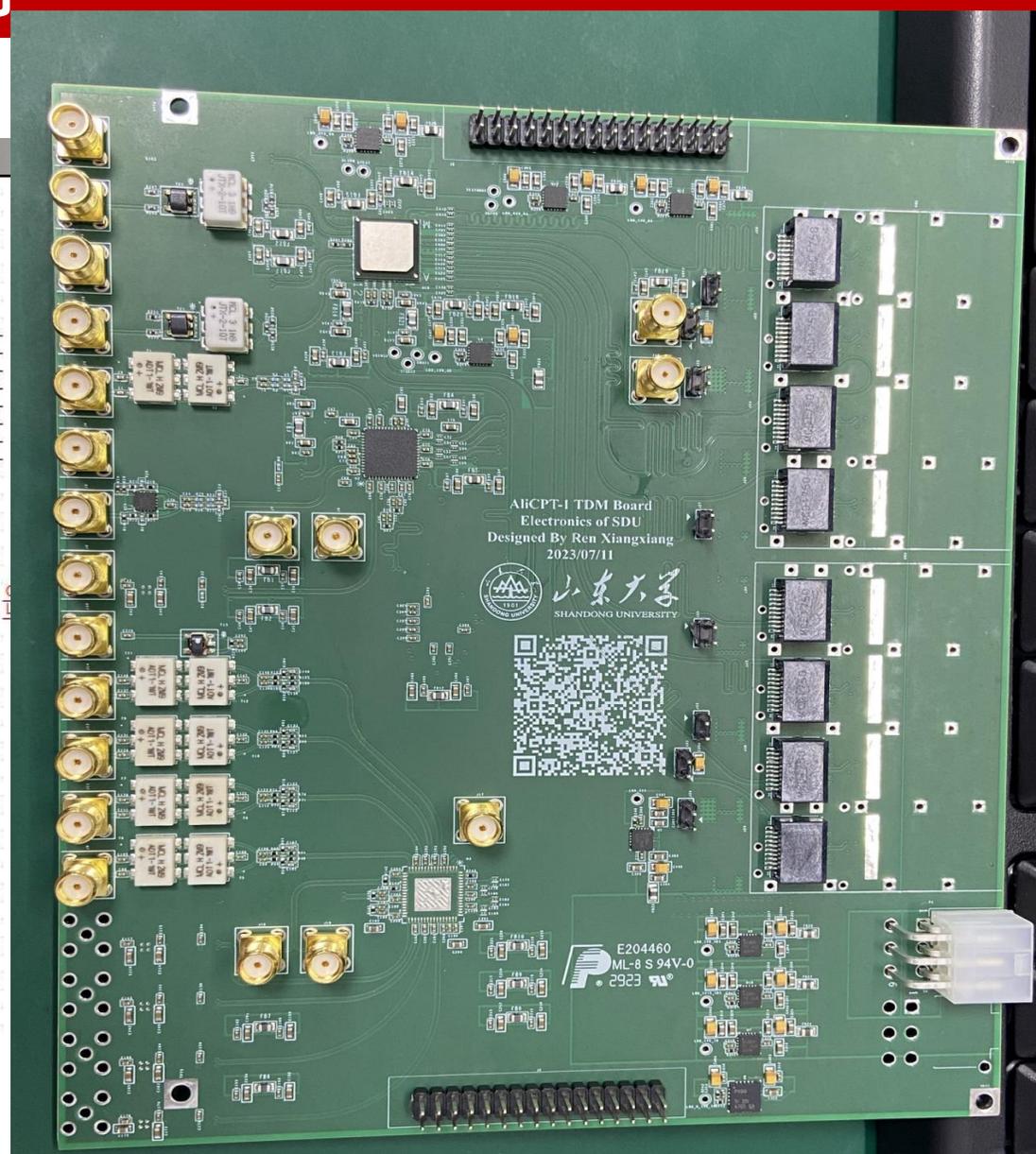
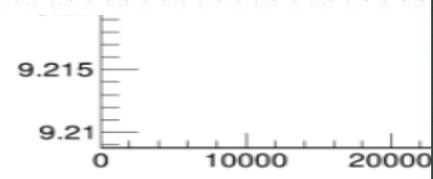
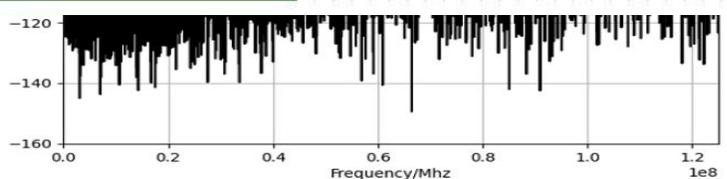
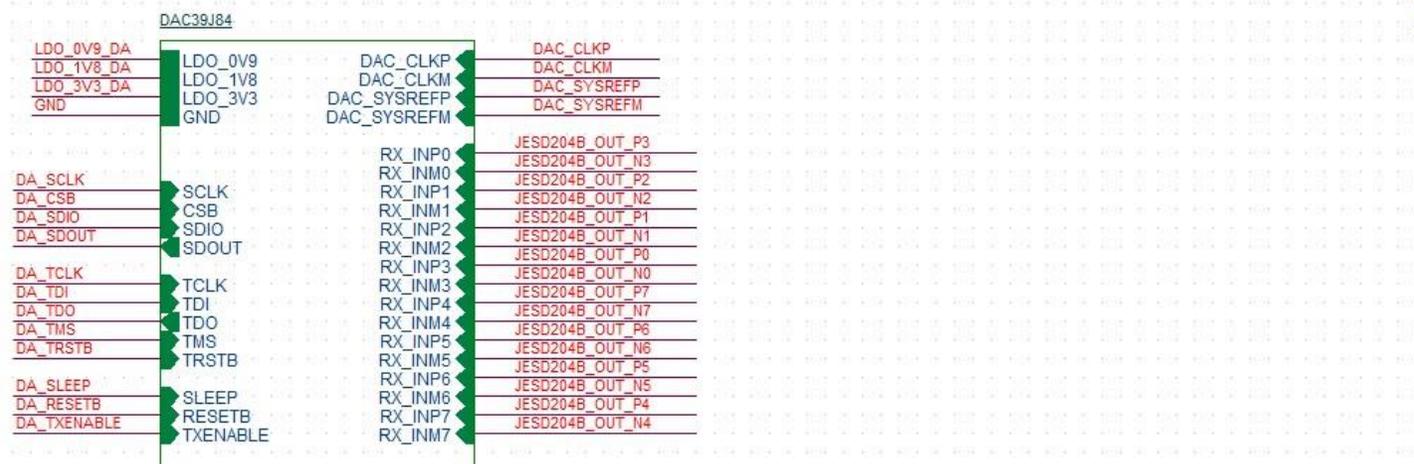
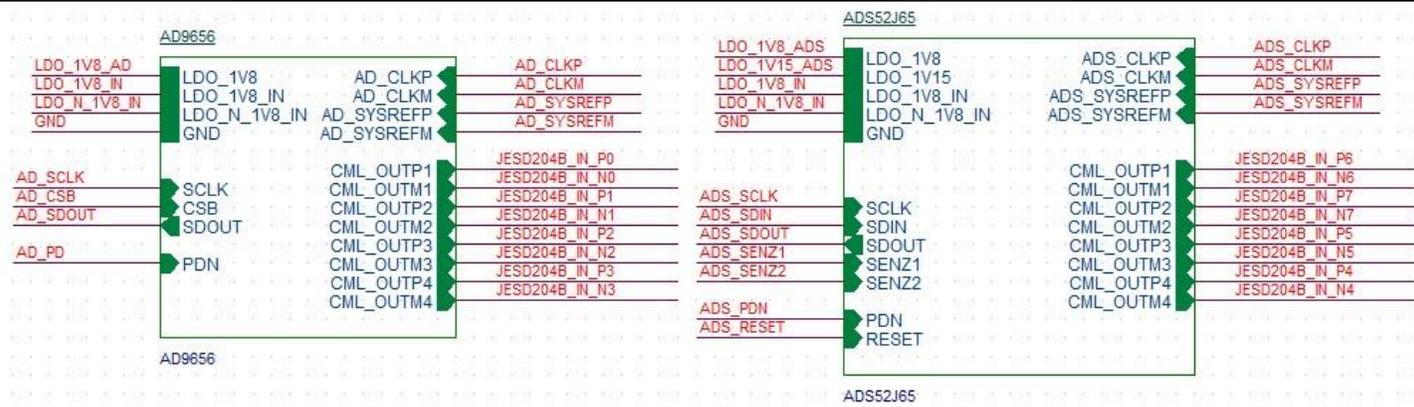
◆ 4 Gbps无死时间实时数据处理



ENOB real time (sorted)

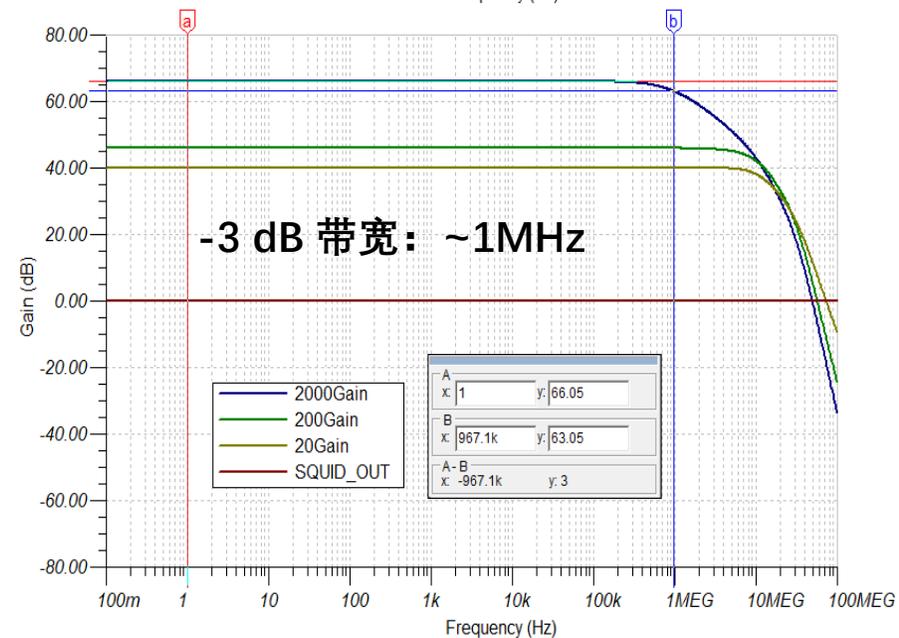
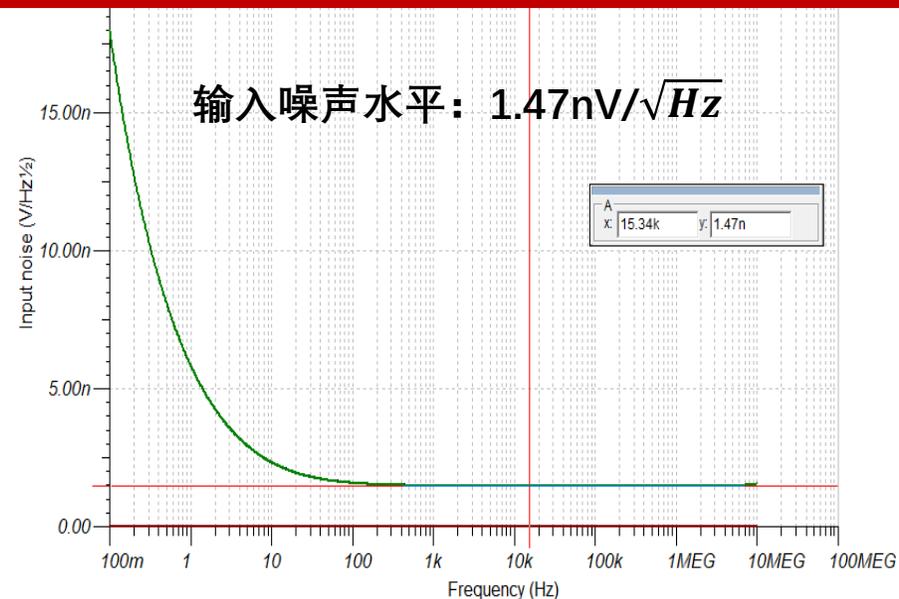
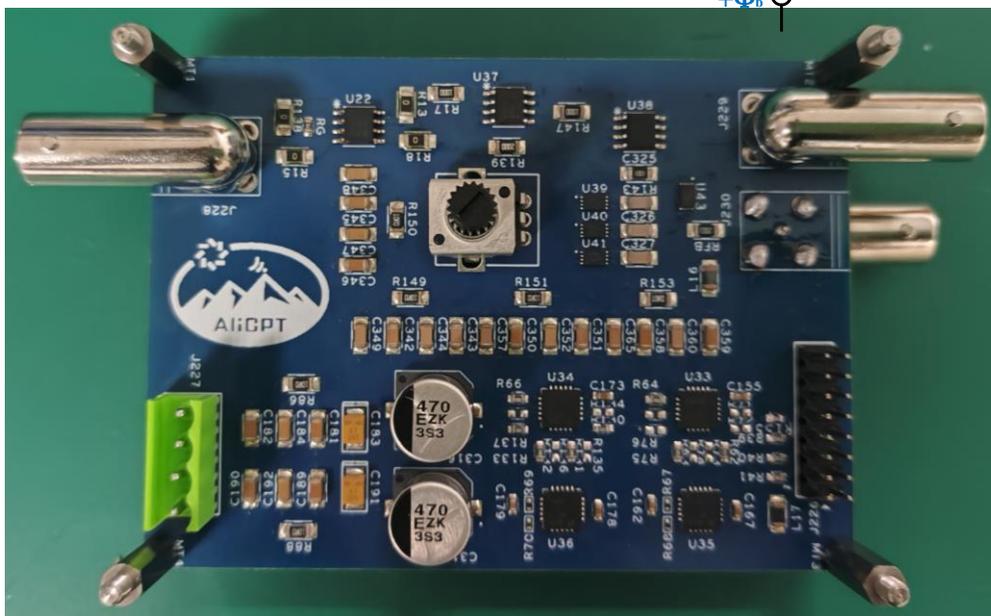
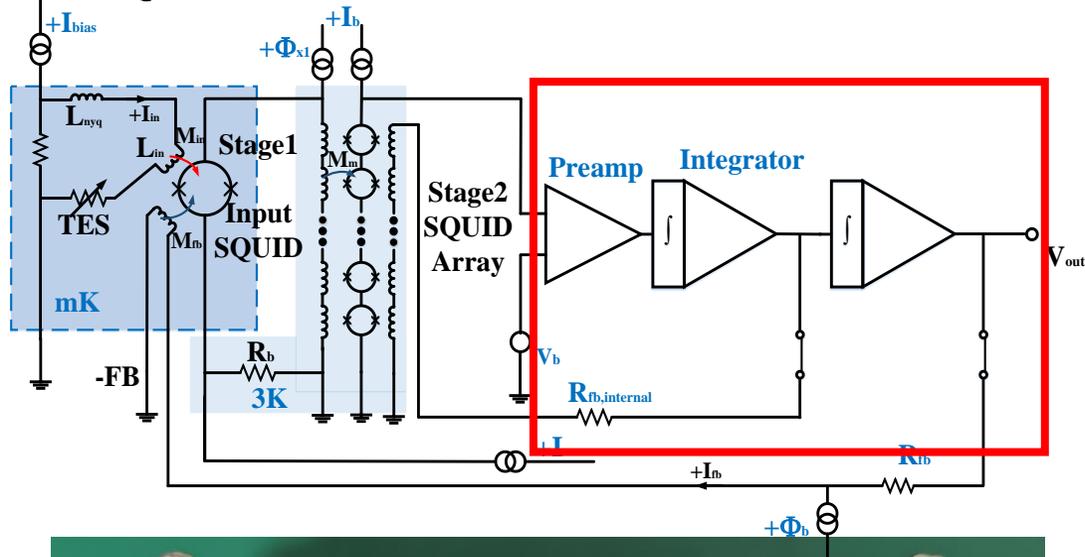


◆ 数字负反馈+读出电子学



模拟负反馈 (AFB)

◆ 基于两级SQUID实现AFB



总结与展望

- ◆ TDM电子学架构比较成熟，广泛应用国外同步辐射线站、微波背景辐射探测、暗物质/轴子/中微子探测
 - ◆ 研制了适用于TES/SQUID的偏置电源，并成功测试验证
 - ◆ 初步研究了电子学读出器件的性能
 - ◆ 初步研究了AFB功能模块，为DFB研究奠定基础
-
- 开发TES复阻抗测试、时间常数等测试功能
 - TES/SQUID 直流/磁通偏置模块集成测试
 - AFB功能验证
 - DFB设计研发

谢谢大家！