

# 时分复用SQUID室温电子学

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# 目录

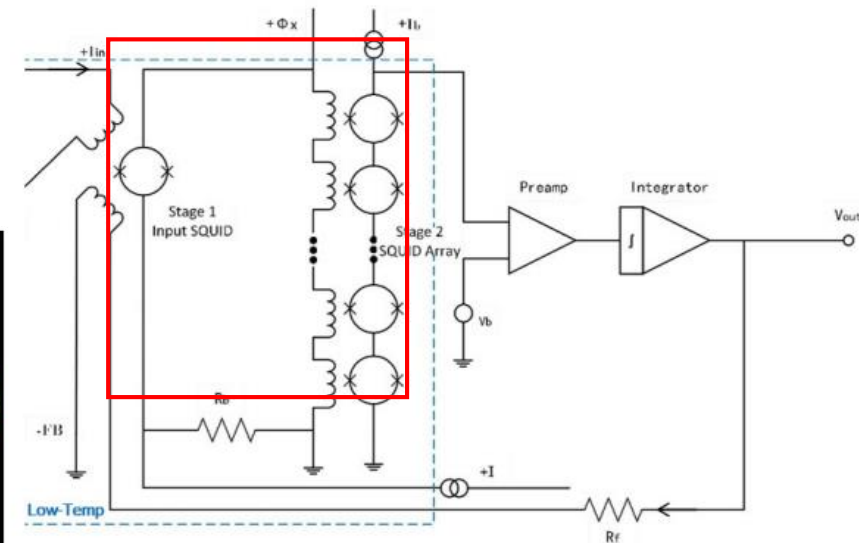
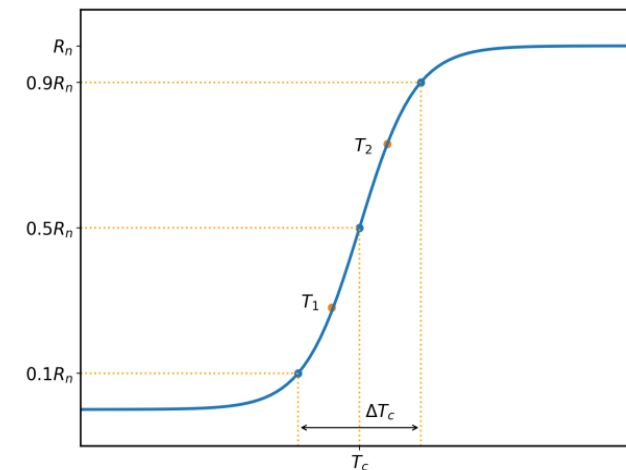
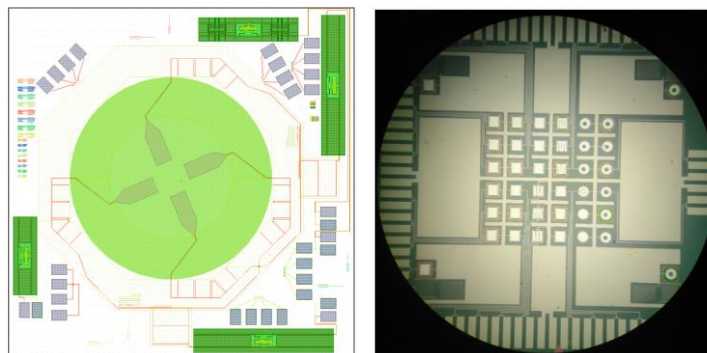
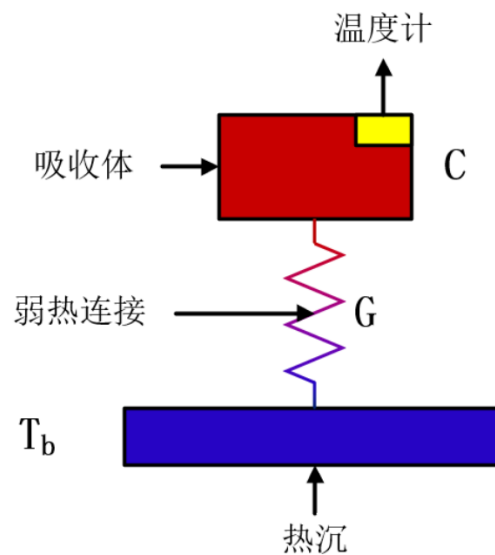
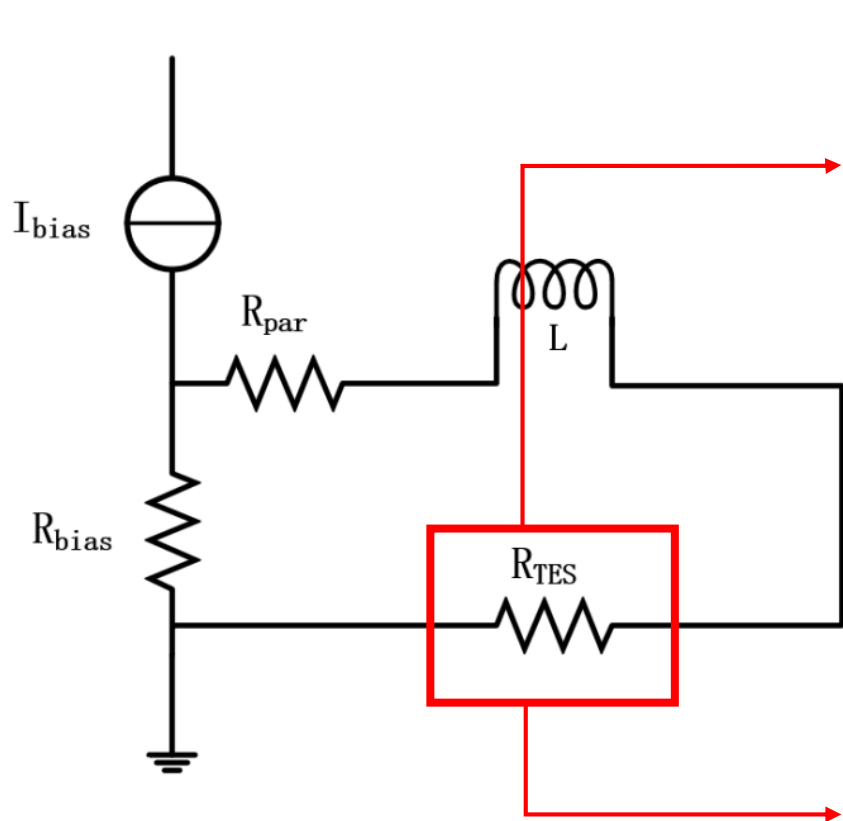
- 背景简介
- 两级SQUID电子学架构
- 时分复用SQUID电子学
- 状态进展
- 总结与展望

# 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

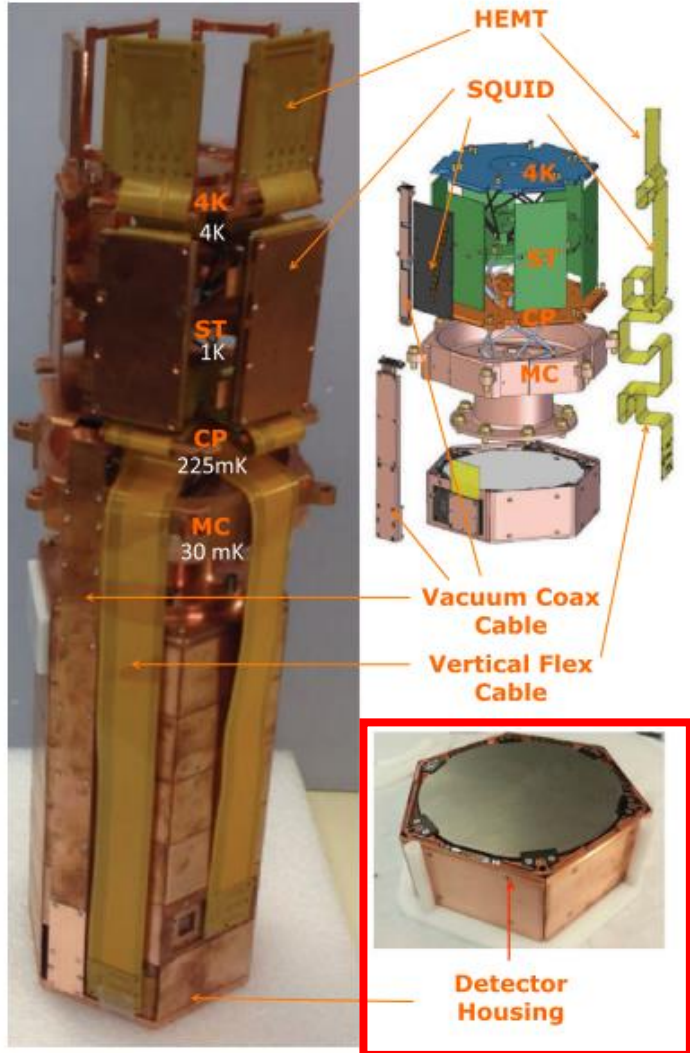
## ◆ Superconducting QUantum Interference Devices (SQUID) 低噪放大





# 背景简介

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



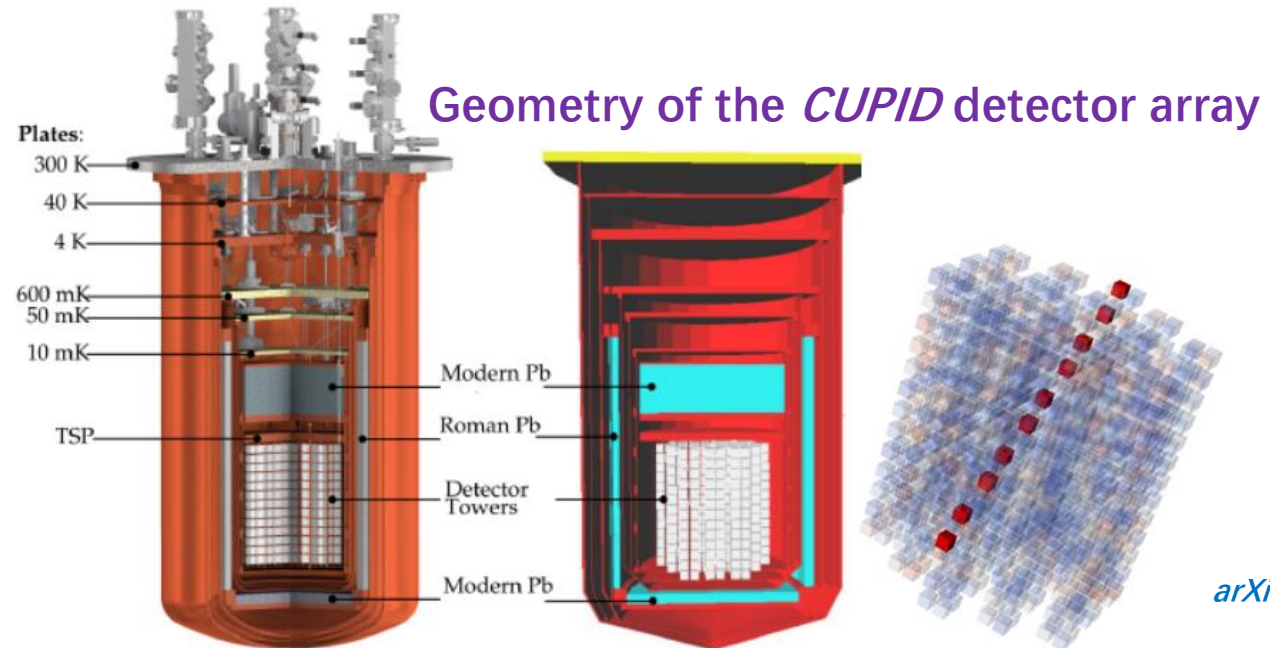
Al Kenany, S., et al. *J Low Temp Phys* 167 (2012): 1167-1172

## *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.



arXiv:1907.09376v1

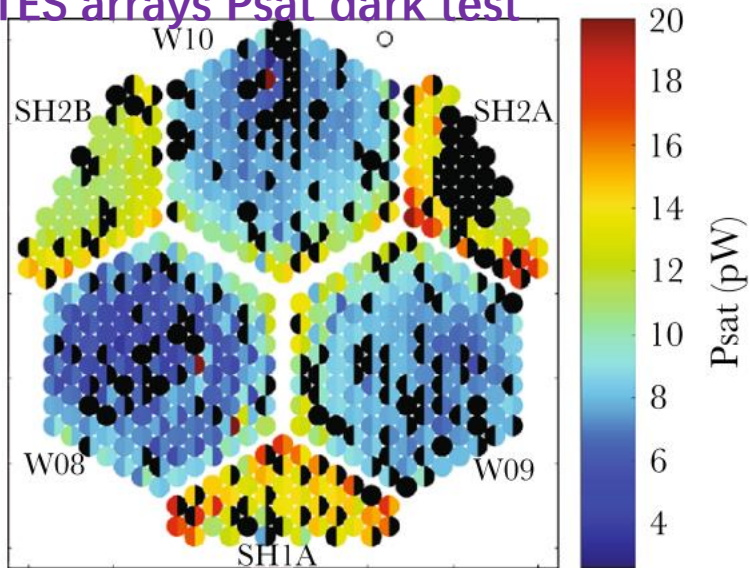
# 背景简介

## ◆ 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

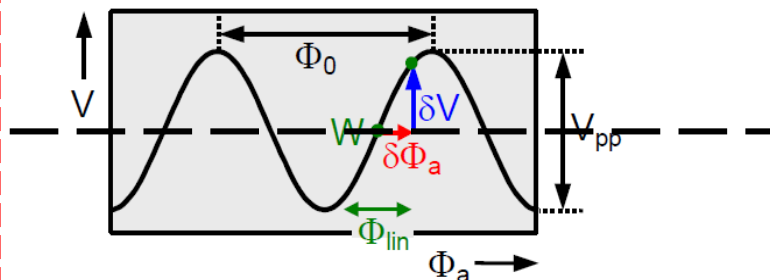
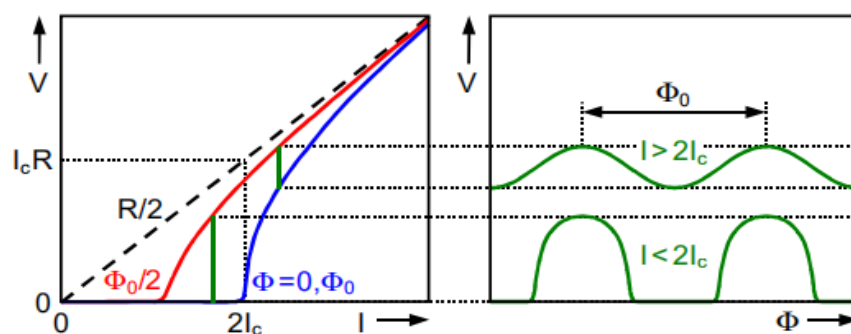




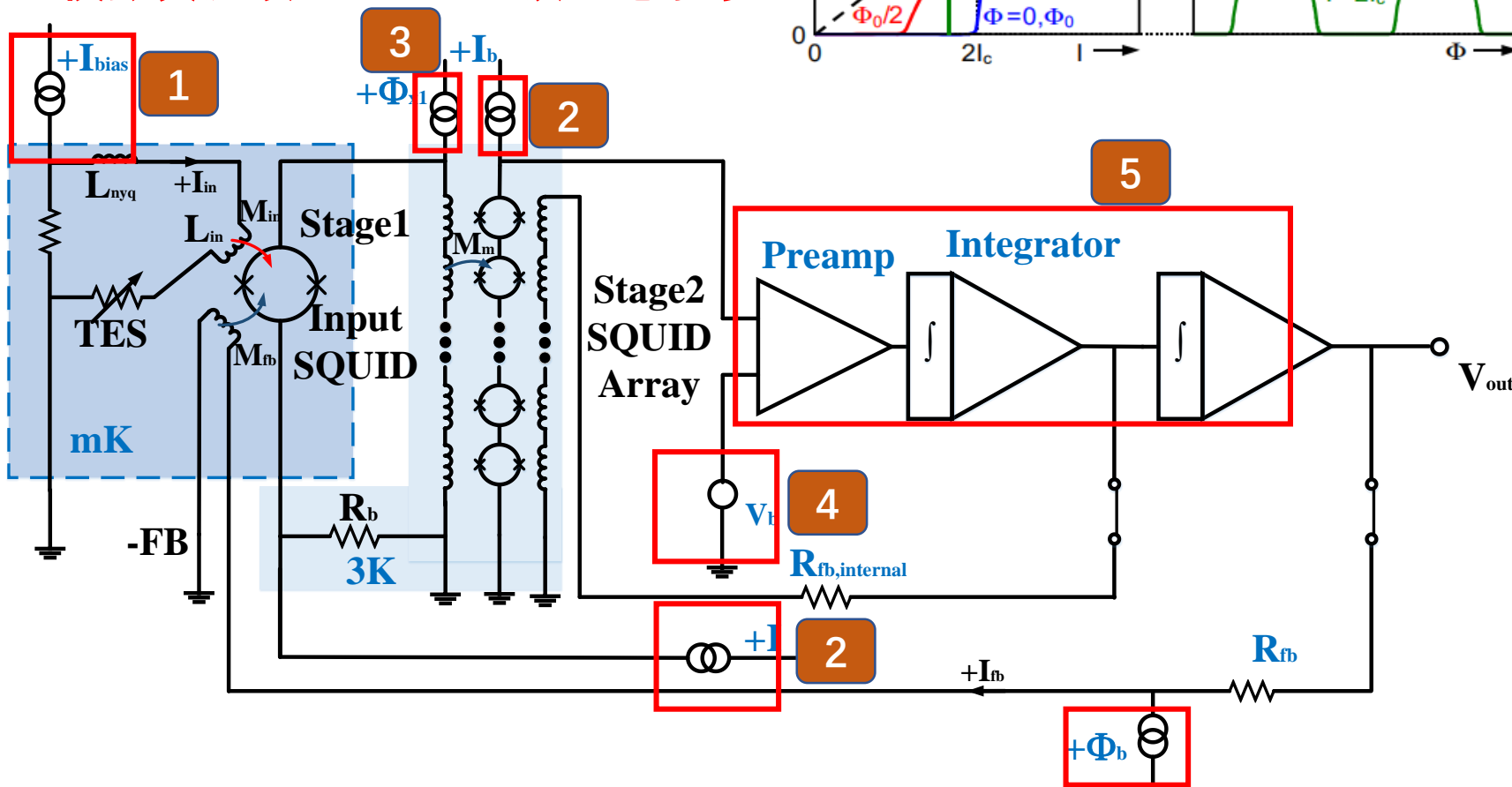
# 两级SQUID电子学架构

- ◆ 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

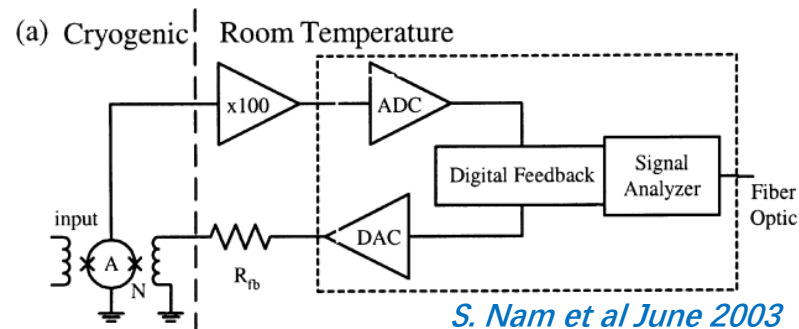
|                            |   |
|----------------------------|---|
| TES bias                   | 1 |
| SQUID/S-Arrays bias        | 2 |
| SQUID/S-Arrays Flux offset | 3 |
| Amplifier DC offset        | 4 |
| AFB                        | 5 |
| DAQ                        |   |

# 时分复用SQUID电子学

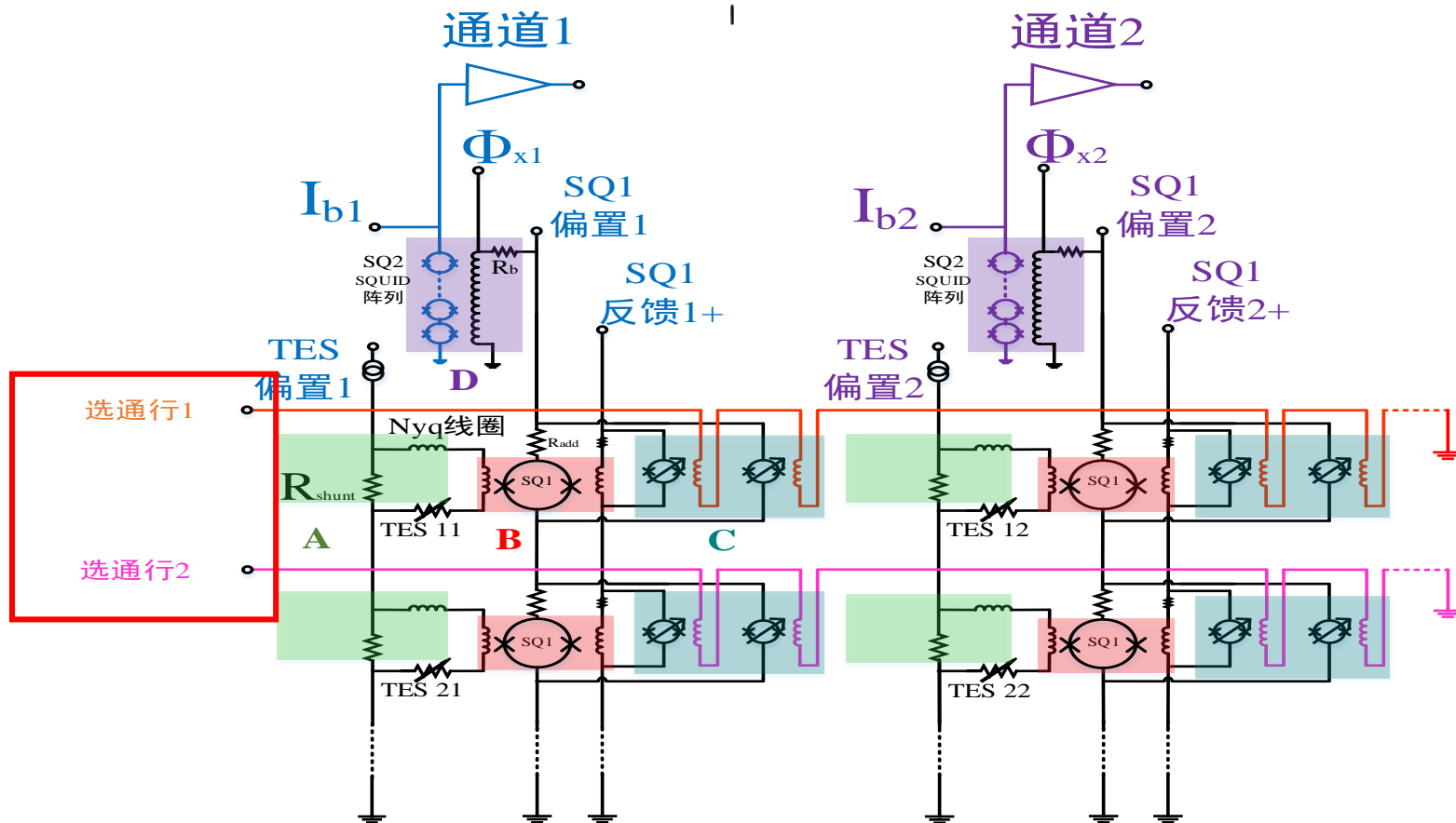
◆ Time-Division Multiplexing SQUID (TDM)

◆ 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                  |

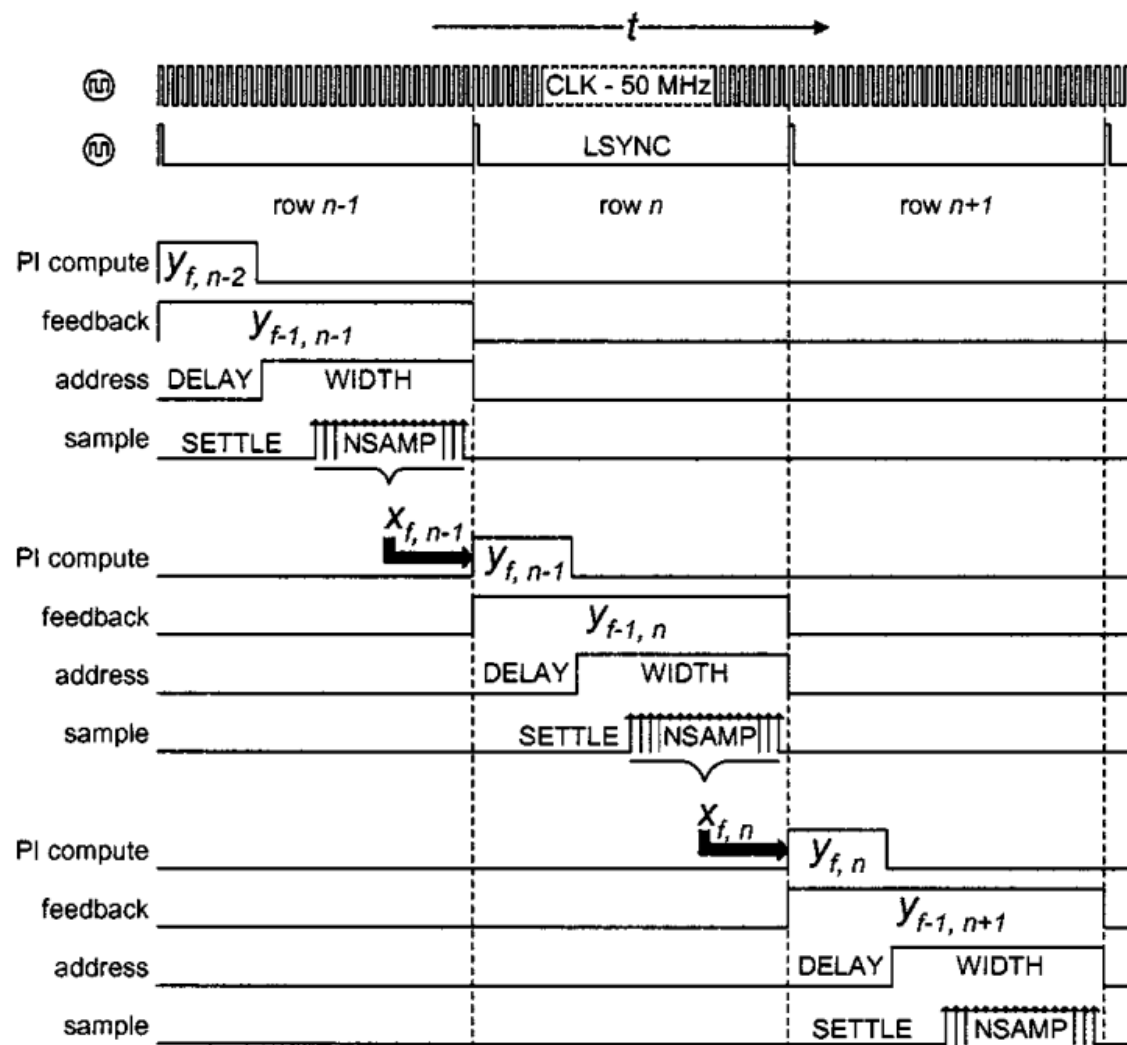
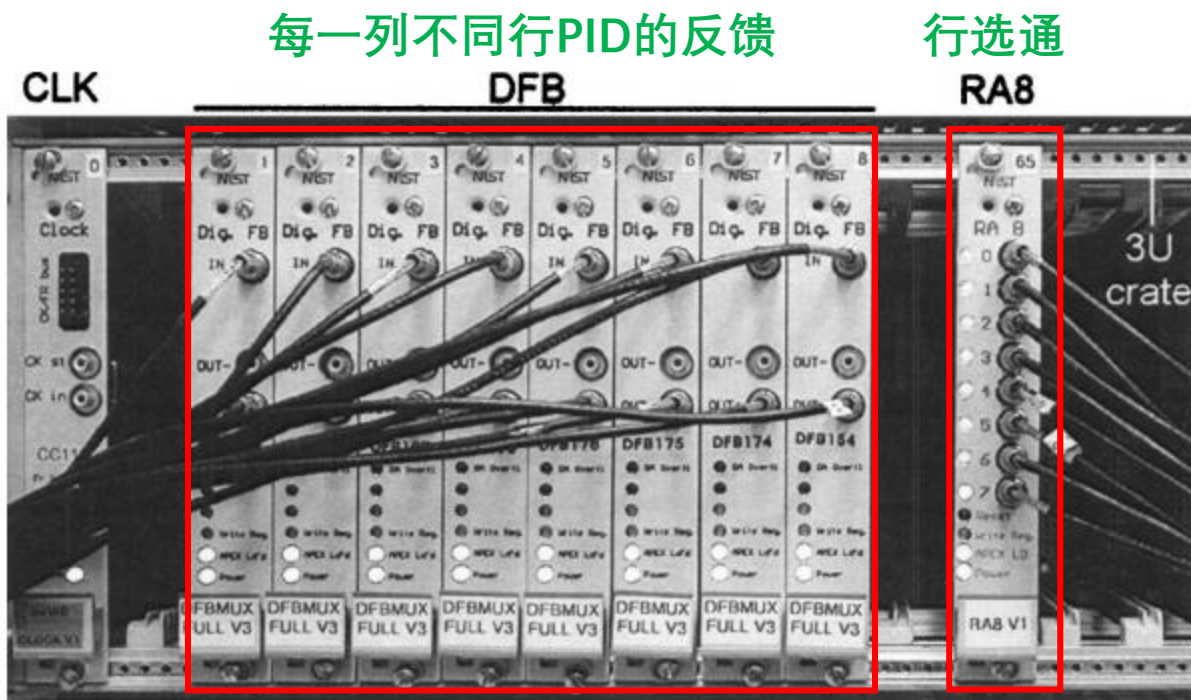


# 时分复用SQUID电子学

◆ 时分复用SQUID (TDM)

◆ 选通逻辑

◆ 数字负反馈 (DFB) + 读出电子学

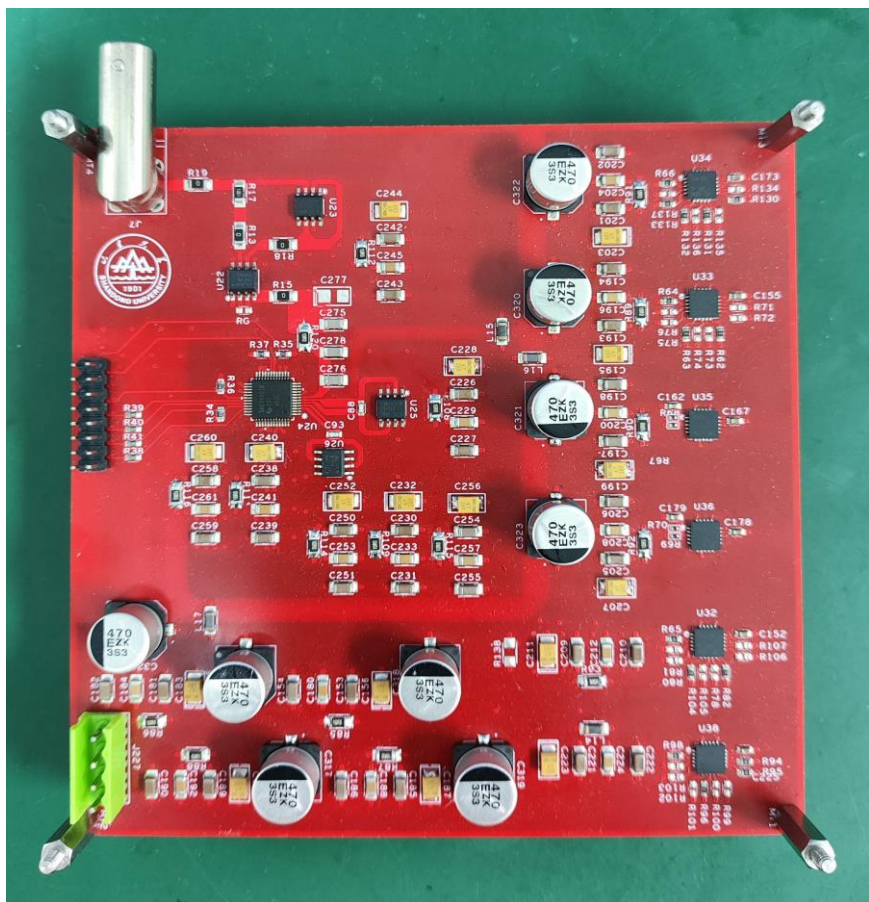


Review of Scientific Instruments 74, 4500 (2003)

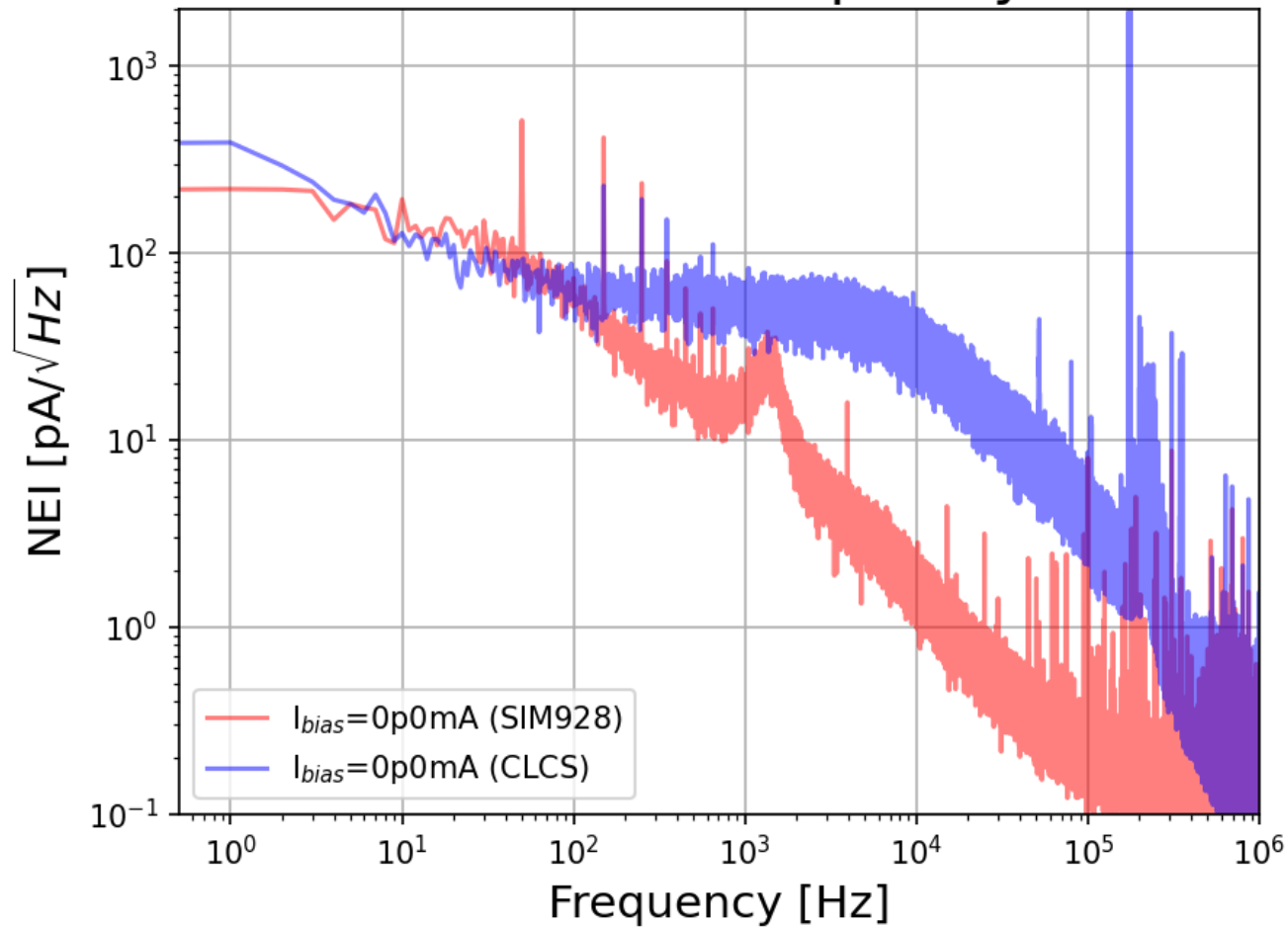


# 可配置低噪声电流源 (CLCS)

## ◆ TES/SQUID 可配置低噪声直流源

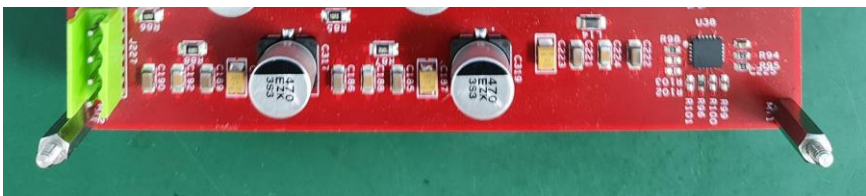
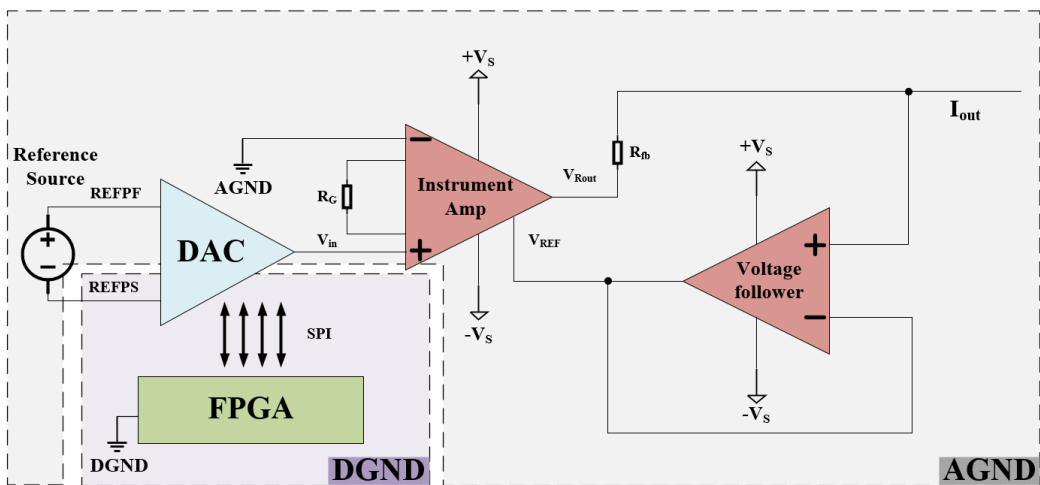


### Bias Source Noise (Frequency Domain)

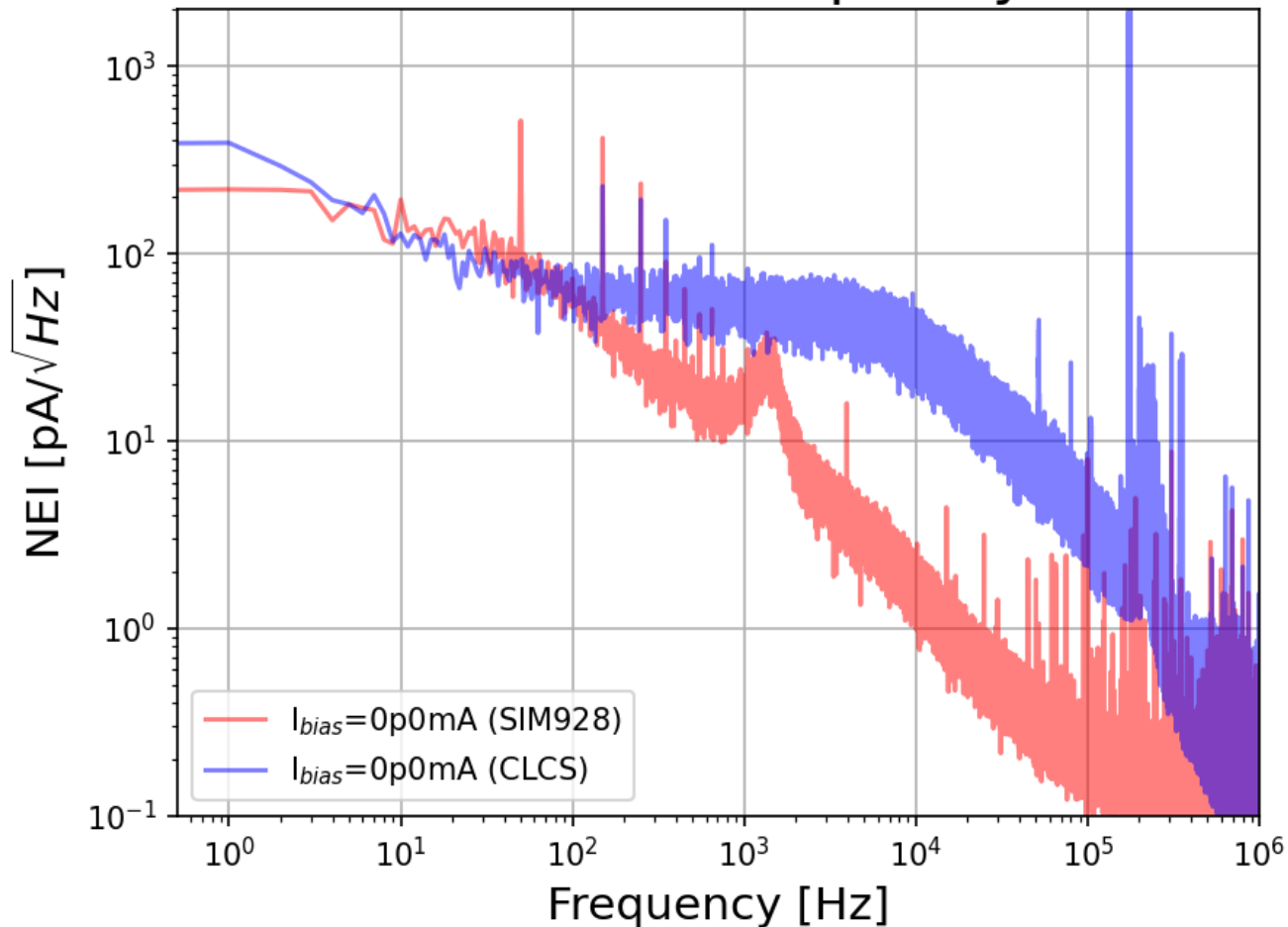


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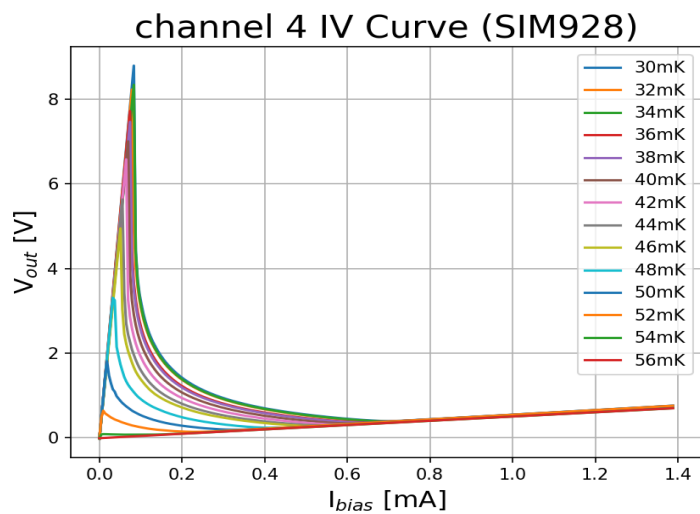
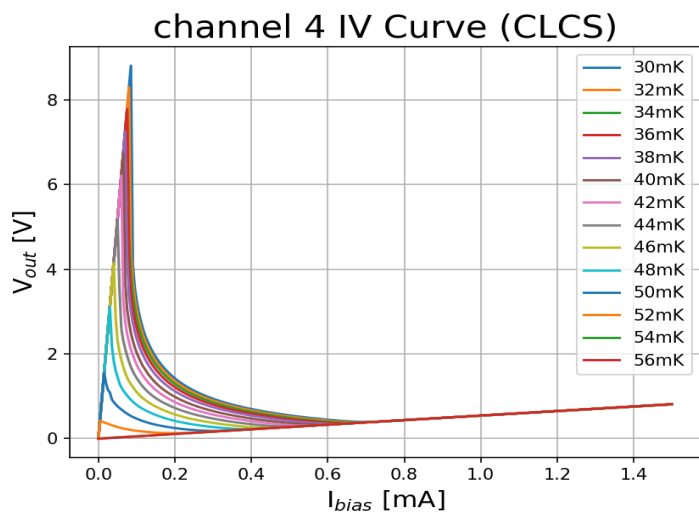
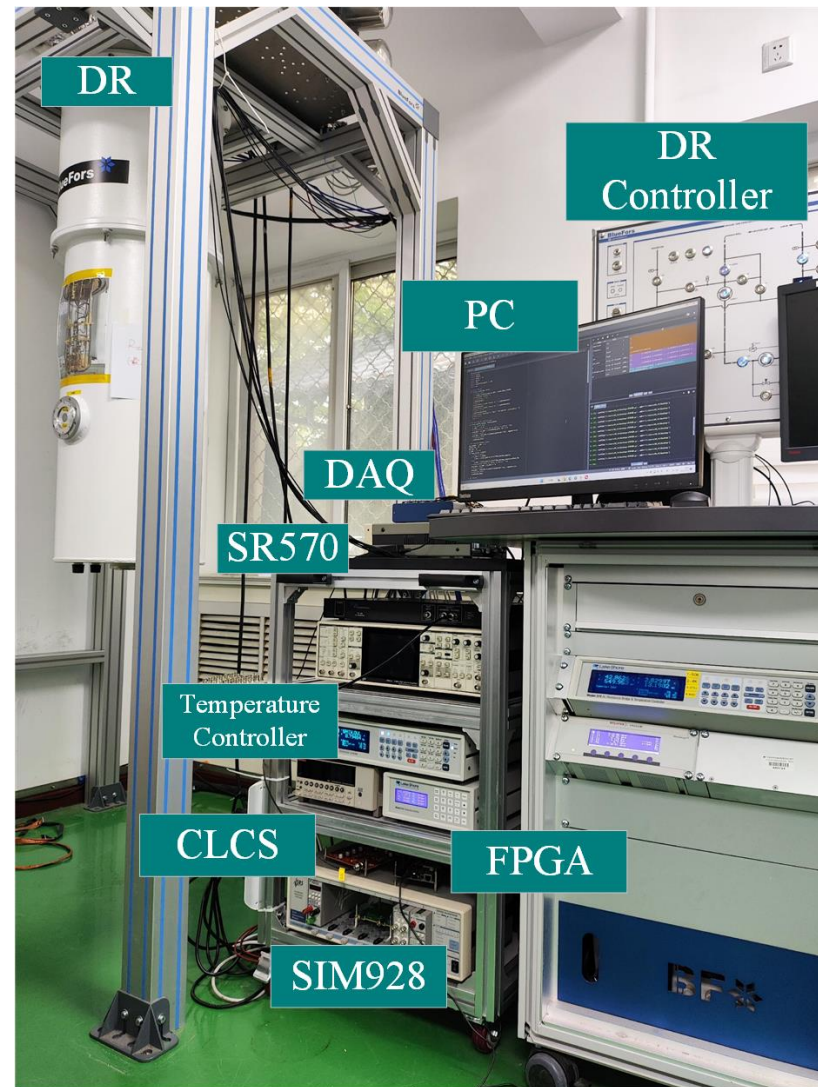
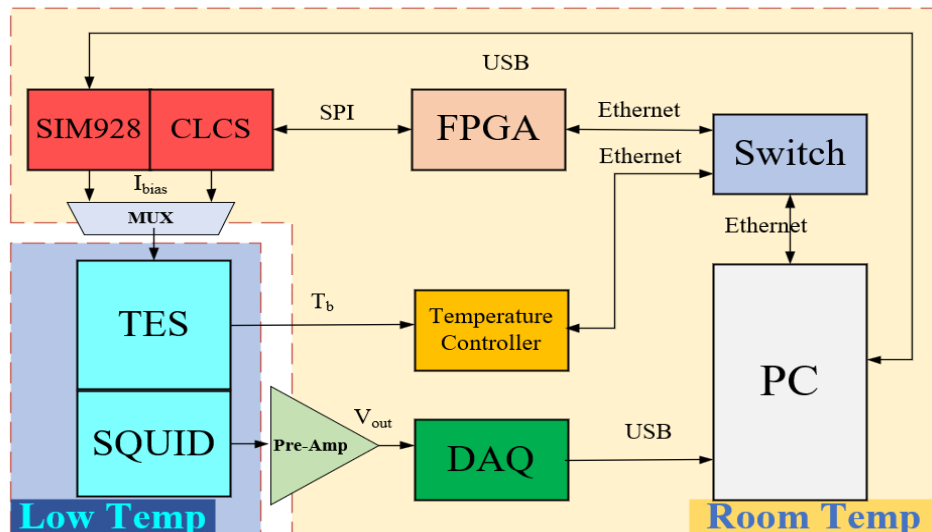
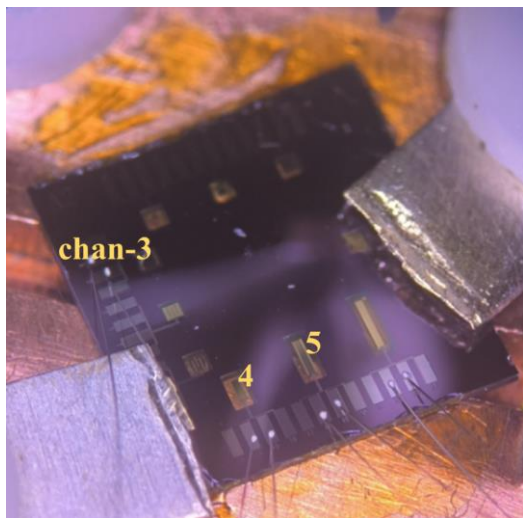


### Bias Source Noise (Frequency Domain)



# 可配置低噪声电流源 (CLCS)

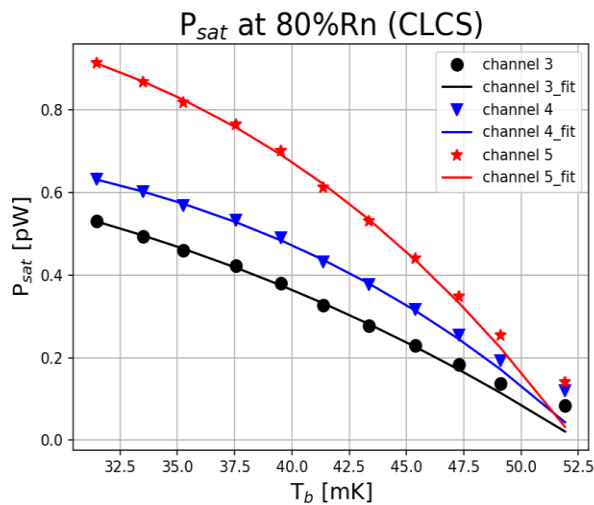
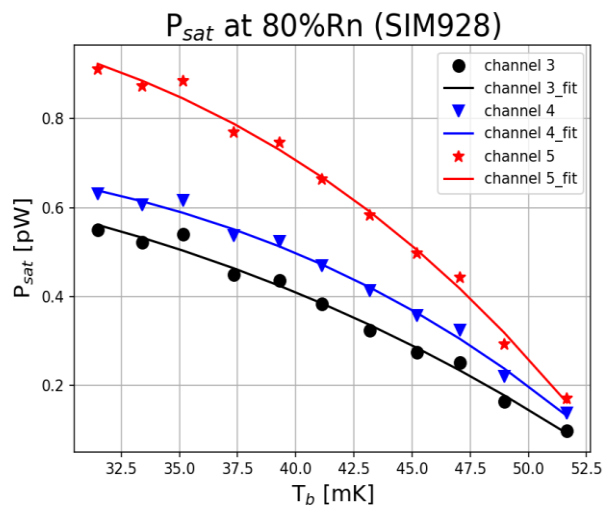
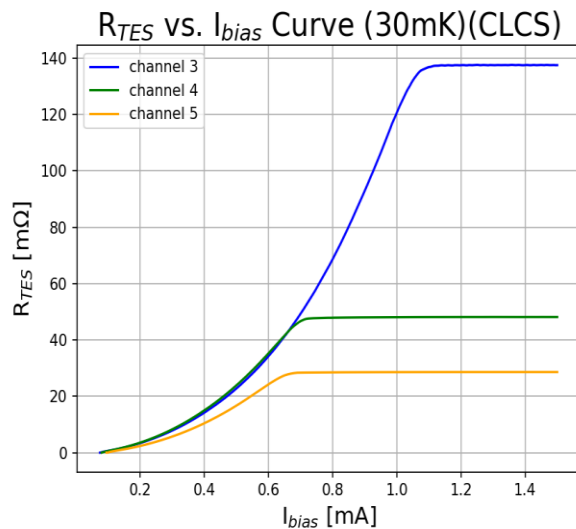
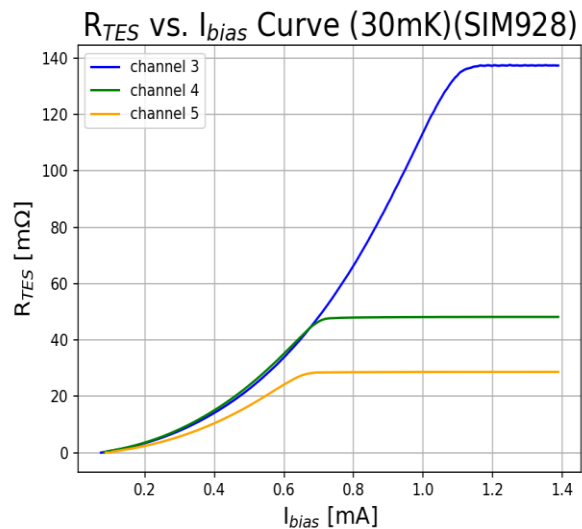
## ◆借助TES测试实用性表现





# 可配置低噪声电流源 (CLCS)

## ◆借助TES测试实用性表现



$$P_{sat} = K (T_c^n - T_{bath}^n) \quad G = \frac{dP_{sat}}{dT_c} = nKT_c^{n-1}$$

| SIM928           | Channel 3 | Channel 4 | Channel 5 |
|------------------|-----------|-----------|-----------|
| Gain (V/A)       | 105950.94 | 105841.68 | 105583.24 |
| Rn (m $\Omega$ ) | 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 (m $\Omega$ ) | 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    |

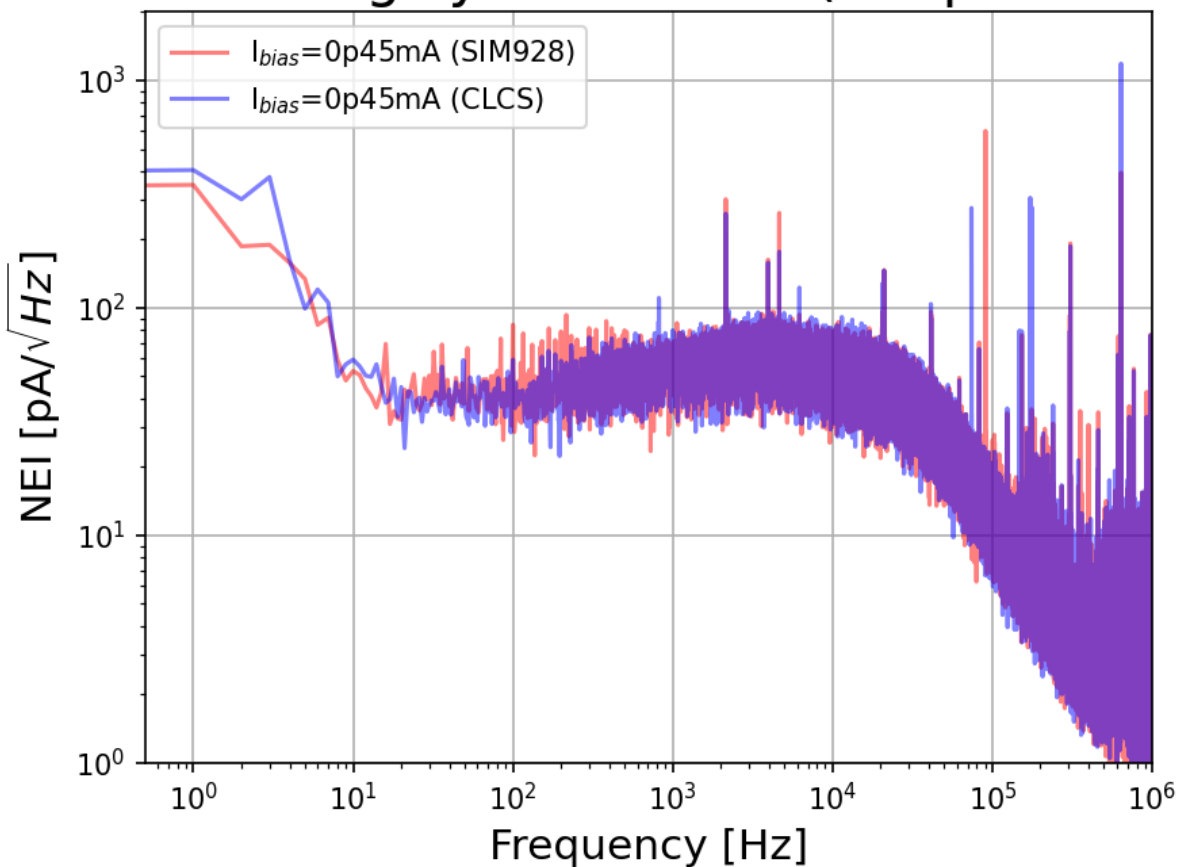


# 可配置低噪声电流源 (CLCS)

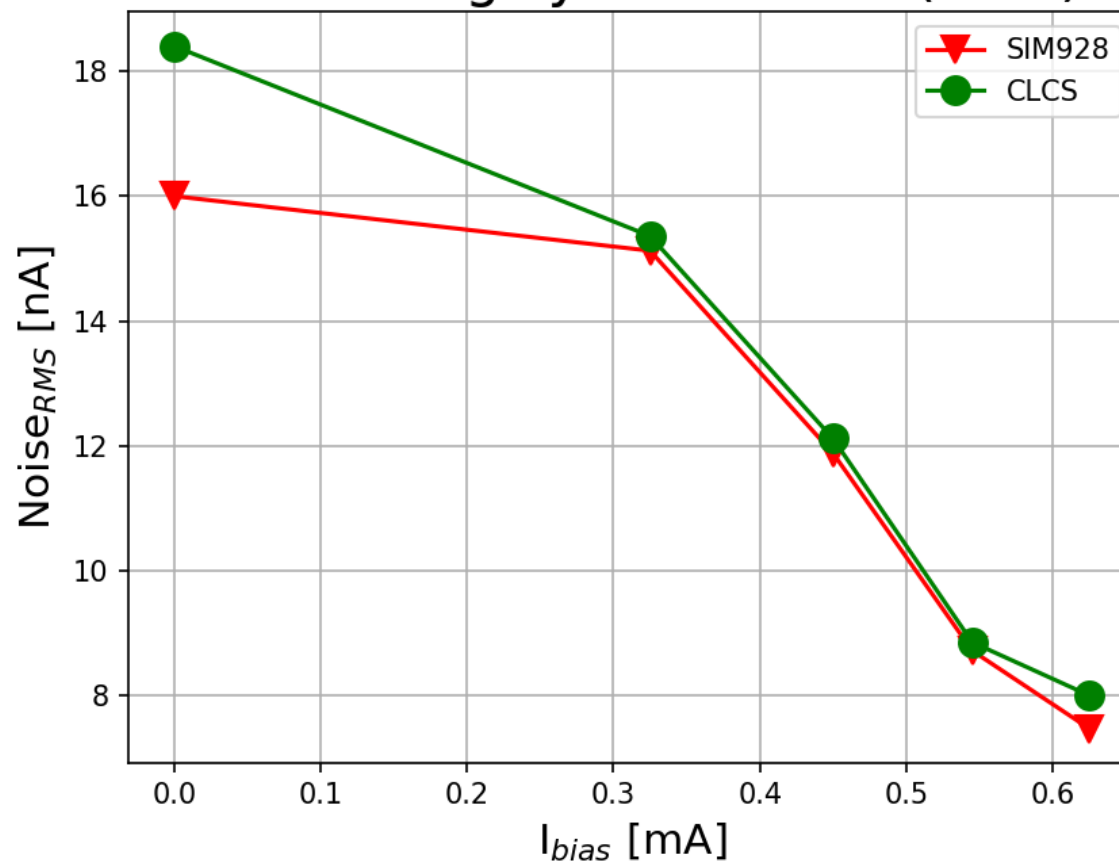
◆ 借助TES测试实用性表现

## Noise测试

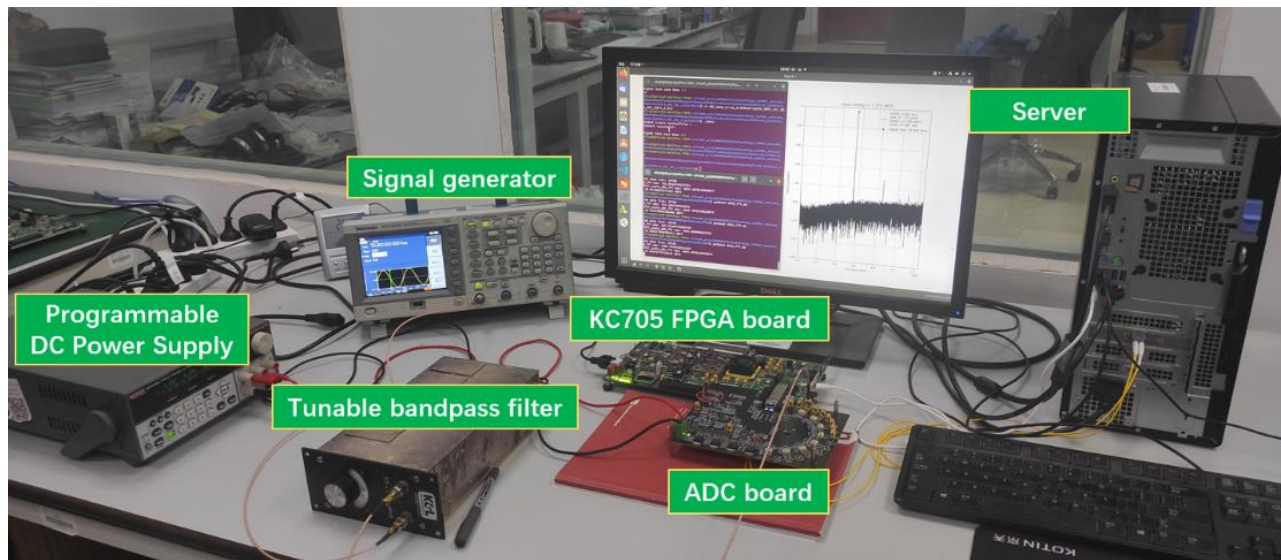
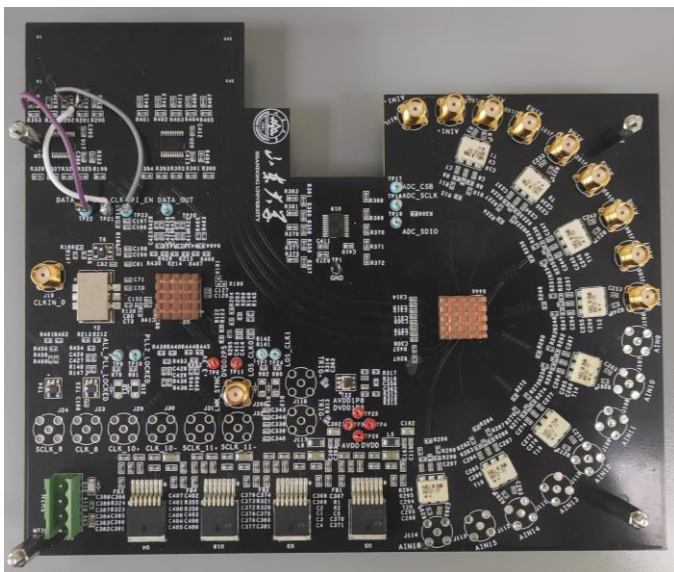
TES testing system Noise (Freq Domain)



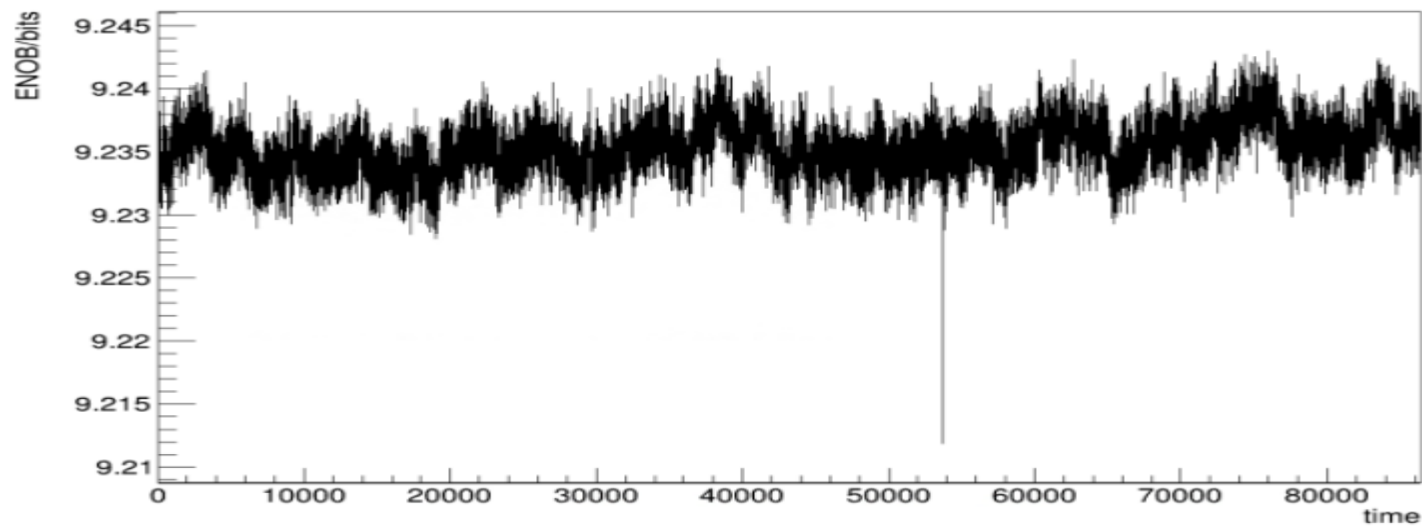
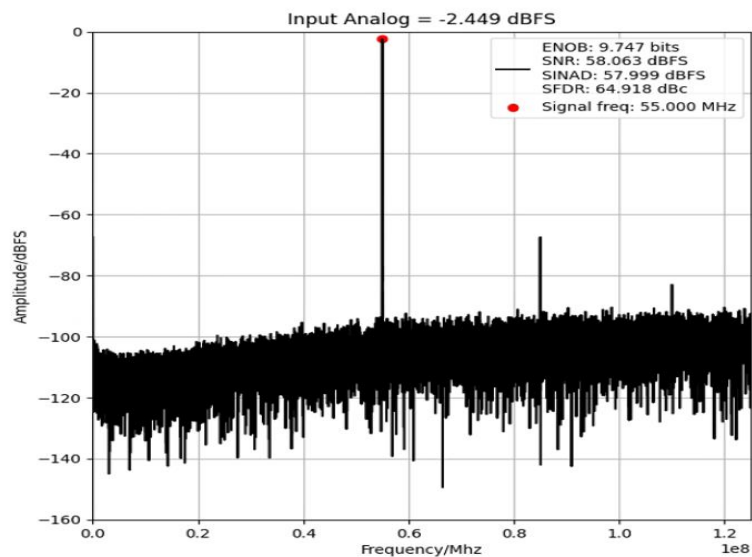
TES testing system Noise (RMS)



## ◆ 4 Gbps无死时间实时数据处理



ENOB real time (sorted)



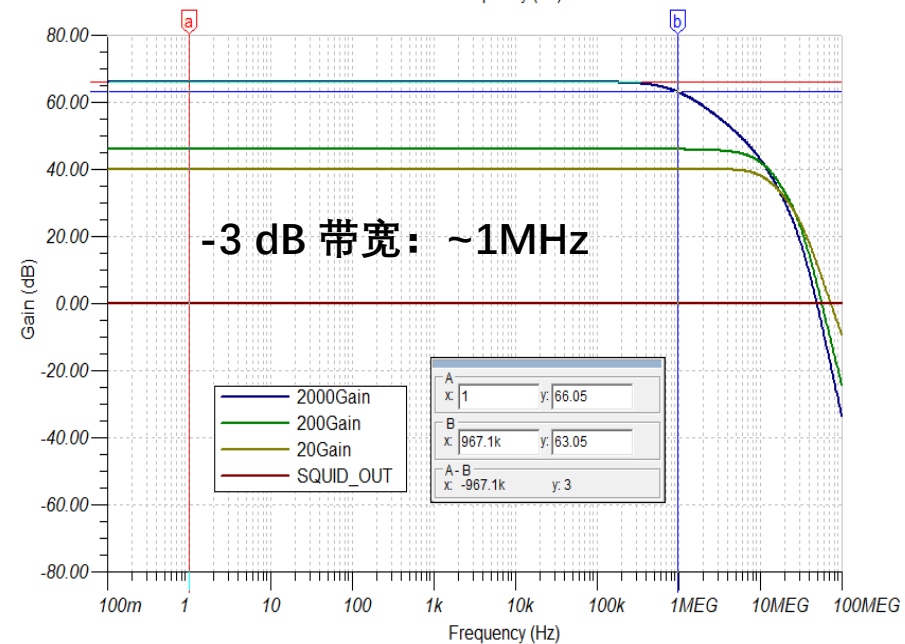
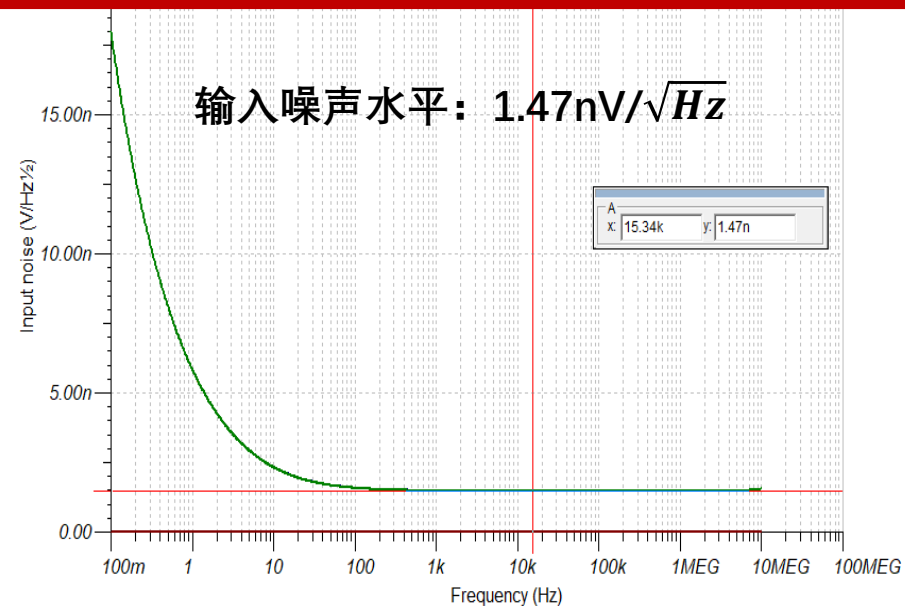
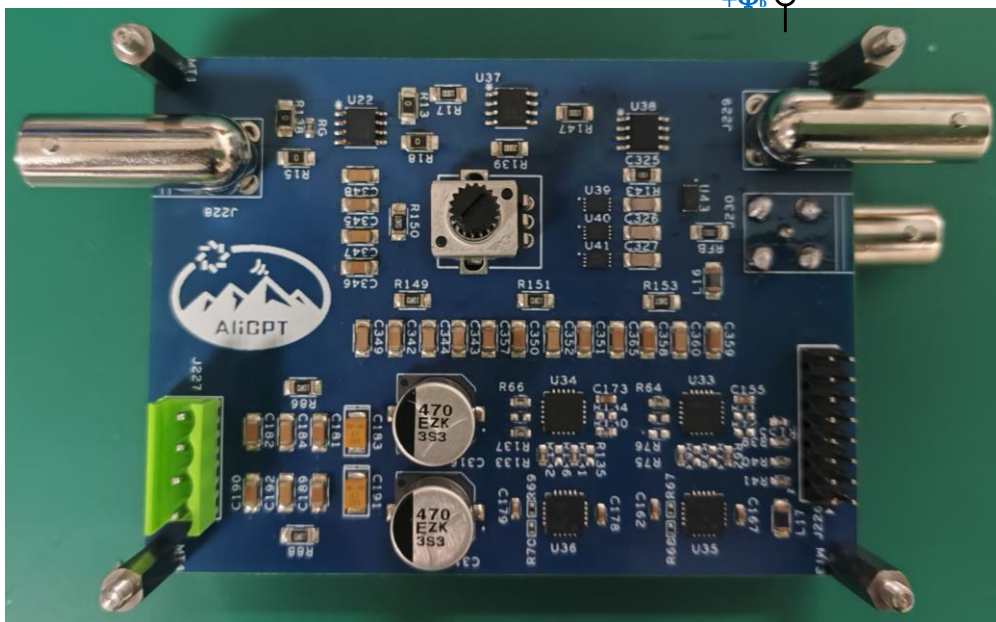
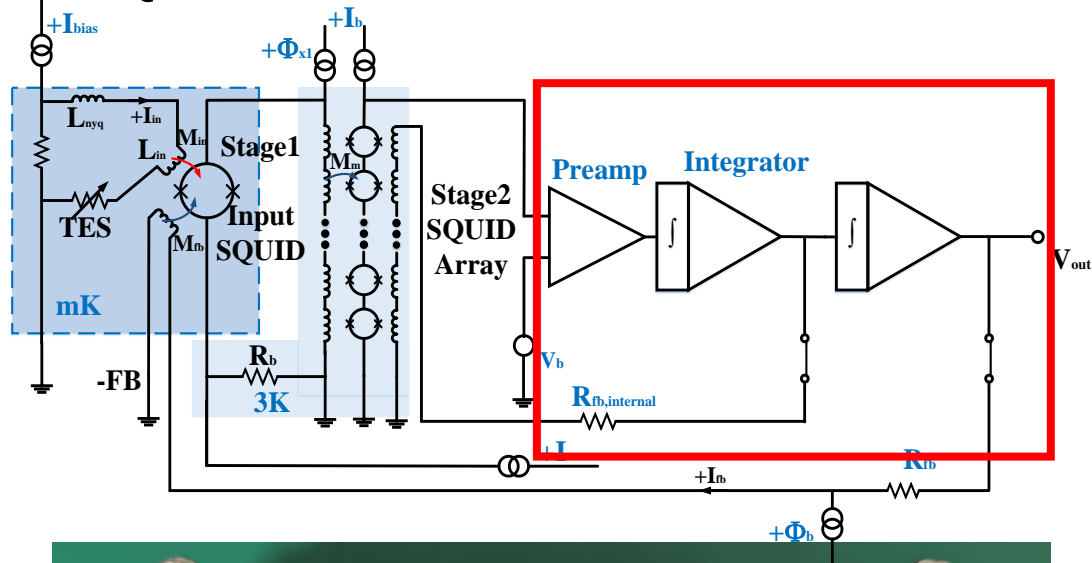






# 模拟负反馈 (AFB)

## ◆ 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！**