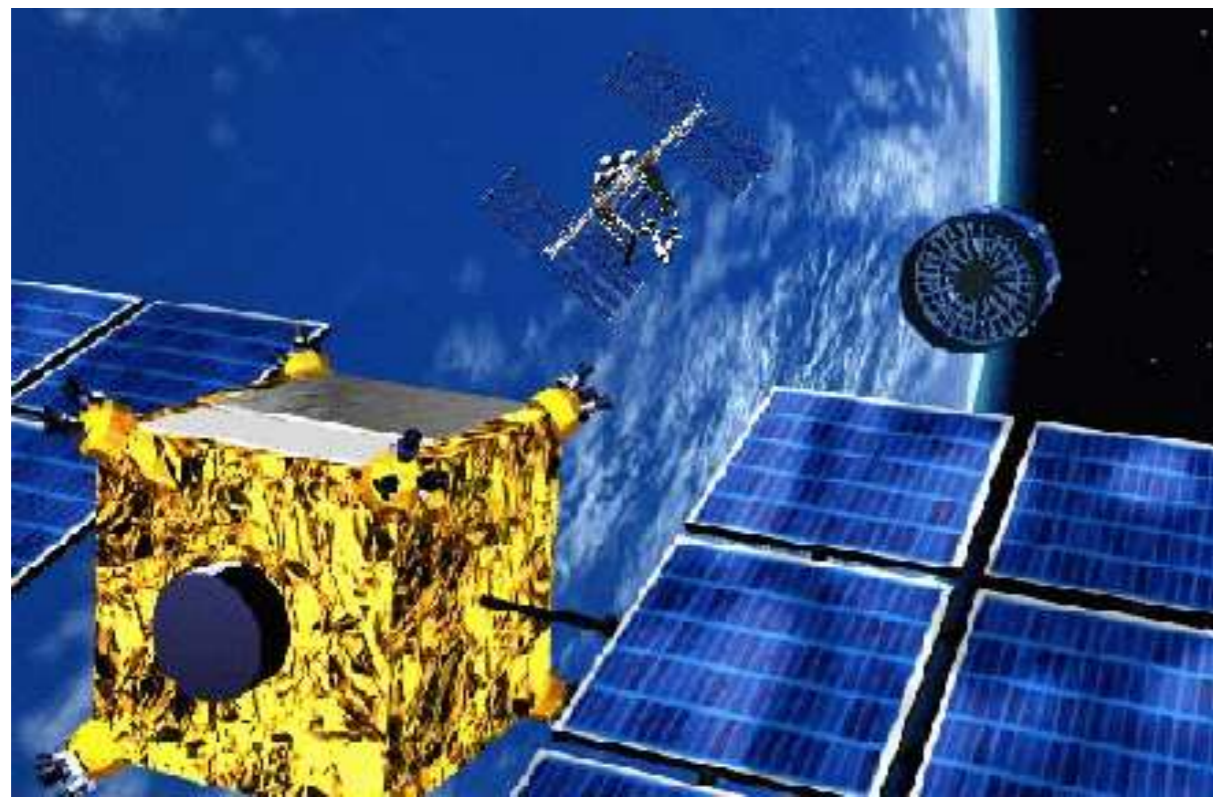


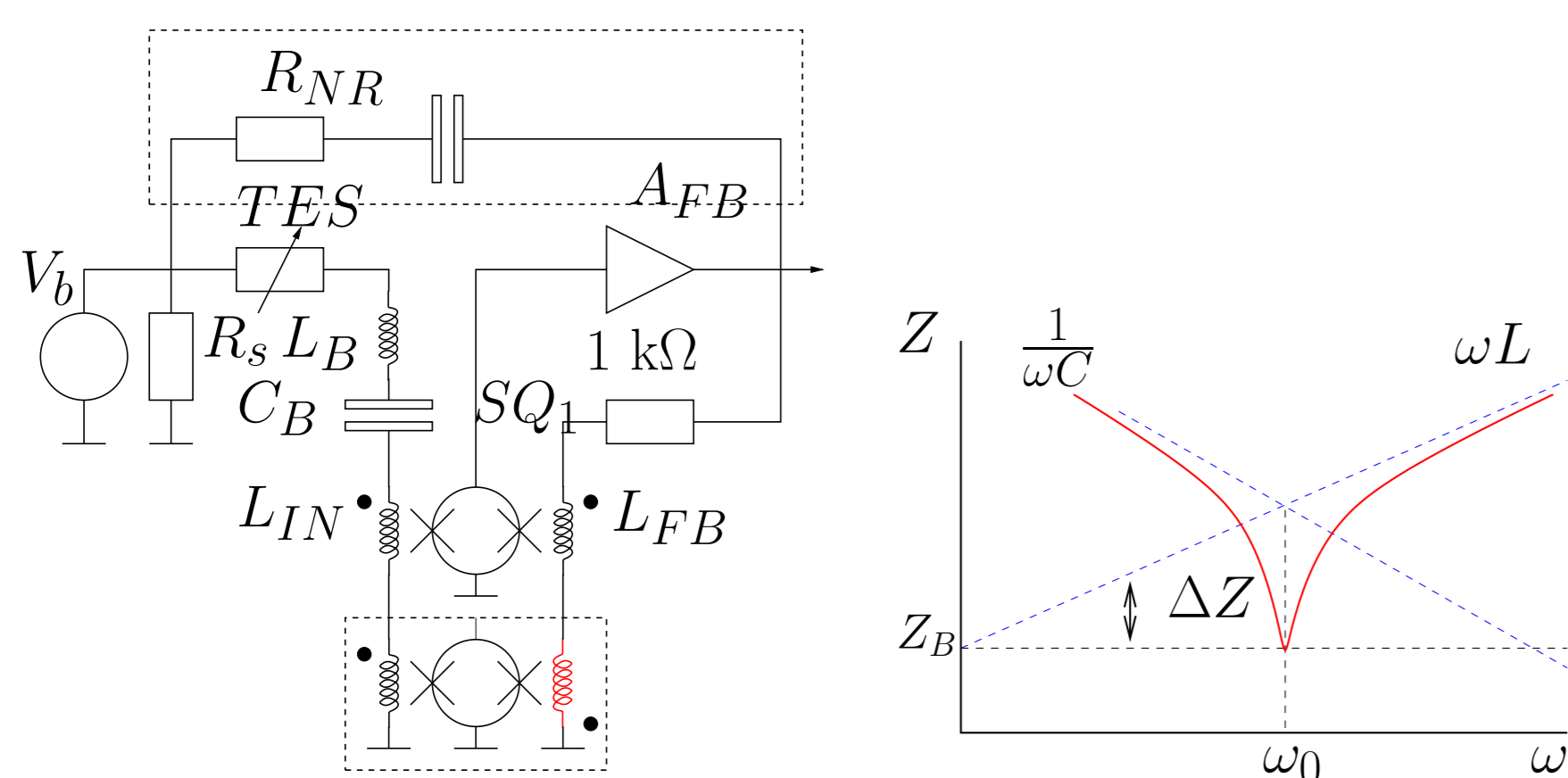
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Introduction



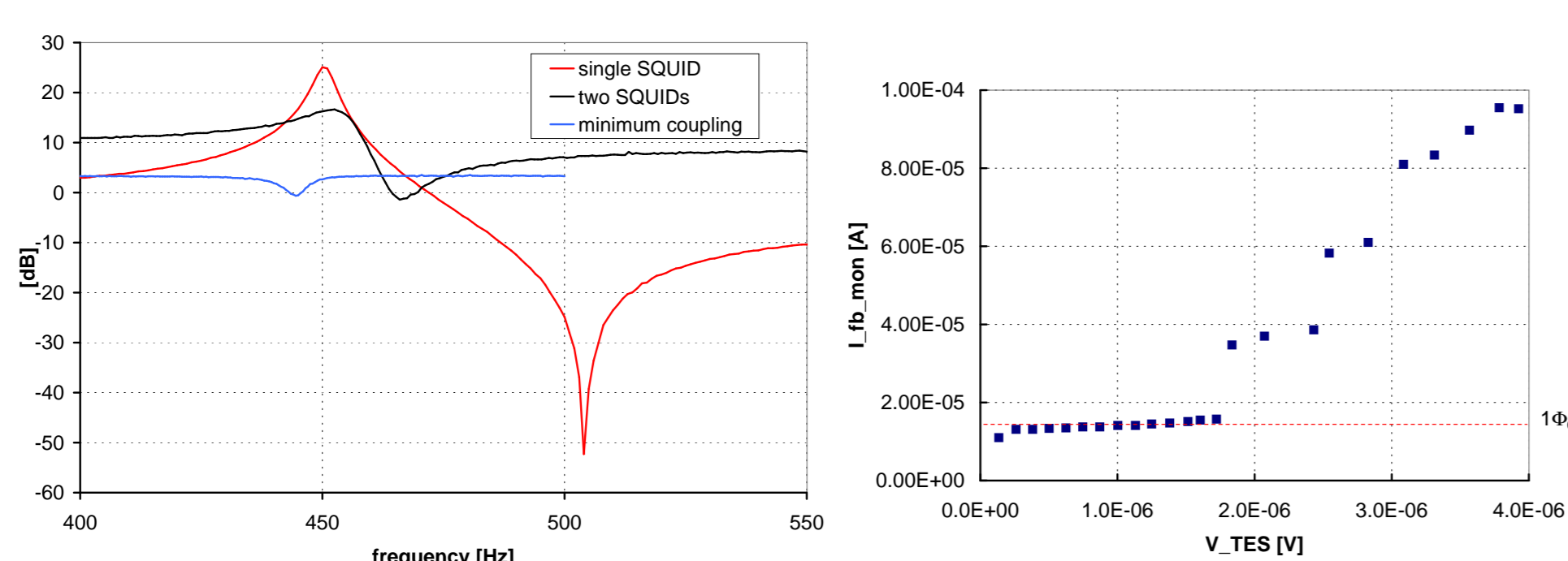
Future X-ray astronomy missions require radiation detectors with high detection efficiency over a large energy band in combination with high energy resolution and imaging. Imaging arrays of microcalorimeters, operating at sub-Kelvin temperature, are considered one of the most promising options. Application of transition edge sensors (TES)-based microcalorimeters arrays are presently under consideration for Constellation-X (NASA) on the X-ray satellite mission XEUS (ESA and ISAS) as well as for several smaller missions.

Experimental Setup



- Voltage source V_b with series resistance $R_s = 4 \text{ m}\Omega$ produce an AC-bias voltage at 500 kHz
- TES is voltage biased (ETF), $R_s < Z_B$
- C_B is a lithographically made superconducting condenser with as dielectricum Ta-Oxide
- SQUIDS are NIST SQUID arrays with $L_{IN} = 0.33 \mu\text{H}$
- at resonance $\omega L_B = -1/(\omega C_B) \Rightarrow \text{Impedance} = Z_B$
- Positive feedback via R_{NR} induces a negative resistance which reduces the series resistance in the bias circuit

Decoupling

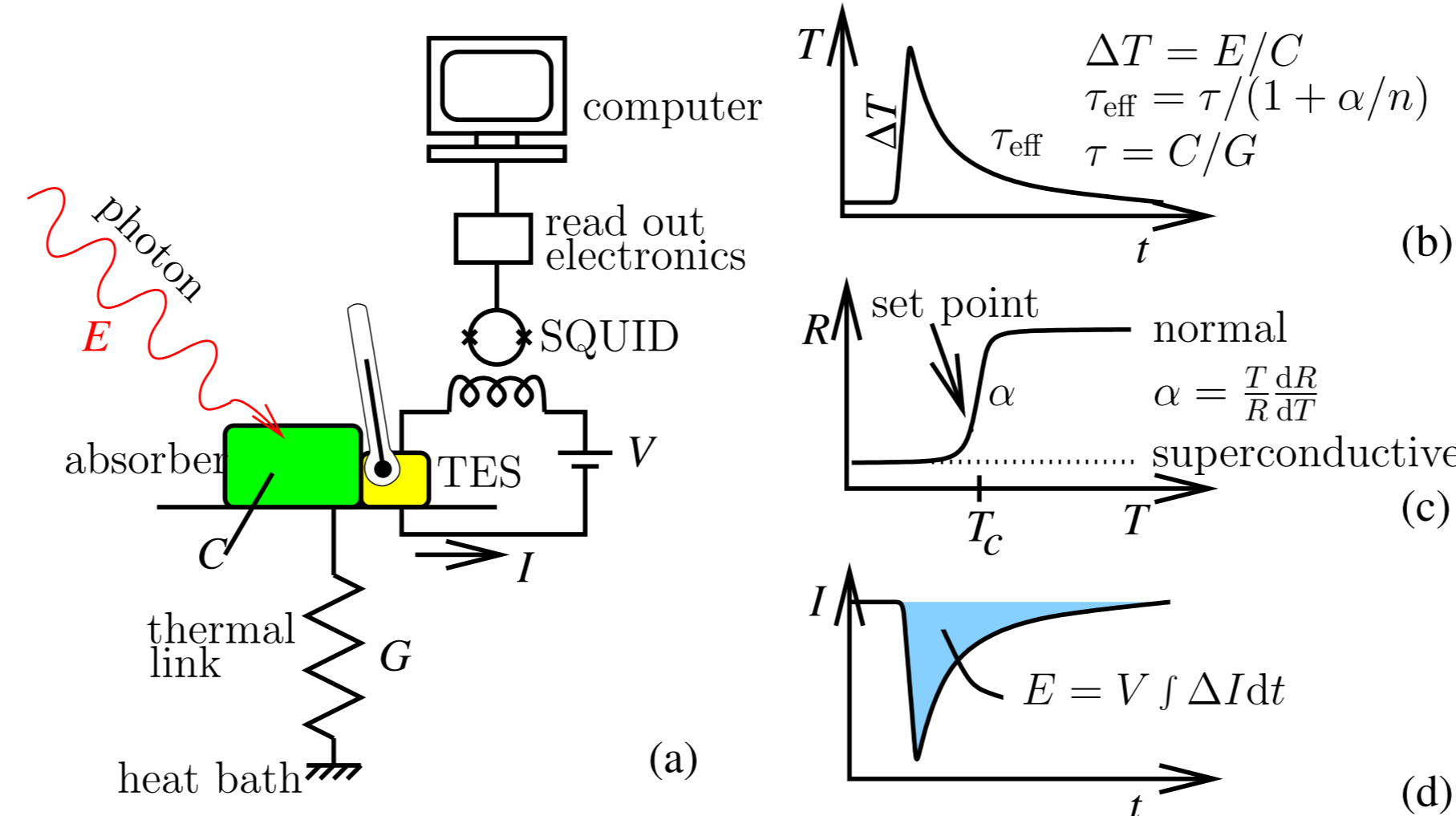


- decoupling by introducing a second SQUID array with inverse connected feedback coil
- 2nd SQUID superconducting \Rightarrow coupling reduced to 43 nH (black)
- both SQUID arrays biased \Rightarrow coupling almost perfect (blue)
- 2nd SQUID results in saturation in FLL as soon as the flux at the 2nd SQUID approaches Φ_0

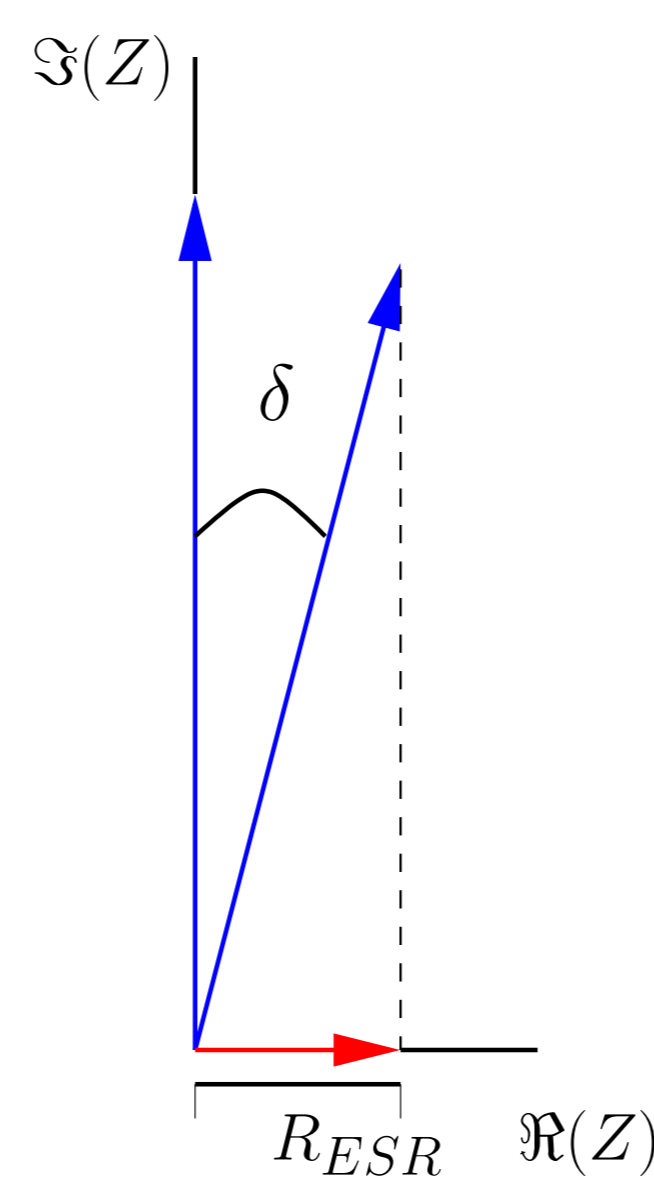
Acknowledgement

This work is supported by the Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO). We also acknowledge supportive discussion with Mikko Kiviranta of VTT microensing, Espoo, Finland and the use of SQUID arrays made available to us by Martin Huber of the University of Colorado Denver, USA.

Transition Edge Sensor Principle



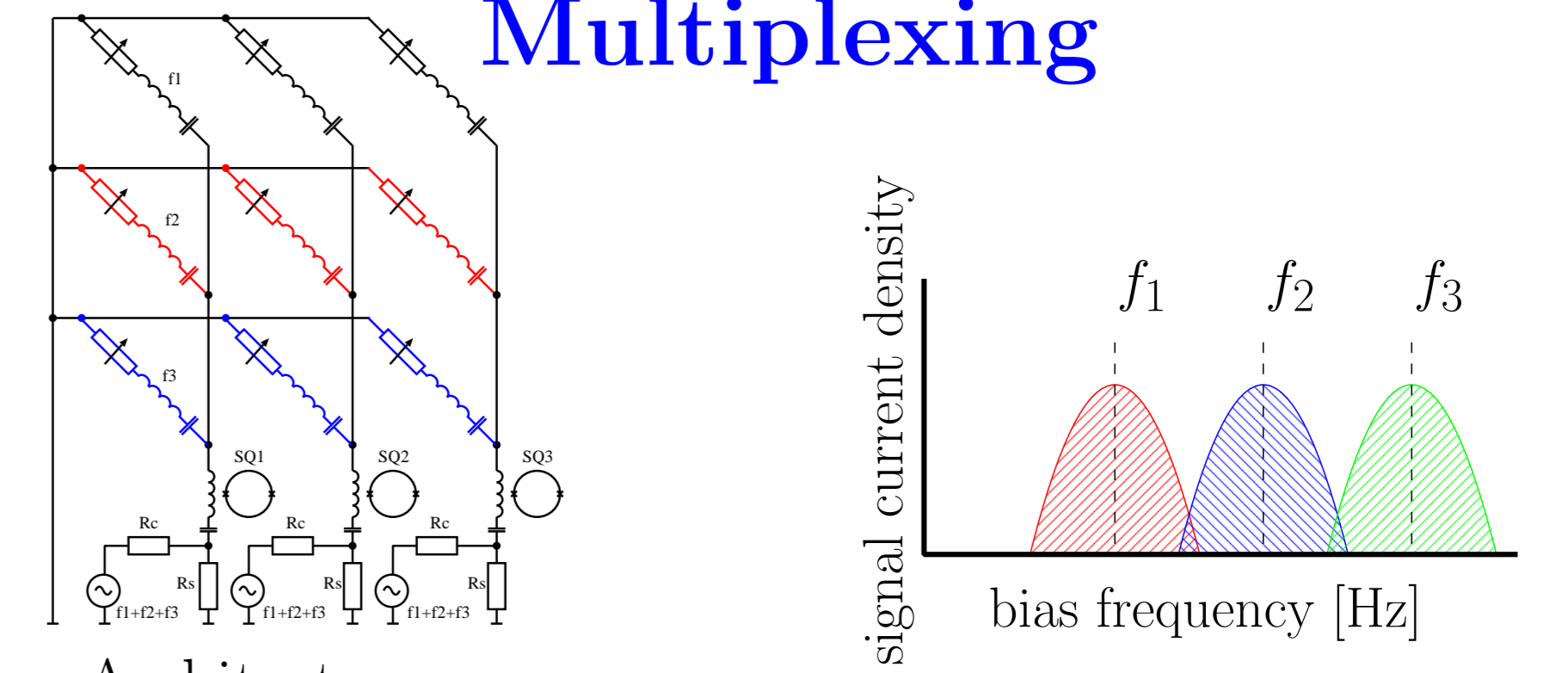
Q-factor



| Material | ϵ_R | $\tan \delta$ |
|--------------------------------|--------------|---------------|
| SiN | 7.8 | 0.0004 |
| Ta ₂ O ₅ | 17 - 26 | 0.014 |
| Al ₂ O ₃ | 9.8 | 0.0002 |
| AlN | 8.8 | 0.0005 |
| Nb ₂ O ₅ | ~ 40 | 0.003 |

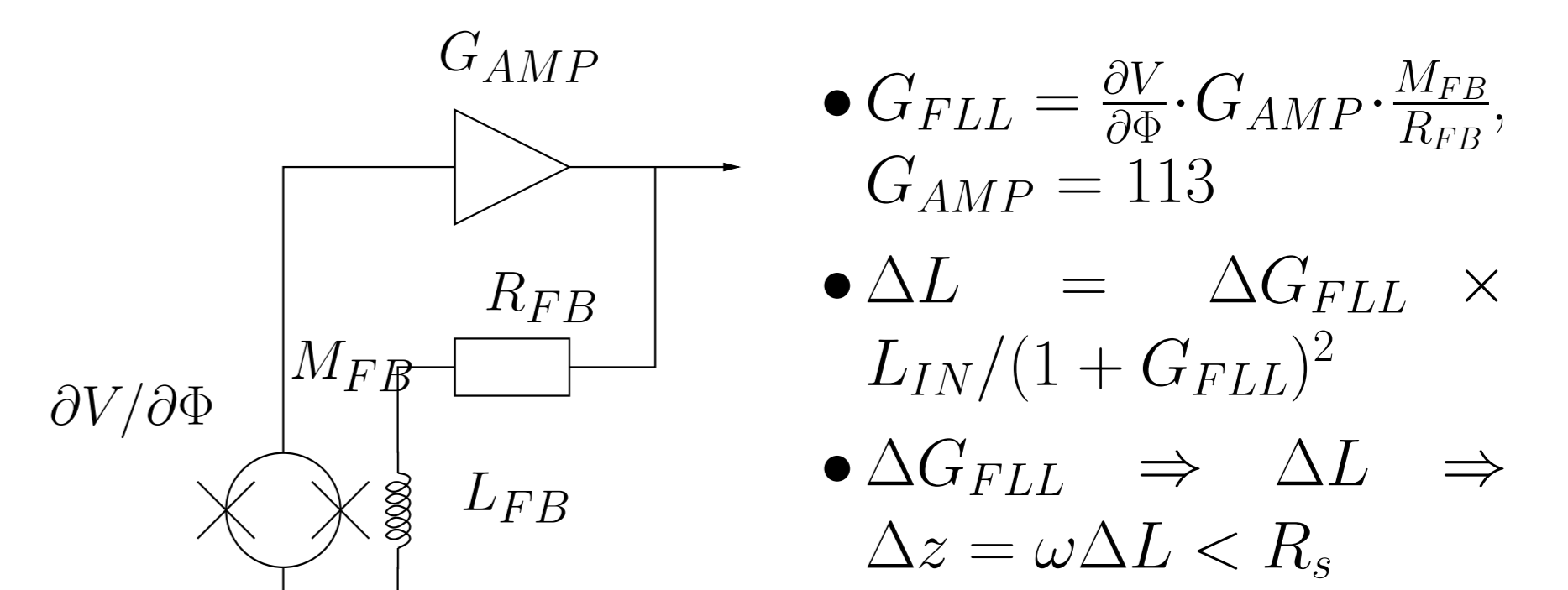
- for good voltage bias $Q = \omega L / (R_s) \approx 800$
- measured $Q \approx 70$ due to dielectric losses in the Ta-Oxide capacitor C_B
- Dielectric losses characterized by loss tangent $\tan \delta = 1/Q = R_{ESR} / (\omega C)$
- extra series resistance compensated by positive feedback, to the bias circuit

Frequency Domain Multiplexing

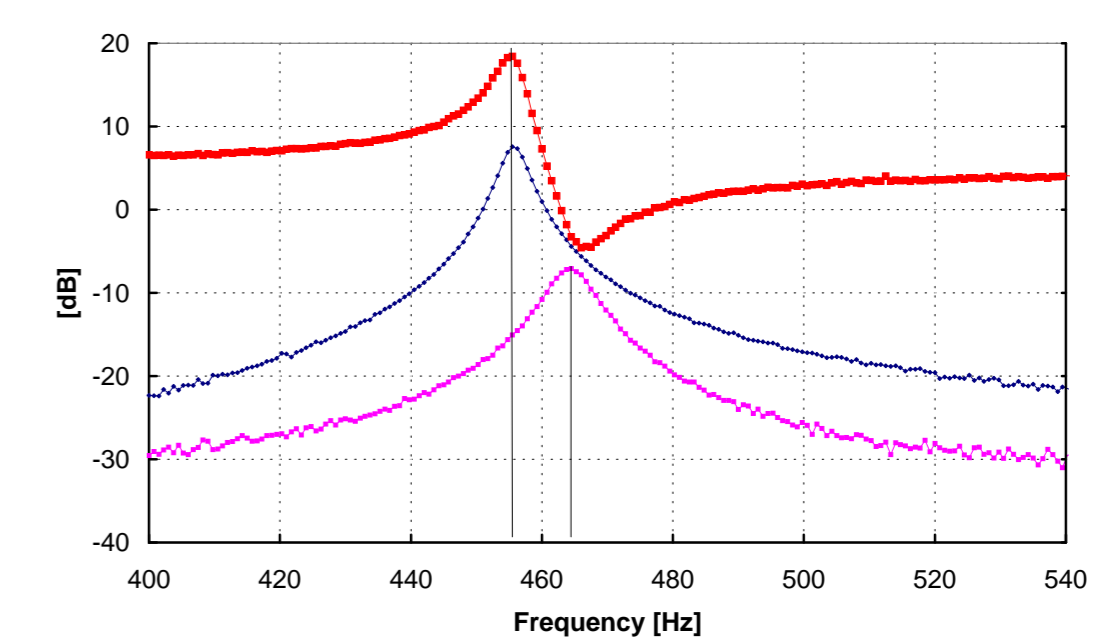


- Architecture
 - row biased at one frequency
 - multi-frequency column read-out with one SQUID
- TES is AM-modulator of AC carrier frequencies
- LC-filters
 - noise blocking of Johnson noise
 - cross talk reduction
 - L/R defines bandwidth
- Bias frequency defines capacitor

FLL at 500 kHz

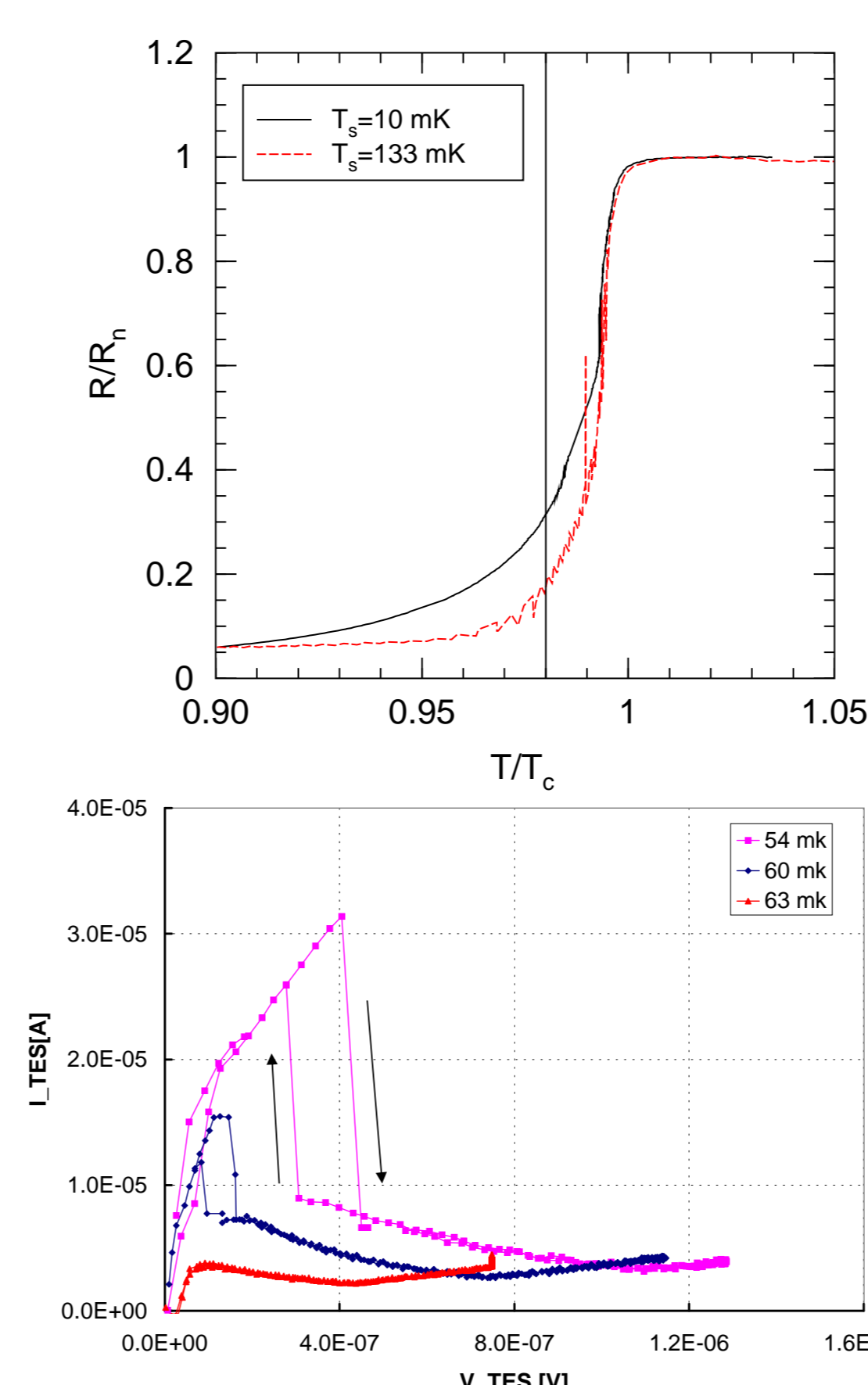


- $G_{FLL} = \frac{\partial V}{\partial \Phi} \cdot G_{AMP} \cdot \frac{M_{FB}}{R_{FB}}$, $G_{AMP} = 113$
- $\Delta L = \Delta G_{FLL} \times L_{IN} / (1 + G_{FLL})^2$
- $\Delta G_{FLL} \Rightarrow \Delta L \Rightarrow \Delta z = \omega \Delta L < R_s$



SQUID response in open loop for a signal on the feedback coil (red) and a signal on the TES (blue). The resonance peak at $\omega = 1/\sqrt{(L_{IN} + L_B)C}$ and the resonance valley at $\omega = 1/\sqrt{(L_{IN} + L_B - L_C)C}$, ($L_C = 230 \text{ nH}$). The resonance frequency in FLL (magenta)

Hysteresis in the I-V curves



- For $T_{\text{bath}} = 54 \text{ mK}$ the TES switches to the superconducting state at about 1/3 of the voltage required to reach the normal state. To switch back to the resistive state a voltage of about 1/2 the normal state voltage is required. For $T_{\text{bath}} = 60 \text{ mK}$ the TES becomes superconducting at 1/8 of the normal state voltage or at $\sim 0.04 R_N$. The resistive state is reached again at 1/4 of the normal state voltage.
- switching due to $R_{\text{TES}} = R(T, I)$, T is constant, I continuously varying.
- hypothesis: measuring I-V with decreasing bias voltage, the TES switches to the superconductive state when $R(T, 0) = 0$ is reached (black line). Hysteresis in I required to switch from resistive to the superconducting state and vice-versa.