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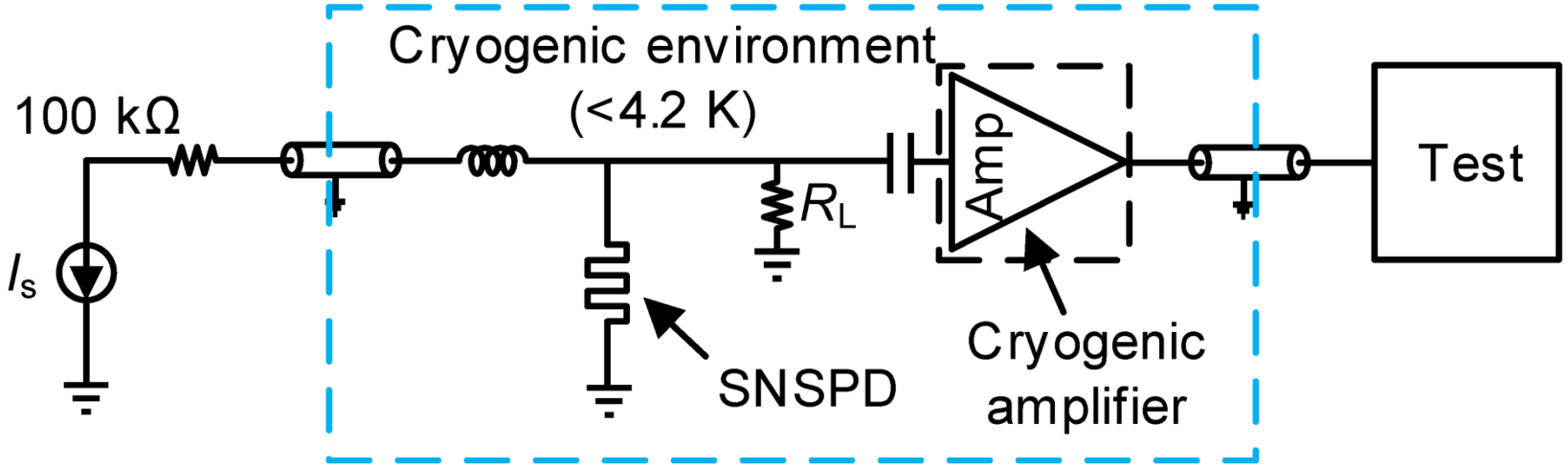
Wideband cryogenic amplifier for a superconducting nanowire single-photon detector

Key words: Cryogenic amplifier; Wideband amplifier; Superconducting nanowire single-photon detector (SNSPD)

Corresponding author: Lianming LI
E-mail: Lianming.LI@seu.edu.cn
ORCID: https://orcid.org/ 0000-0003-1873-4806

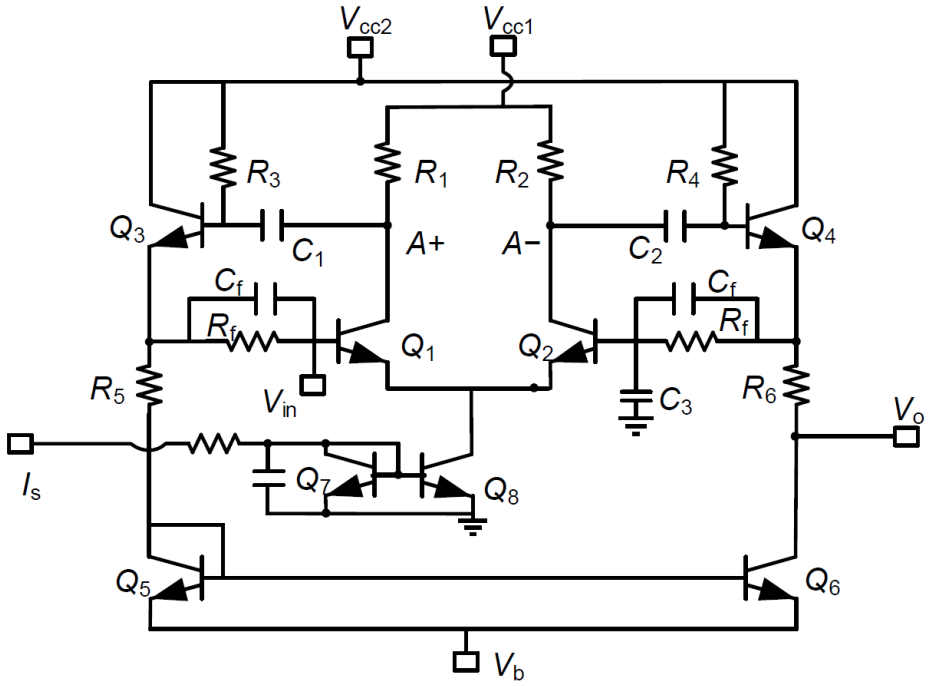
Motivation

- Superconducting nanowire single-photon detector (SNSPD) has a wide range of applications, such as quantum key distribution for quantum communication, free-space optical communication, integrated circuit defect detection, spectrum measurement, and radiation detection.
- Due to the critical cryogenic working environment and very weak output signal, the cryogenic readout amplifier is an indispensable part of the compact SNSPD readout system and faces several challenges in implementation, such as low power, wide bandwidth, and lack of a cryogenic device model.

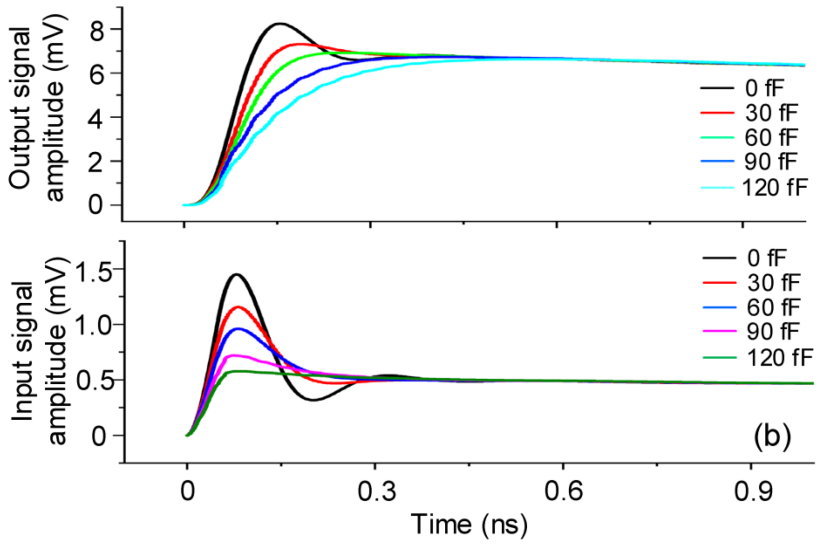


Amplifier design

- Two-stage inductorless wideband amplifier with shunt-shunt feedback: an input amplifier stage and an emitter follower
- Independent DC biasing point
- Increased design and optimization flexibility
- Input impedance matching with optimized stability



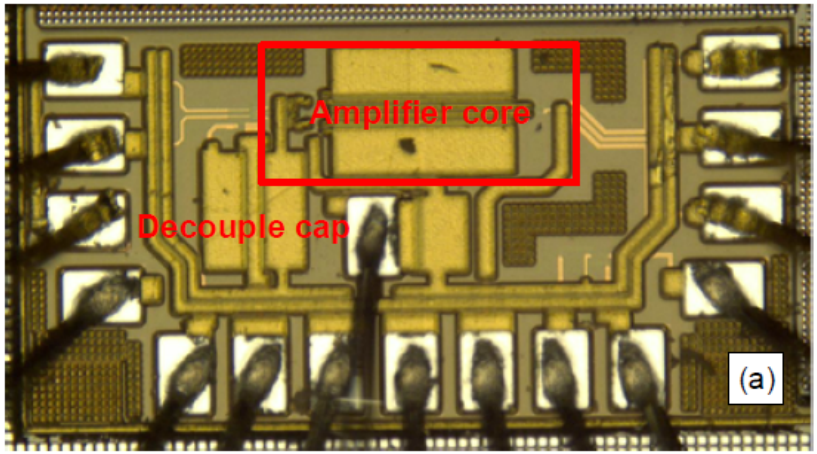
Schematic of the wideband cryogenic amplifier



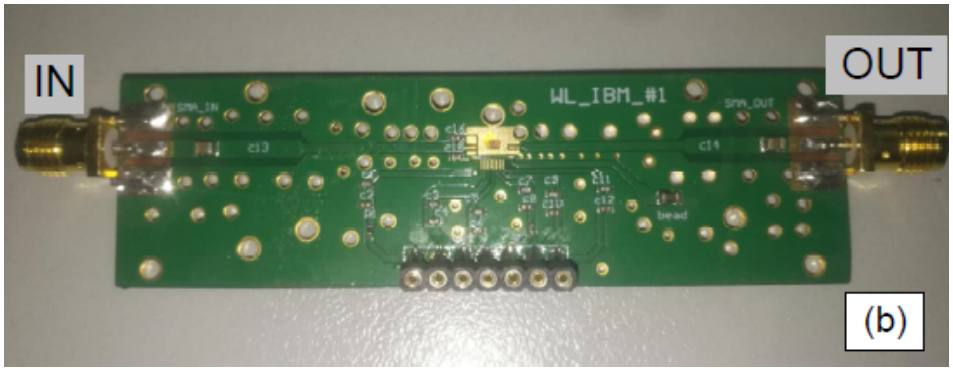
Stability analysis

Chip and PCB

- Fabricated by a 0.13-μm BiCMOS process
- Without using any inductor, and excluding all the test pads, the chip active area is only about 0.43 mm×0.17 mm.

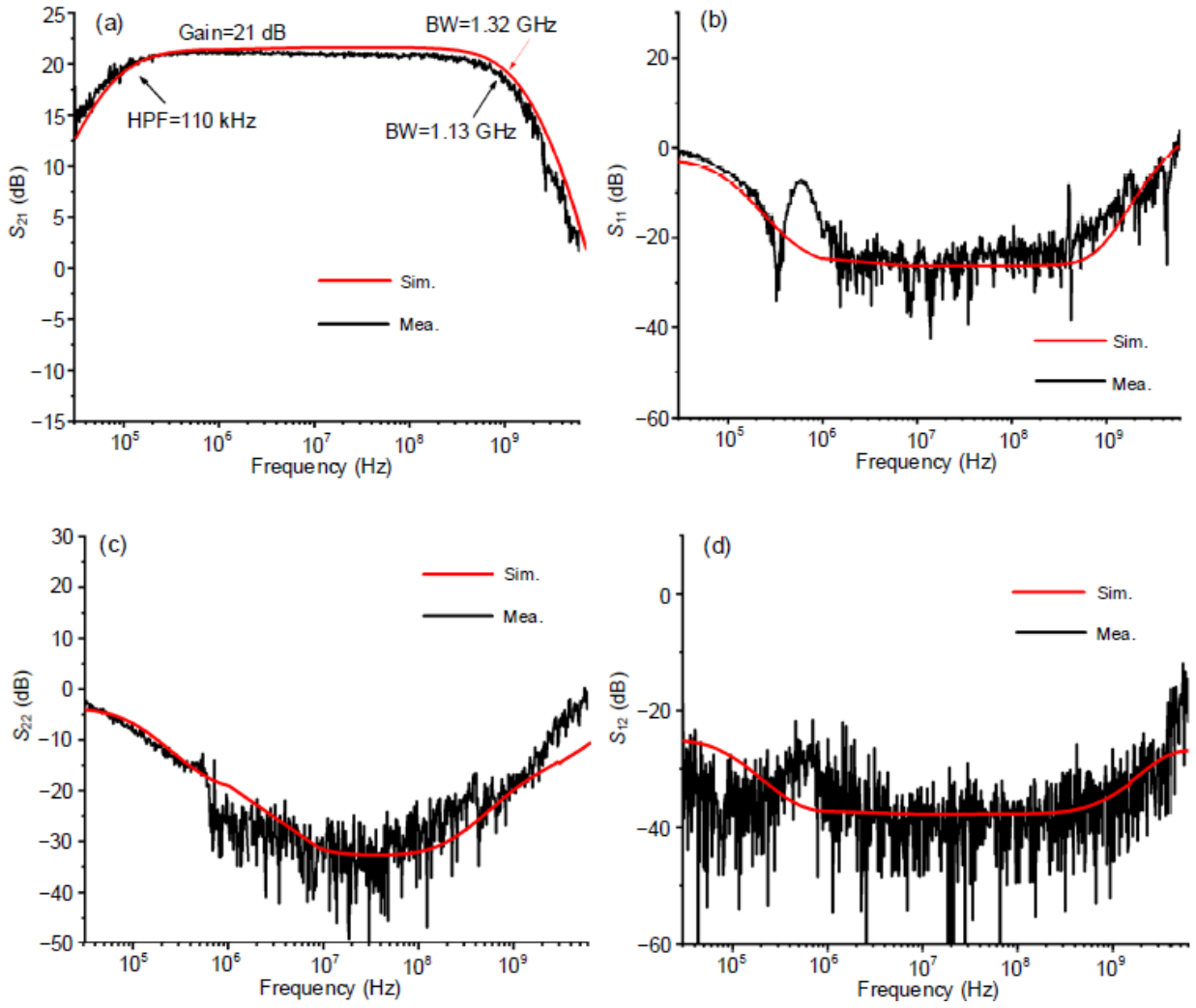


Chip micrograph (1 mm×0.5 mm)



PCB for measurement purpose

Simulation and measurement results @300 K

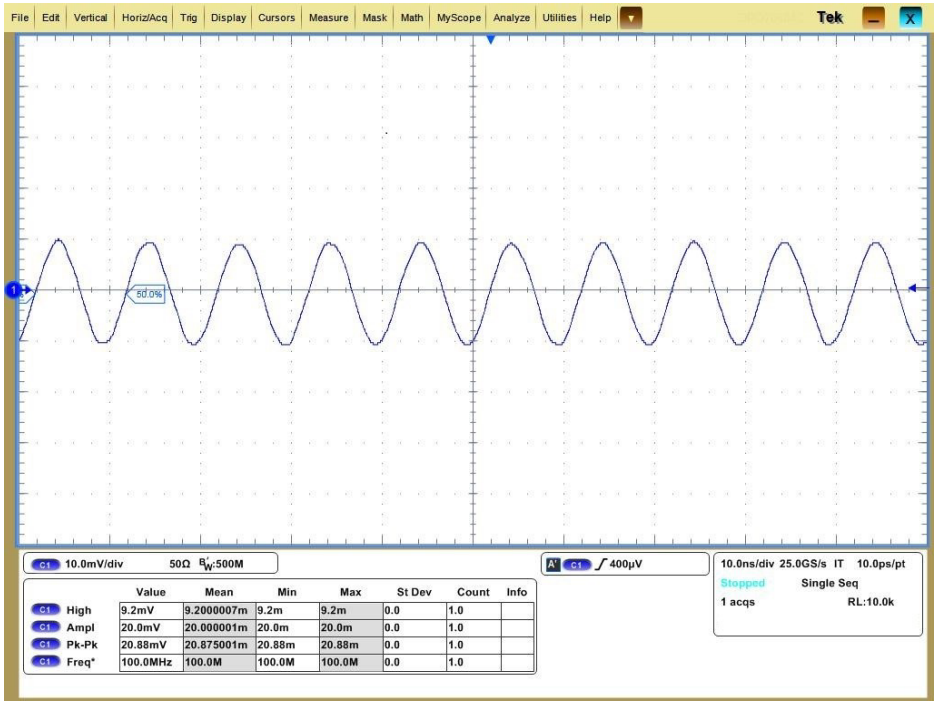


Measured and simulated *S*-parameters at room temperature 300 K

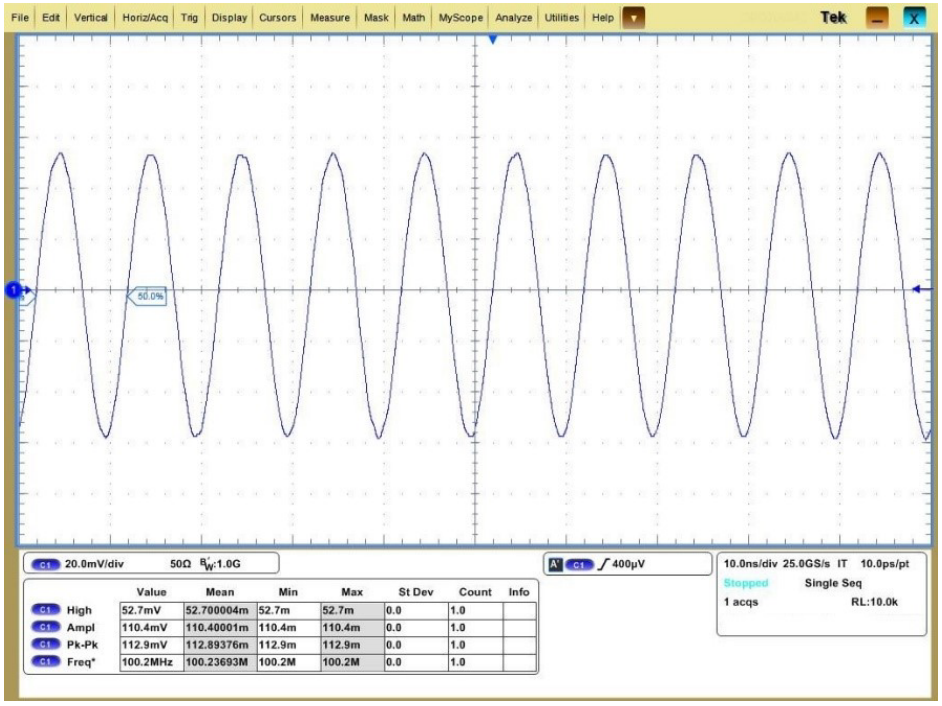
- The amplifier gain in the passband: 21 dB
- Tested bandwidth: 1.13 GHz
- S_{12} is lower than −30 dB, good isolation between amplifier input and output
- Both amplifier input and output return losses are less than −10 dB
- The measurement results agree well with the simulation results

Transient measurement results @300 K

- The measured transient response proved that the amplifier is very stable, agreeing well with the *S*-parameter measurement results, when taking into account the interconnecting line insertion loss.
- Input $P_{1\,dB}$ is −29.4 dBm, and output $P_{1\,dB}$ is −9.4 dBm.

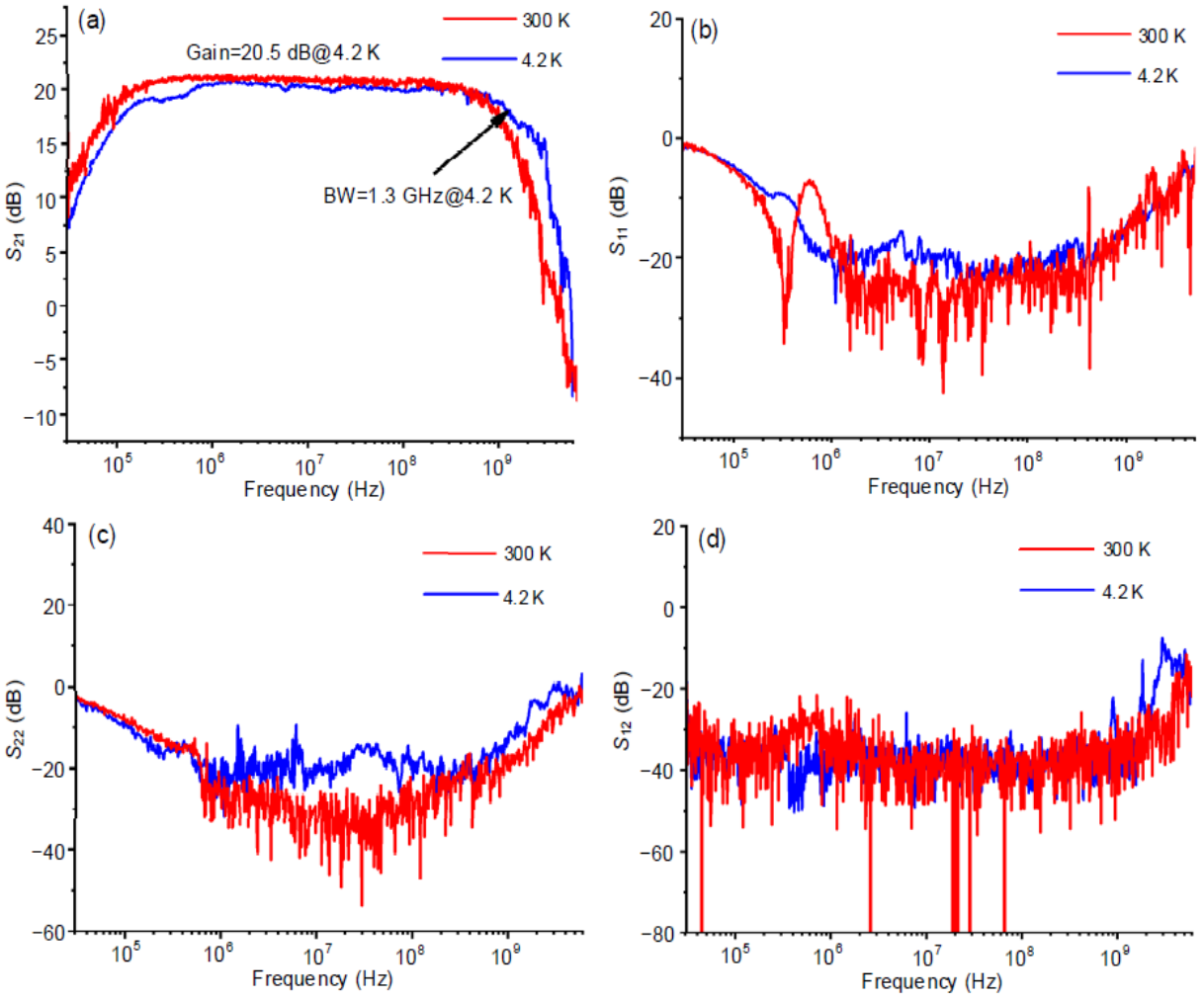


Transient response of output with −50-dBm input at 100 MHz (300 K)



Transient response of output with −35-dBm input at 500 MHz (300 K)

Measurement results @4.2 K and comparison

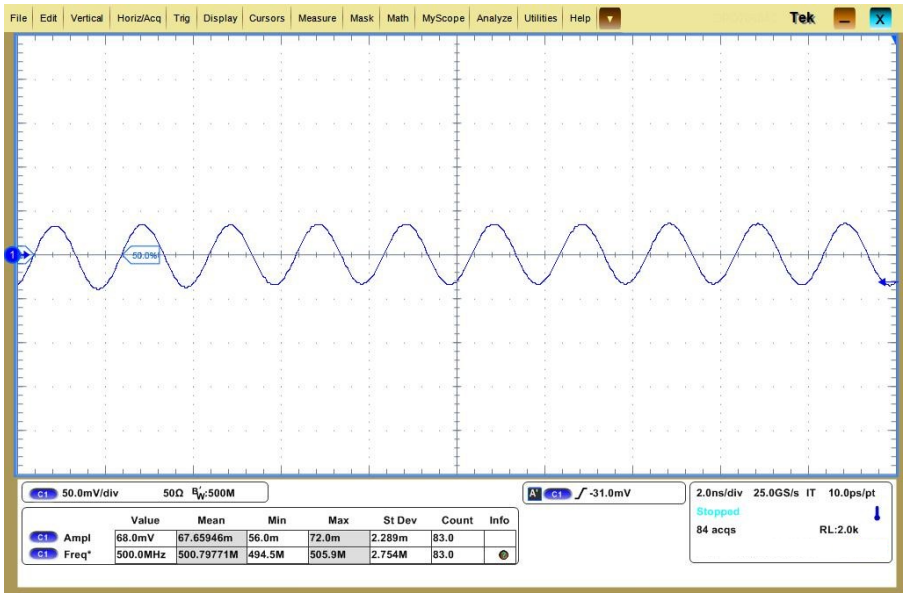


Measured *S*-parameters at 4.2 K and 300 K

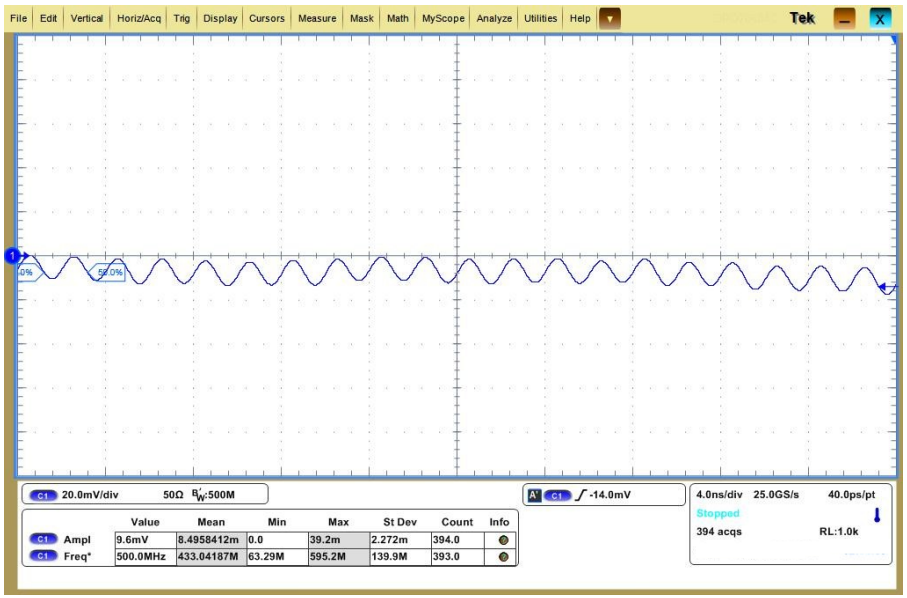
- The amplifier gain and bandwidth @4.2 K: 20.5 dB, 120 kHz to 1.3 GHz
- S_{12}<−30 dB, good isolation between amplifier input and output
- Input and output return losses<−10 dB
- The measured *S*-parameters agree well with each other at 4.2 K and 300 K

Transient measurement results @4.2 K

- The signal quality is quite high, showing no compression or resonance issue and proving that the amplifier is very reliable and stable.
- With −57 dBm input signal, the output signal is still very clear, showing very good signal-to-noise ratio (SNR) and meeting typical SNSPD readout requirements.



The 68-mV 500-MHz output sinusoidal signal at 4.2 K



The 9.6-mV 500-MHz output sinusoidal signal at 4.2 K

Conclusions

- With a 0.13-μm SiGe BiCMOS process, a low-power inductorless wideband cryogenic amplifier was produced for a superconducting nanowire single-photon detector.
- By highlighting the relationship between the gain and the tunable design parameters, this amplifier can operate at temperatures from 4.2 to 300 K.
- An RC shunt compensation structure was introduced to improve the amplifier's closed-loop stability and to suppress the amplifier overshoot.
- With good input and output matching, the measurement results showed that the amplifier achieved a 21-dB gain with a 3-dB bandwidth of 1.13 GHz at 300 K.
- At 4.2 K, the gain of the amplifier can be tuned from 15 to 24 dB, achieving a 3-dB bandwidth spanning from 120 kHz to 1.3 GHz and consuming only 3.1 mW.



李连鸣，博士，研究员。2001年毕业于东南大学物理系，后保送至东南大学无线电工程系（现信息科学与工程学院）攻读硕士学位，毕业后留校。2006年赴鲁汶大学MICAS（微电子及传感器）小组攻读博士学位，师从Michiel Steyaert、Patrick Reynaert教授。作为该组60 GHz毫米波电路方向第一位博士生，从事CMOS毫米波电路设计研究。2011年从鲁汶大学博士毕业后，受聘于东南大学，参与并主持多项CMOS毫米波及太赫兹重大课题、自然基金及重点研发项目研究工作。其所在团队从零开始，两年内即完成国内第一块基于CMOS工艺60 GHz毫米波射频前端单片收发系统及封装模组，实现高清视频业务传输。在IEEE JSSC、T-MTT、TAP、T-CPMT等期刊、会议发表论文60余篇。研究兴趣包括通信及雷达用高频毫米波系统、模拟和射频集成电路、封装天线设计等。



何龙，博士，2014年博士毕业于东南大学，后加入紫金山网络通信与安全实验室。研究兴趣包括低温集成电路、低功耗宽带模拟基带电路、电源管理电路等高性能模拟集成电路设计。