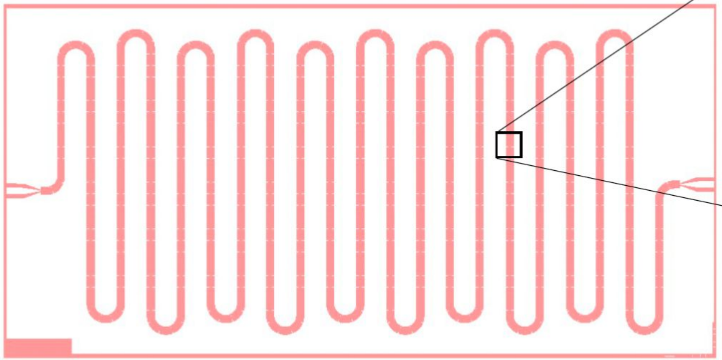
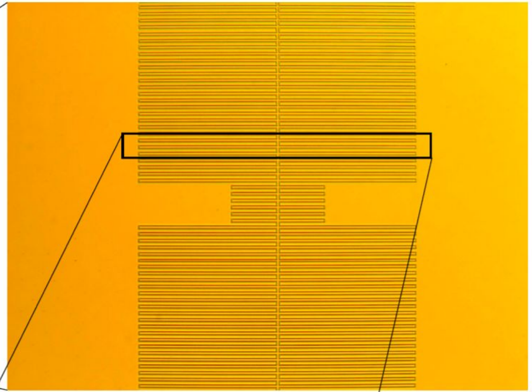
TWPA Characterization

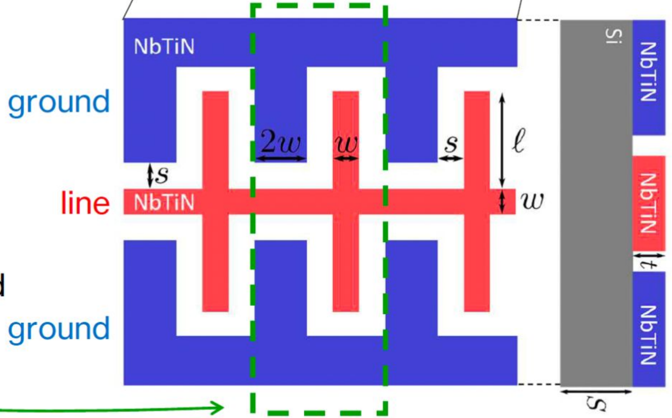
Pietro Campana, Rodolfo Carobene, Marco Gobbo
December 21, 2023

University of Milano-Bicocca, INFN Milano-Bicocca
Bicocca Quantum Technology Centre

Chip design





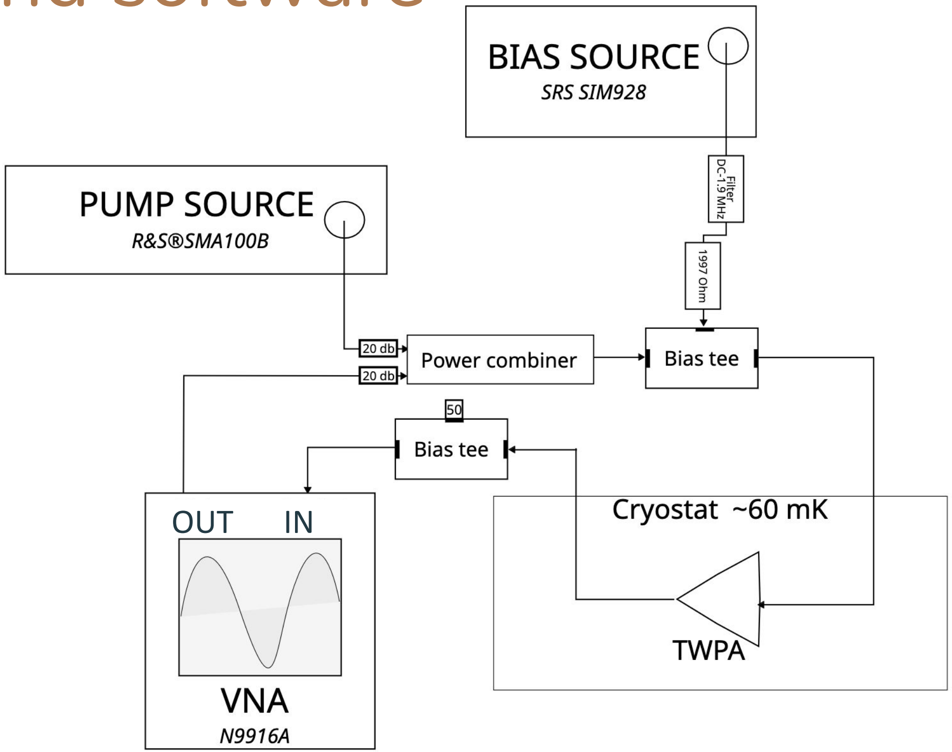


- Chip size: 2 cm × 1 cm
- Total length 17.5 cm
- $s = w = 1$ µm ⇒ cell length: 5 µm
- $N_{sc} = 523, N_u = 60, N_l = 6 \Rightarrow N_c = 34'518$
- ℓ = 102 µm for unloaded cells, 33.5 µm for loaded ones
- $S = 525$ nm
- $t = 13$ nm

Experimental setup and software

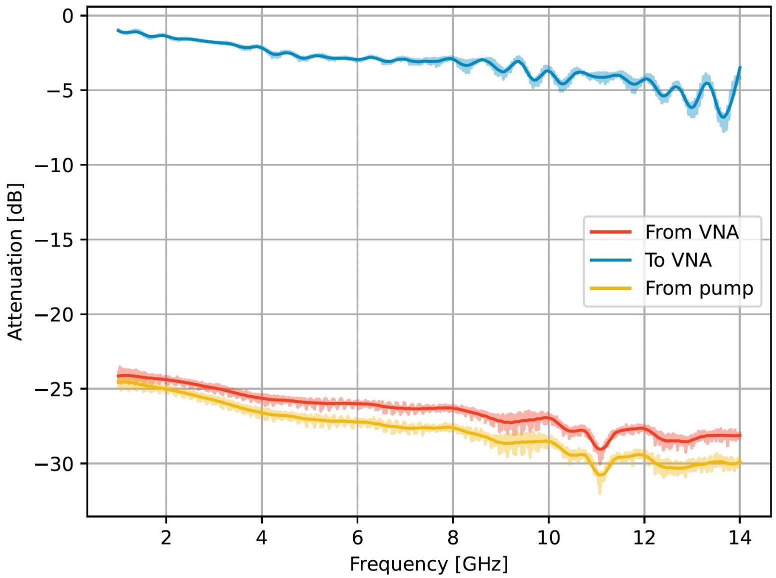
Controlled devices:

- R&S®SMA100B RF and microwave signal generator **to provide the pump signal f_p**;
- Isolated voltage source Stanford Research Systems SIM928 **to provide the bias current I_{bias}**
- Handheld Microwave Analyzer FieldFox N9916A **to provide the signal and measuring the response**

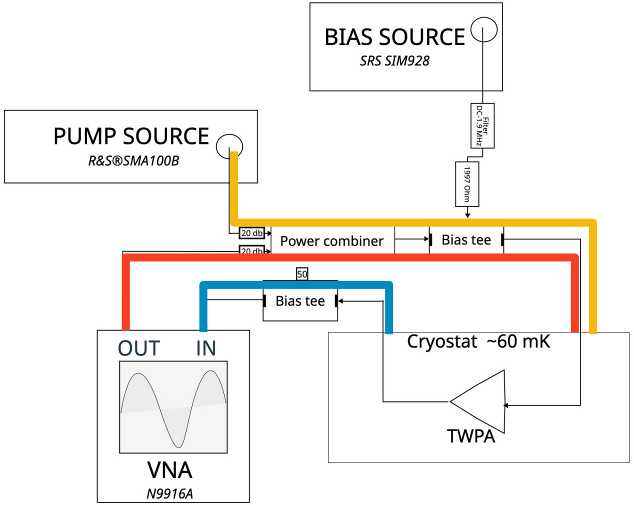


Qinst - Instrumentation Tools for the BiQuTe Lab
https://github.com/biqute/qinst

Attenuations



- Internal attenuations estimated assuming symmetric lines inside the cryostat

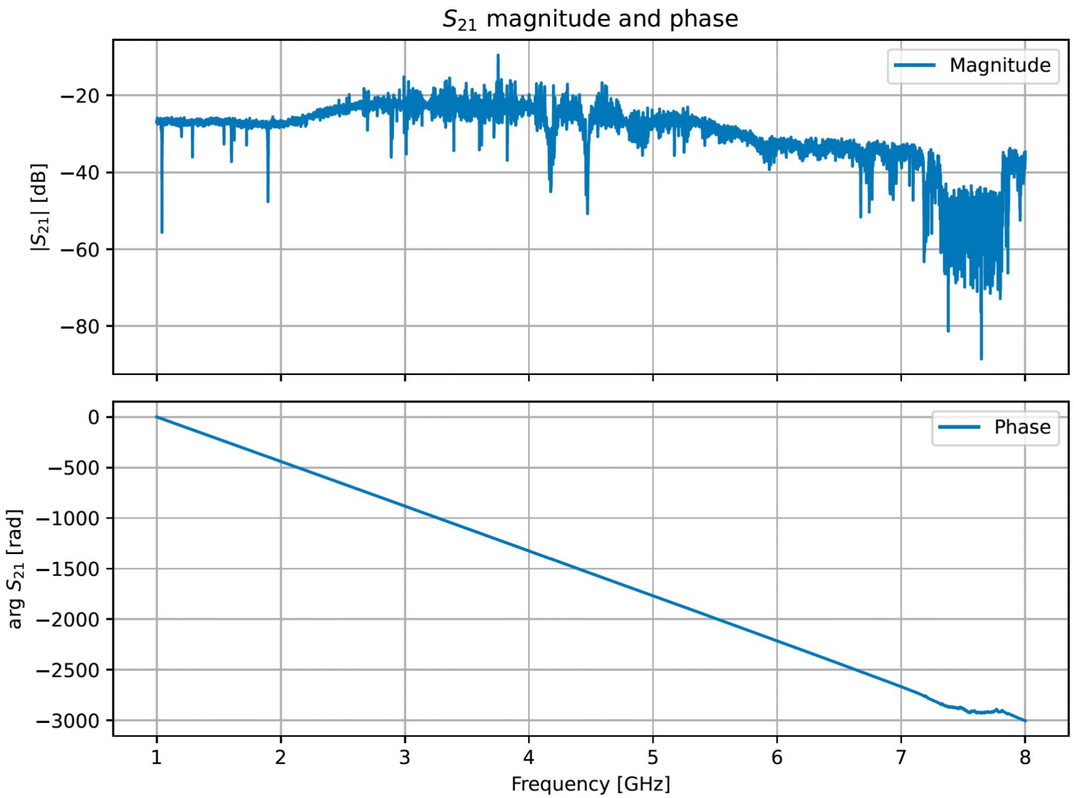


	@ 4 GHz	@ 8 GHz
From VNA	- 25.64 dB	- 26.3 dB
To VNA	- 2.18 dB	- 2.94 dB
From pump	- 26.61 dB	- 27.61 dB
Internal line	- 2.55 dB	- 5.17 dB

Stop band

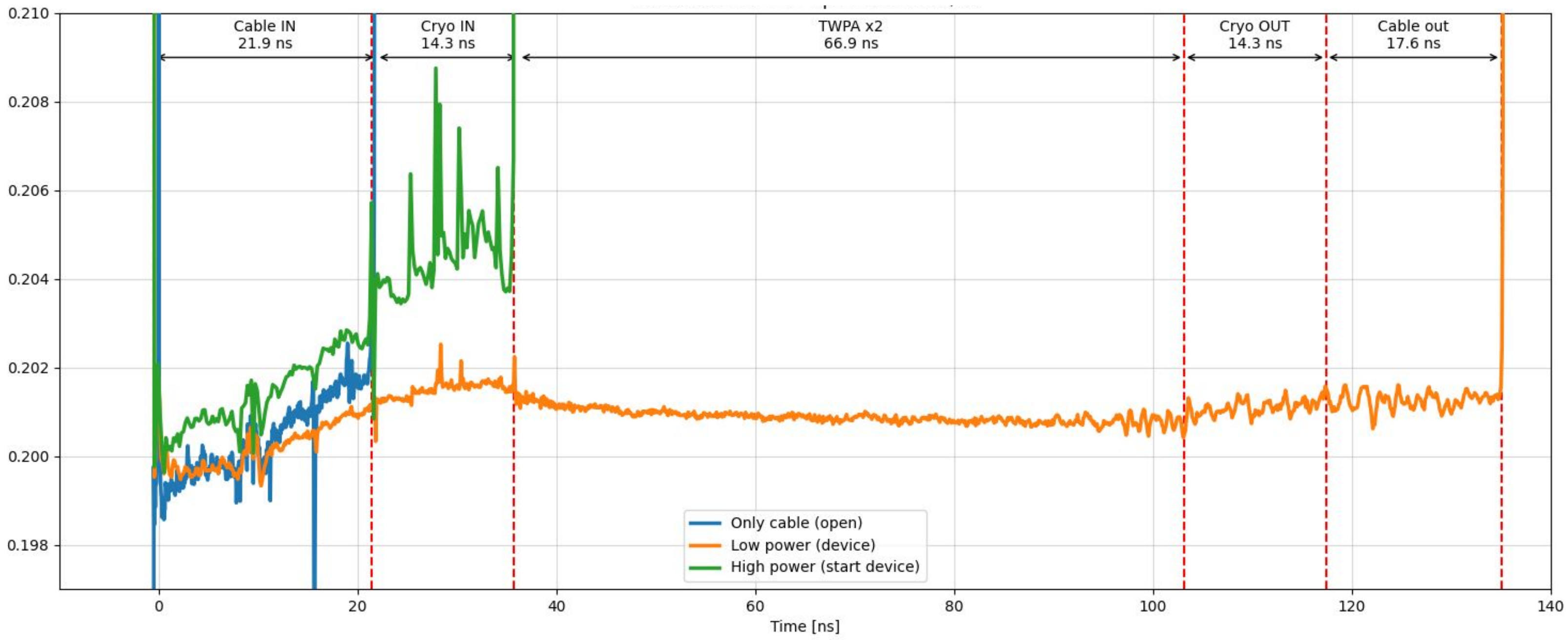
- Major resonances in amplification band from packaging
- Estimation of phase velocity from stop-band central frequency:

$$\begin{aligned} v_p &= \lambda f_b \\ &= 2 \cdot 66 \cdot 7.7 \text{ GHz} \\ &= 1016 \text{ cells/ns} \end{aligned}$$



TDR and Phase velocity

$$v_p = \frac{N_{\rm sc} \cdot L_{\rm sc}}{\Delta t_{\rm TWPA}} = \frac{523 \cdot 66}{33.51\ \text{ns}} = 1030\ \text{cells/ns}$$

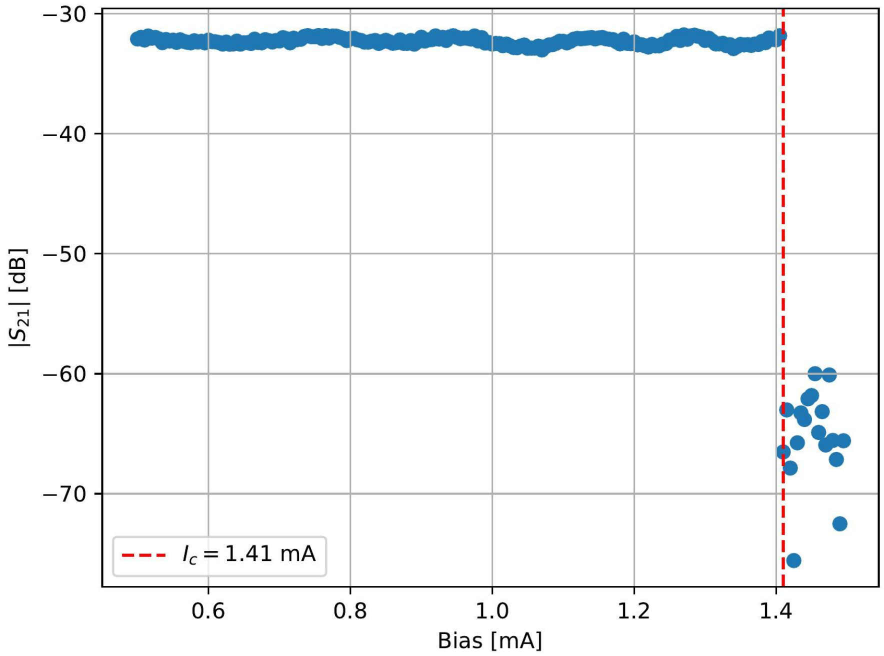


S21 Vs Bias: critical current

- For a fixed frequency, determined by discontinuity in S21 amplitude vs bias:

$$I_c = 1.41 \pm 0.01\text{mA}$$

- Results are consistent over the whole 1-10 GHz range and with the result (1.53 mA) published in *Phys. Scripta 98 (2023) 12, 125921*



S21 Vs Bias: I*

- For a fixed frequency *f*, fit rescaled phase of S21 as function of bias current:

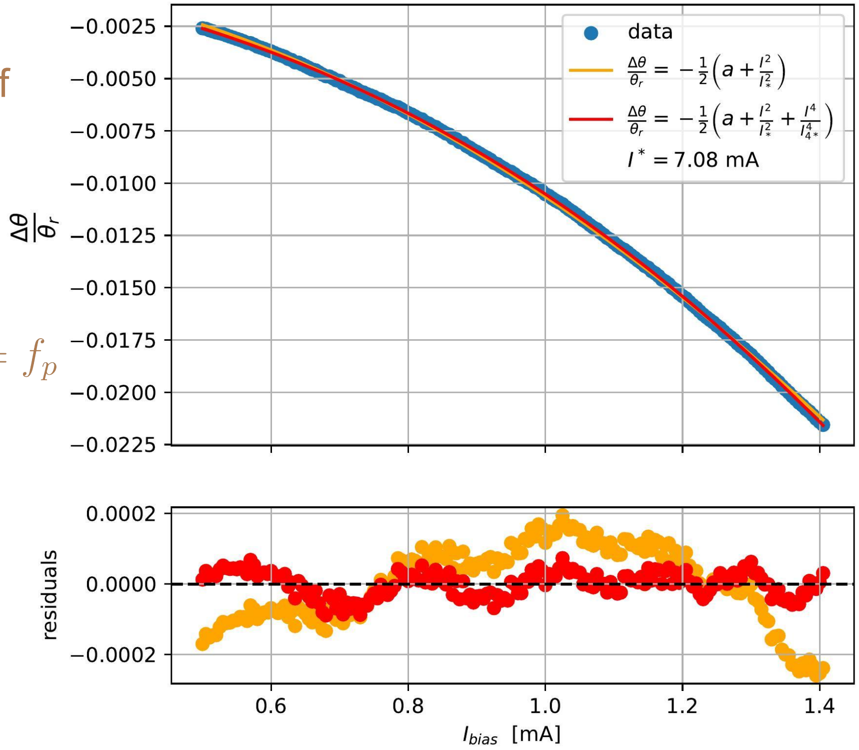
$$\frac{\Delta\theta}{\theta_r} = -\frac{1}{2}\left(\frac{I_b^2}{I_*^2}\right) \qquad \theta_r = 2\pi f \Delta t_{\text{TWPA}}$$

- Consistent alternative estimate of θ_r at $f = f_p$

$$\theta_r(f_p) = 1673 \sim \pi N_{sc} = 1643$$

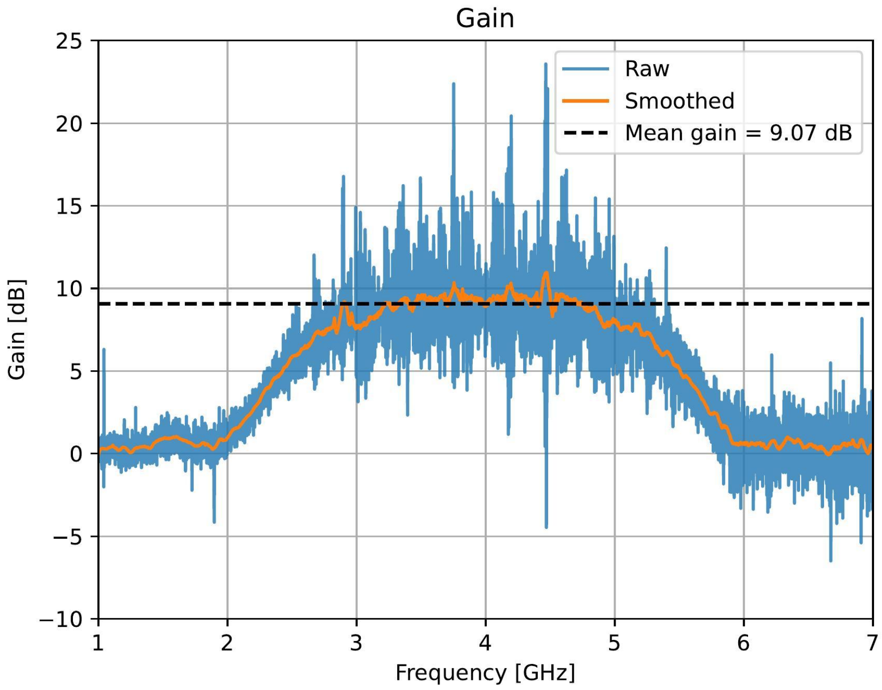
- Best results with quartic fit
- Overall estimate similar to one published (I_c = 5.3 mA)

$$I_* = 7.06 \pm 0.11 \text{ mA}$$



Gain and bandwidth

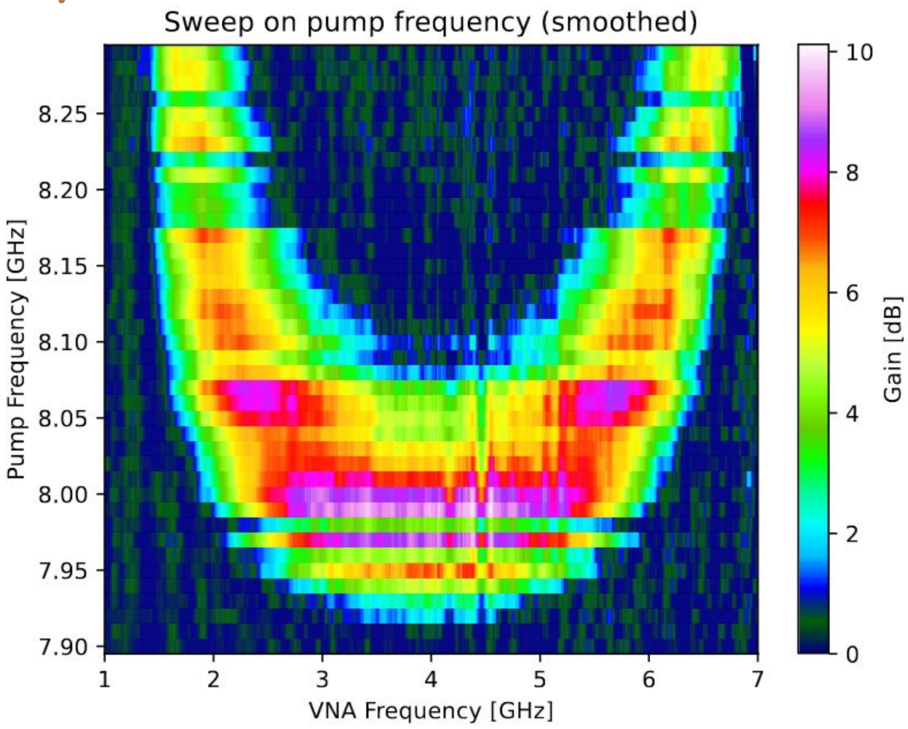
- Max gain = + 10.11 dB
- Average gain = + 9.07 dB
- Bandwidth = [3 - 5] GHz
- Large ripples due to standing waves traveling across the device



Gain Vs Pump frequency

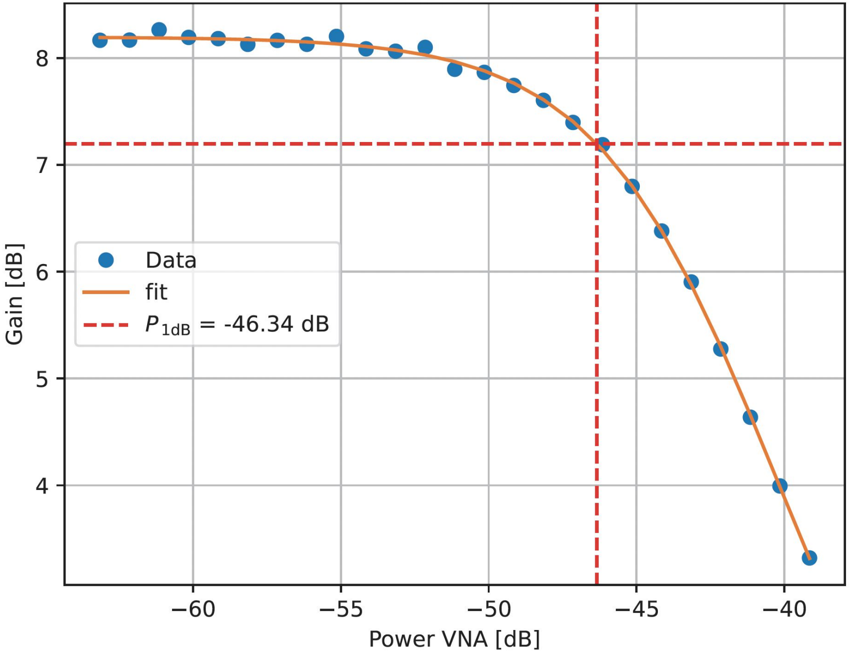
- Observed splitting of the amplification band with increased pump frequency

- Max gain = + 10.11 dB
  - Pump frequency = 7.99 GHz
  - Pump power = - 39.4 dB
  - I_{bias} = 1.2 mA



1-dB compression point

- Overall gain as a function of signal power
- Corrected for external and internal cable attenuation

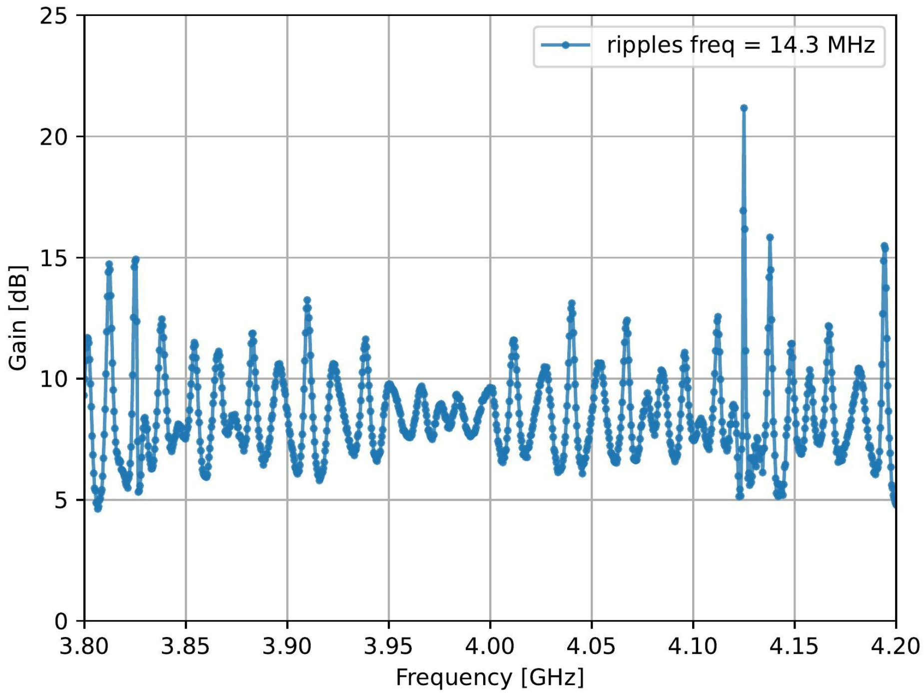


Ripples

- Ripples frequency estimated from peaks in FFT of the gain profile

- Ripple length is approximately integer multiple of device length, consistent with standing waves

$$\frac{v_p}{N_{sc} L_{sc} f_{ripple}} = 2.08$$



Results

Stopband frequency	7.7 GHz
Phase velocity	1016 cells/ns
Amplification bandwidth	3 - 5 GHz
1-dB compression point	-46.34 dB
Ripple frequency	14.3 MHz
Critical current	1.41 mA
I^*	7.06 mA

Max gain	10.11 dB
Optimal pump frequency	7.99 GHz
Optimal pump power	-39.4 dB
Optimal bias current	1.2 mA