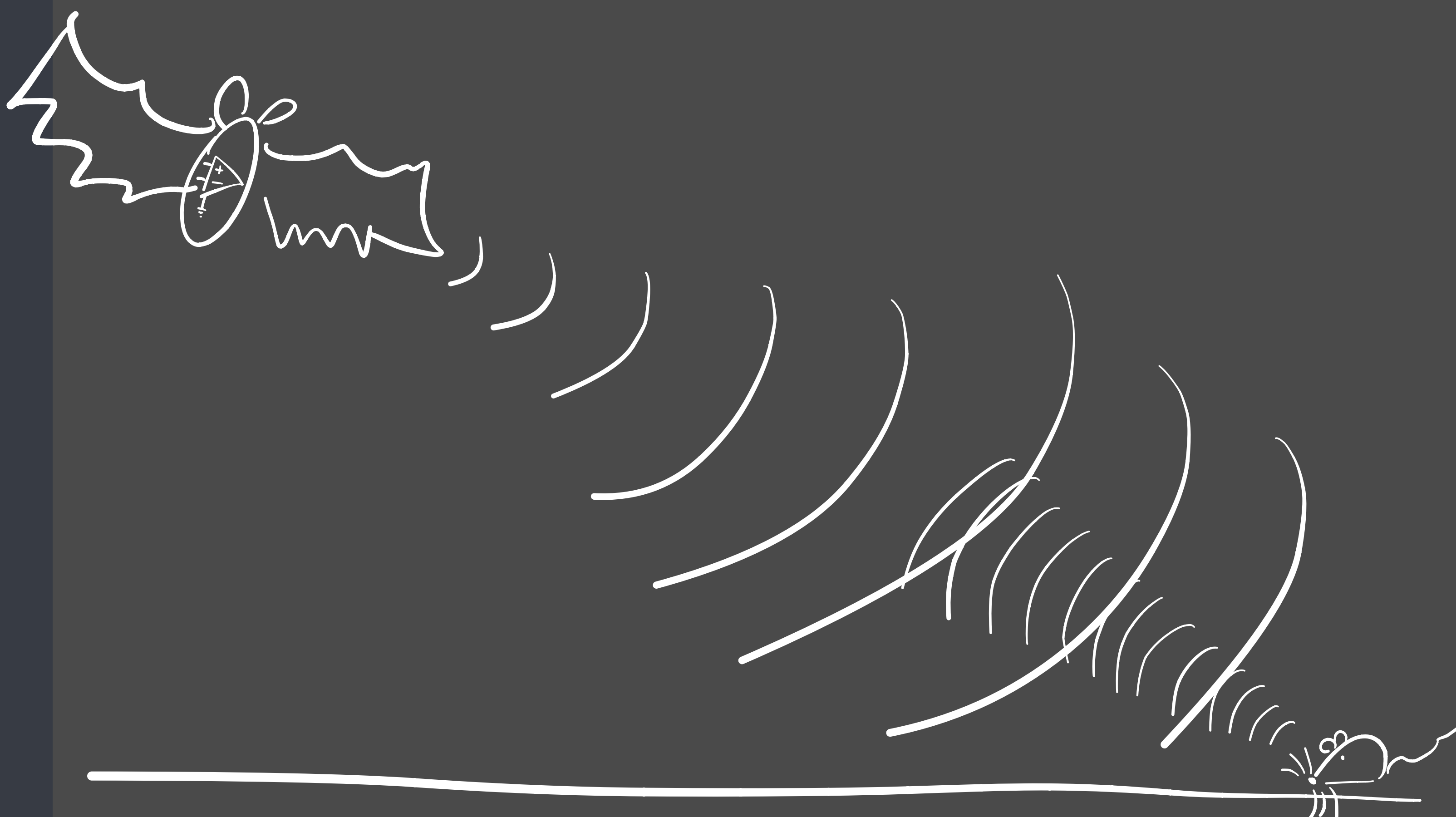
Virtual-Spin J C

Fast single-charge sensing /w a RF quantum point contact



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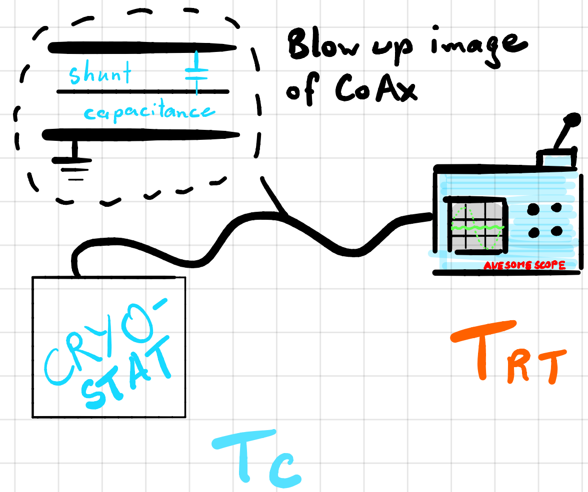
May 19th, 2020

INTRO

- SETs & QPCs → sensitive & non-invasive

- BUT, speed of operation limited by large $\tau = RC$ and shunt capacitance of wire →



$$\tau = RC \quad \begin{cases} R > 50\,k\Omega \\ C \approx 100\,pF \end{cases}$$

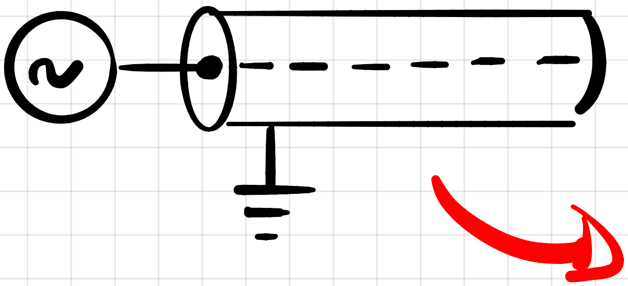
→ Plays large role in DC meas.

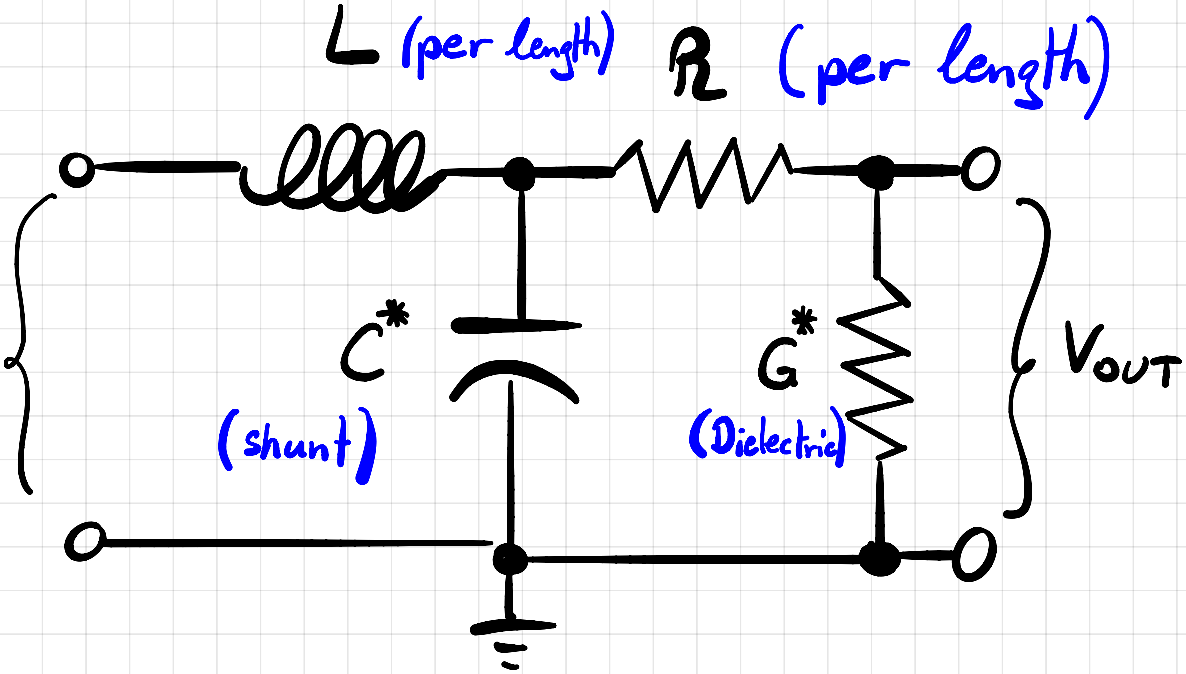
- Solve this issue /w impedance matching network toward typ. $Z_0 = 50\,\Omega$ of trans. line. (AC)

- Also desire high f → 1/f noise $\xrightarrow{(f \gg 1)}$ 0 (AC)

Quick detour „The TL-model"

Regular CoAx:





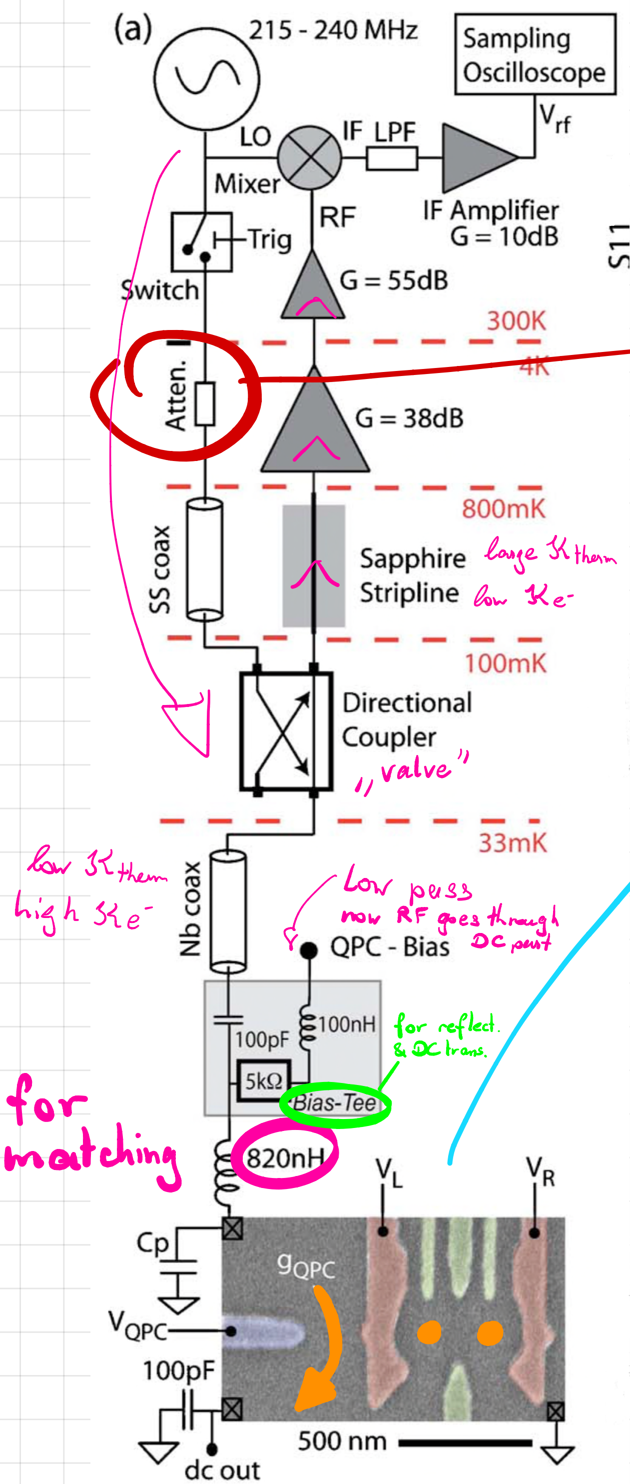
$$Z_0 = \sqrt{\frac{R + i\omega L}{G + i\omega C}} \rightsquigarrow Z_0 = \sqrt{\frac{L}{C}}$$

lossless line (what we mainly care about in AC, + simpler)

Attempt to match this Z_0 by choosing an L' down @ sample s.t. together w/ C' from bonds the resulting LC-circ. matches Z_0.

Reflection: $\Gamma = \frac{Z' - Z_0}{Z' + Z_0} \xrightarrow{(Z' \to Z_0)} \emptyset$ changes of Z' coming from sample, manifest in reflected signal.

Device

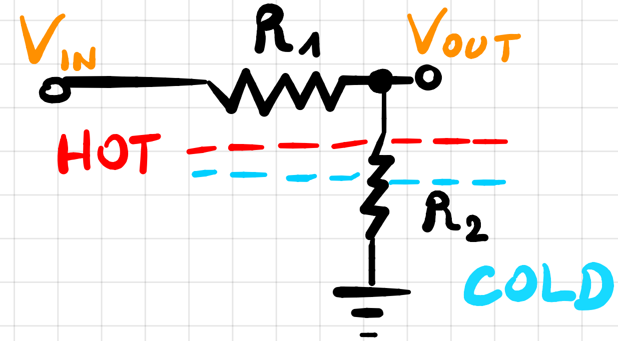


attenuators: i) better SNR

ii) thermalization through electrons

$$V_{OUT} = V_{IN} \frac{R_2}{R_1 + R_2}$$

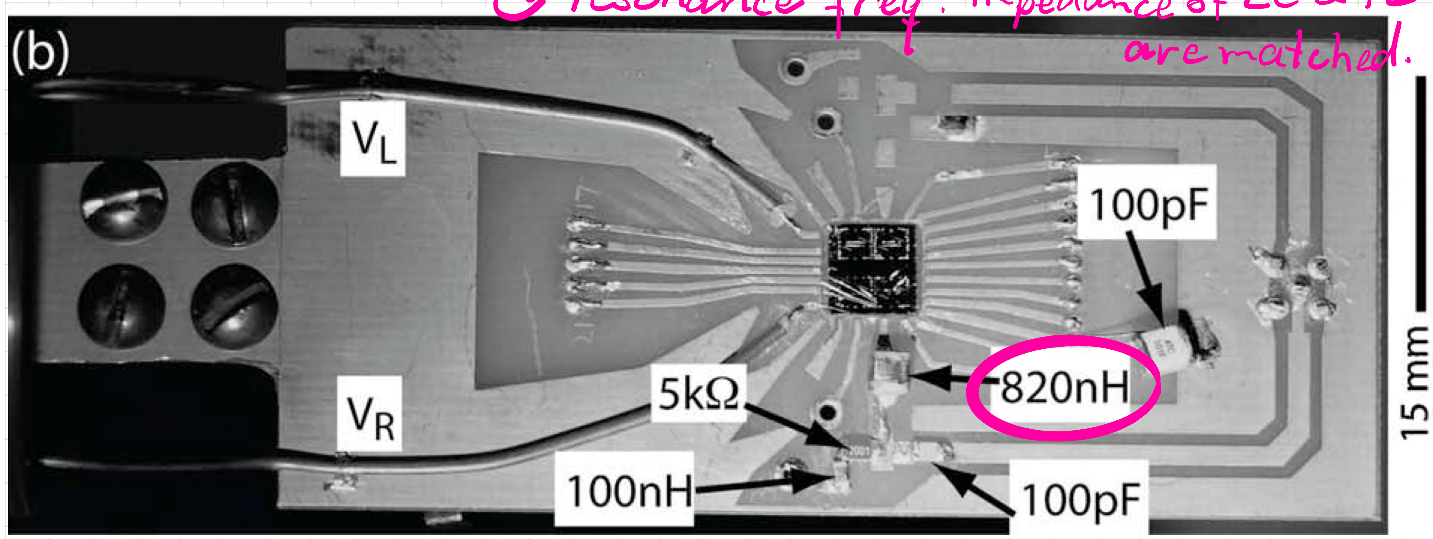
$$R_1 > R_2$$



$T_e = 120\,mK$

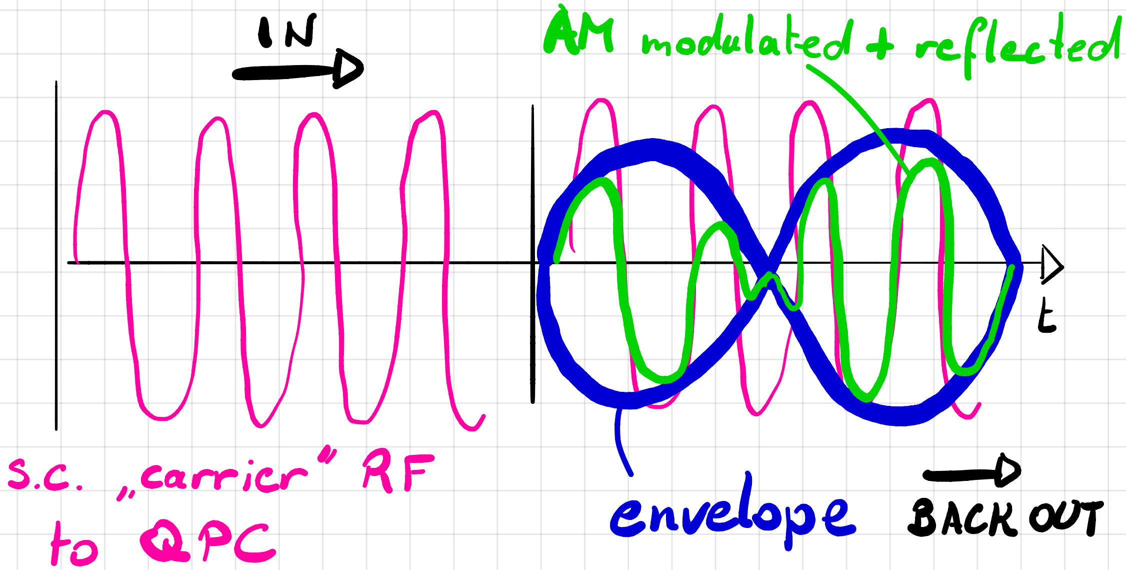
changes in g_{QPC} modulate Γ from matching circuit

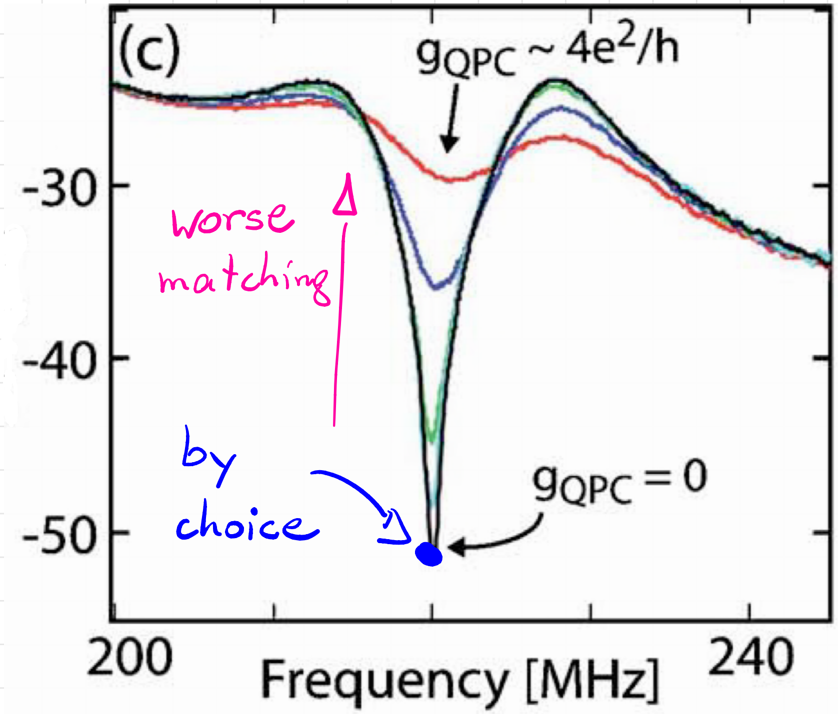
@ resonance freq. impedance of LC & TL are matched.



Characteristics

- matching via chip inductor
  820 nH & parasitic C from bonds ~ 0.63 pF.
  $\Delta g_{QPC} \Rightarrow \Delta\Gamma$ (modulates reflected power)

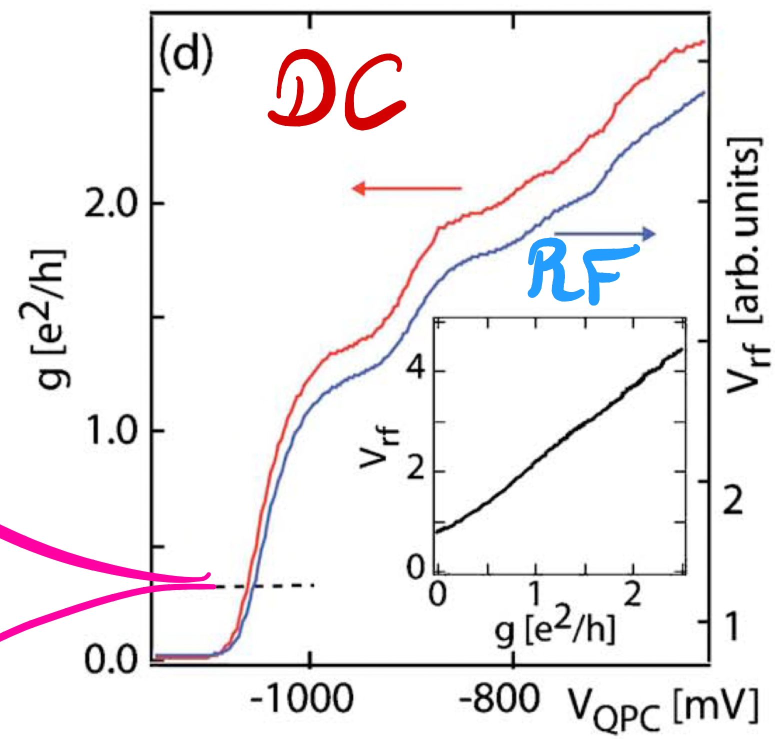




(~) is demodulated on local oscillator LO @ RT to get intermediate freq., then low pass filtered & amplified to yield $V_{RF} \propto g_{QPC}$.

Characteristics

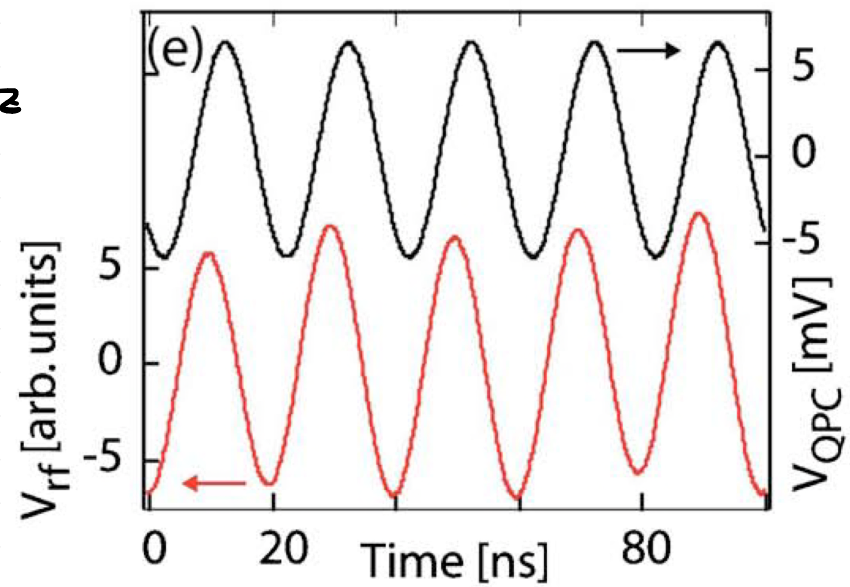
- Simultaneous RF & DC



tuned V_{QPC} here for max sensitivity

- For $g_{QPC} \geq e^2/h$ & $L_{match} = 560nH$

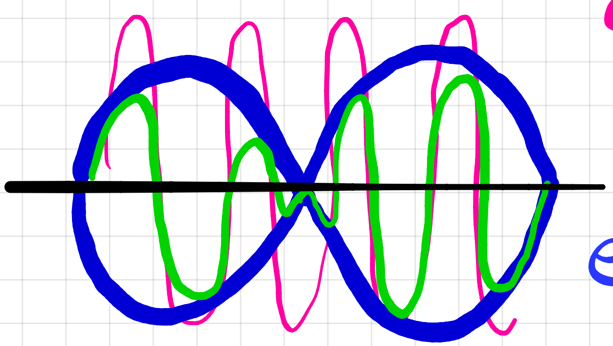
→ under coupled regime. Bandwidth ~100MHz determined by rise time of V_{RF} in response to 50MHz bias on gate.

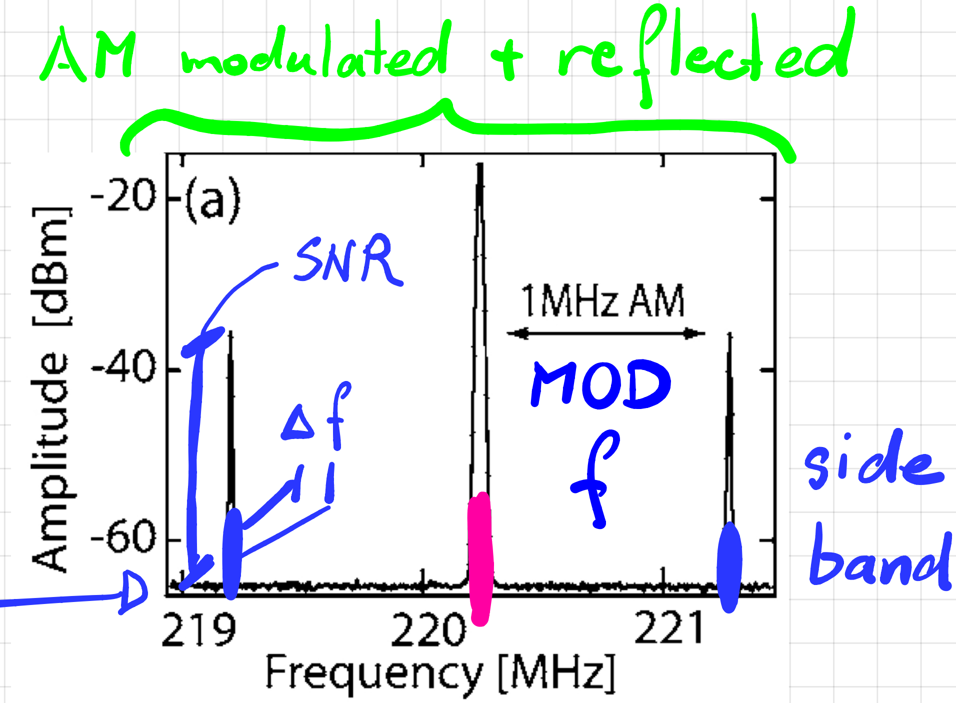


? How do I see this ?

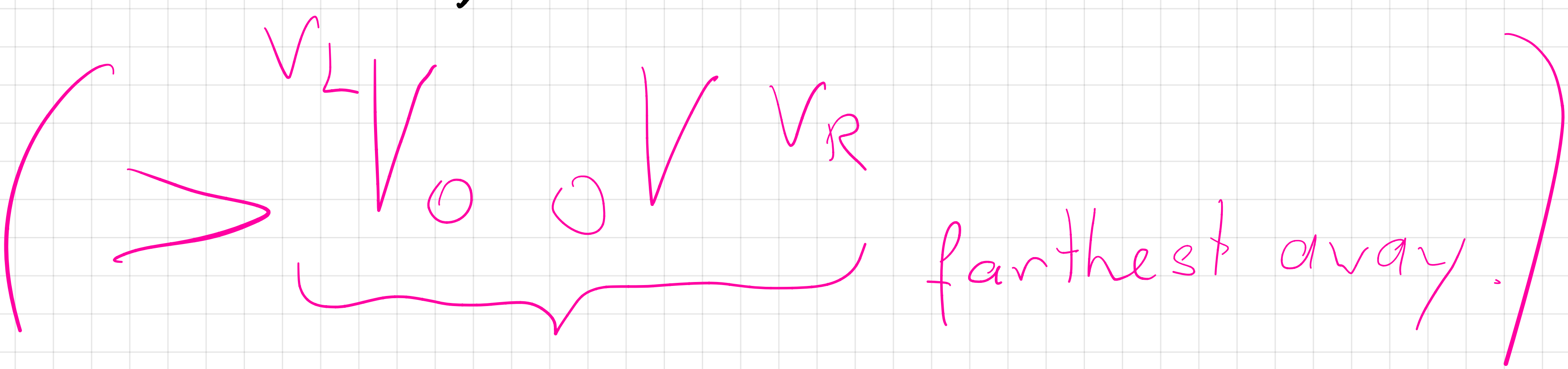
Sensitivity

- Apply $V_R = 0.7\,\mathrm{mV}$ @ $1\,\mathrm{MHz}$ ⇝ modulate $\Delta g_{QPC} \sim 0.018\, e^2/h$



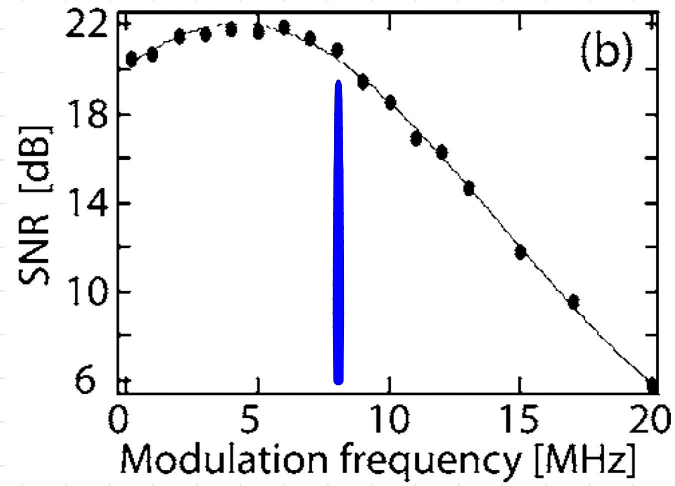


- Sensitivity allows for $\Delta g_{QPC} = 0.01\, e^2/h$ with $SNR = 1$ in $\tau_{int} = 0.5\,\mu s$.

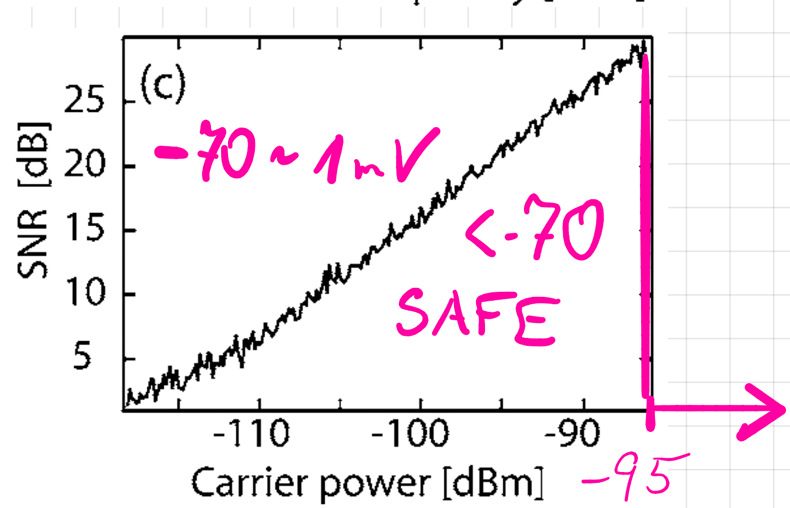


Limitations

- $f \gtrsim 8\,MHz$, $Q \sim 15$ limits the sensitivity. $\left(Q = \frac{f_r}{\Delta f}\right)$

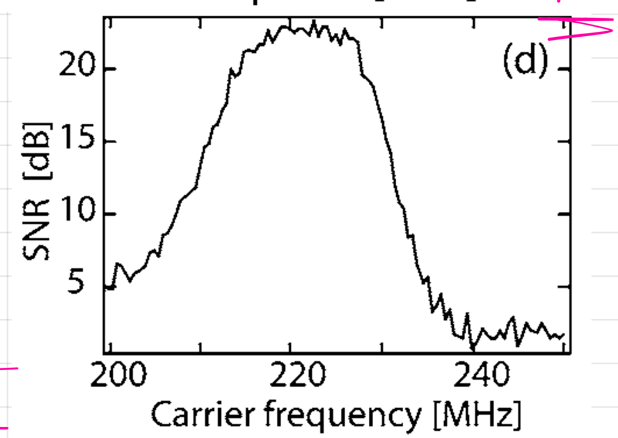


- SNR ↗ /w $P_{CARRIER}$ ↗
  limit set by E-scale of 1D subband spacing (~ mV).



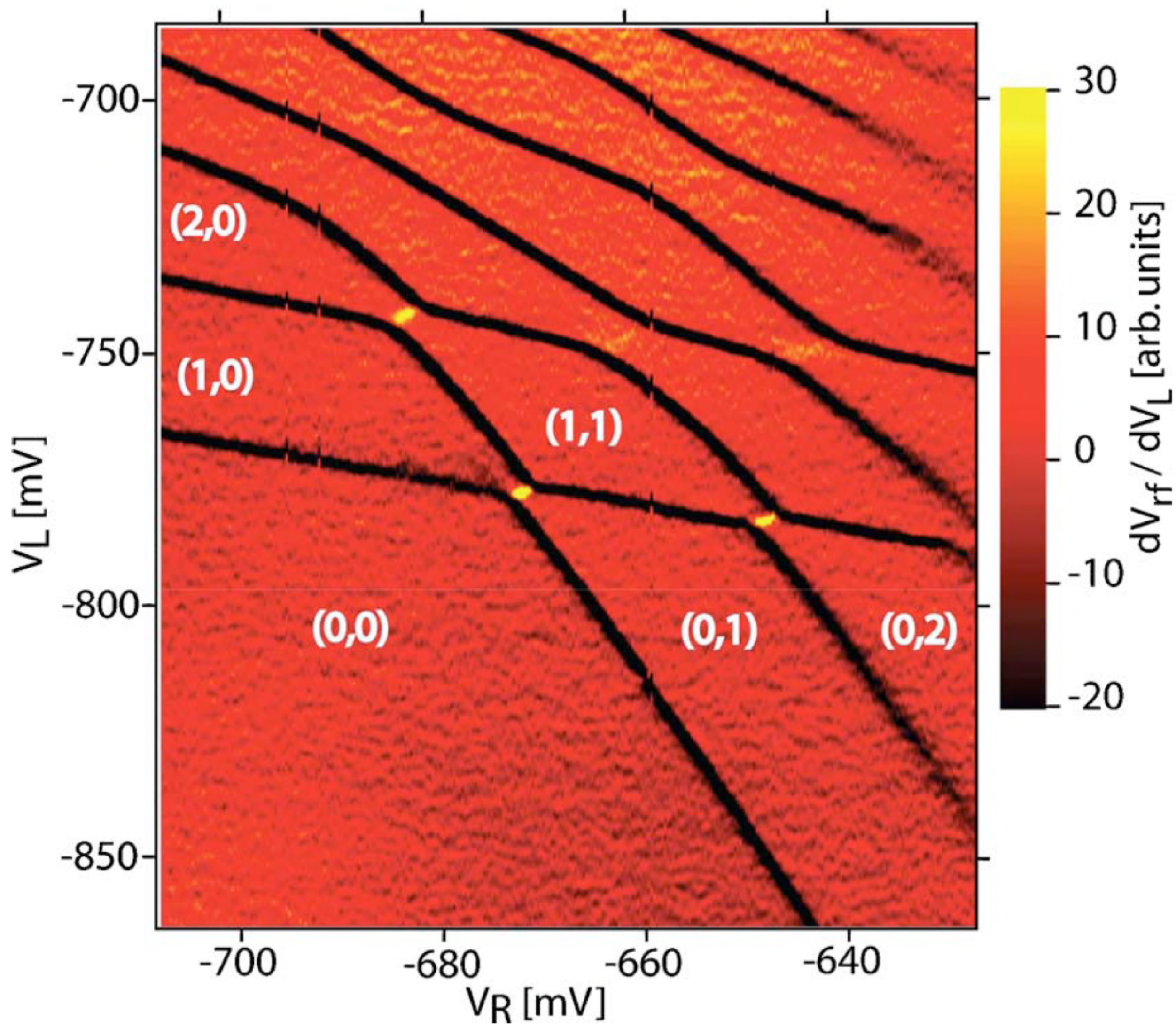
- @ − 75 dBm upper side band SNR (What is „consistent" with Fig 1c ?)

Quick Math: −75 − 20 = −95



Result

- Biased QPC @ $0.3\,e^2/h$ → very sensitive.
  Below, V_{RF} as func of V_R & V_L. 32 avg p.p.



Challenges & Improvements

- RF on QPC : i) back-action (shot noise) can drive unwanted transitions
- @ high RF carrier power → distortion of CSD (heat).

- circumvent problems by using a solid-state RF switch.
- Q fac sets 50ns ? for QPC to enter meas.
- After delay of 1μs meas is triggered.
- SNR ~4