Reflectometry report

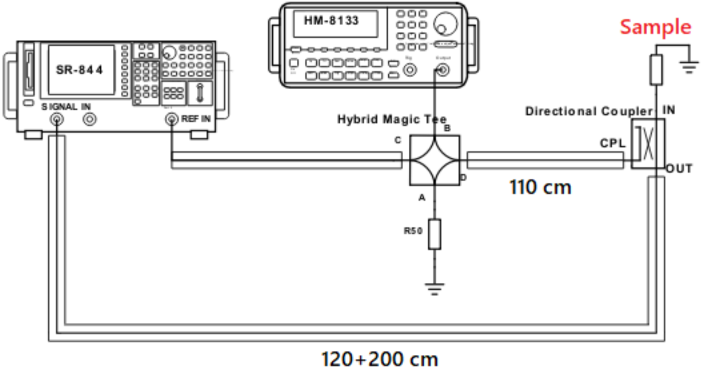
About normalizing measured data

Tamas Kalmar

2019.03.04.

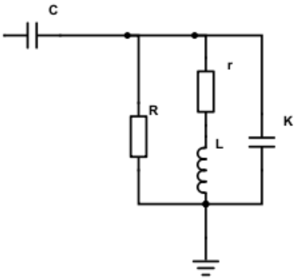
MŰEGYETEM 1782

Setup



Sample
HM-8133
SR-844
SIGNAL IN
REF IN
Hybrid Magic Tee
B
C
D
A
R50
Directional Coupler
IN
CPL
OUT
110 cm
120+200 cm

Setup



$$L = 430\,\mathrm{nH}$$

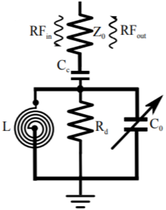
$$C = 5\,\mathrm{pF}$$

$$r \approx 1\,\Omega$$

$$R = 10\,\mathrm{k}\Omega$$

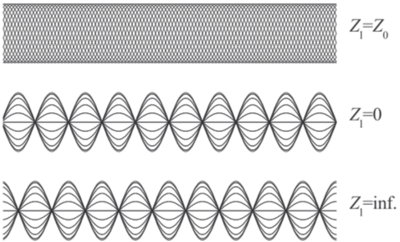
$$K = 1{,}1\,\mathrm{pF}$$

Fernando Gonzalez-Zalba's setup in Cambridge (1801.09759v1 [physics.app-ph] 29 Jan 2018)

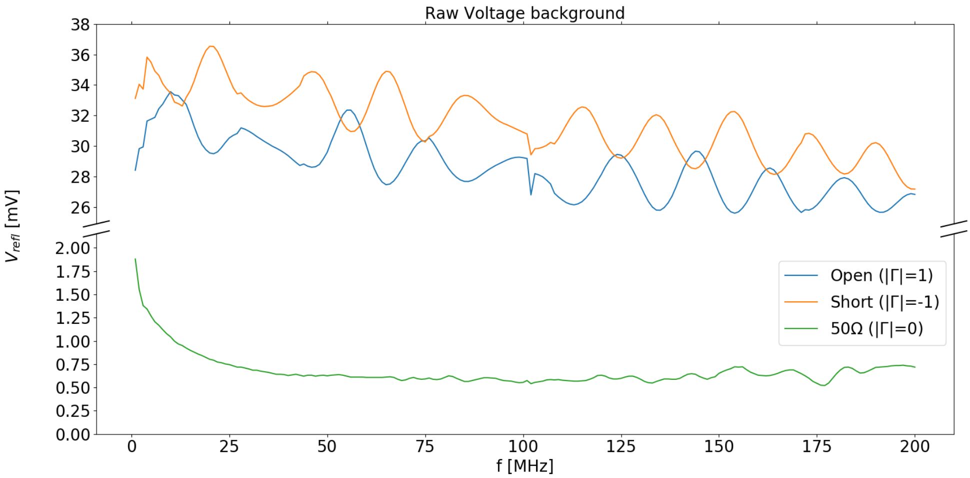


Background measurement

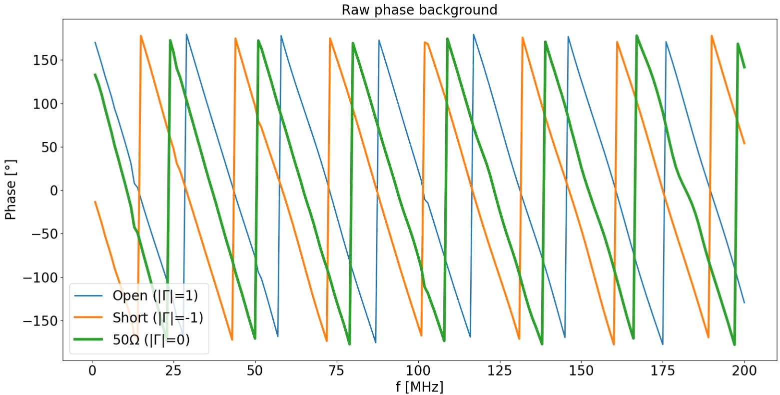
- Inhomogeneous output from RF synthesizer
- Losses in cable and connectors
- Inductive elements in couplers (noise)
- Behaviour for Open($R \rightarrow \infty$), Short($R \rightarrow 0$) and Matching ($R = 50\,\Omega$) termination



Background measurement

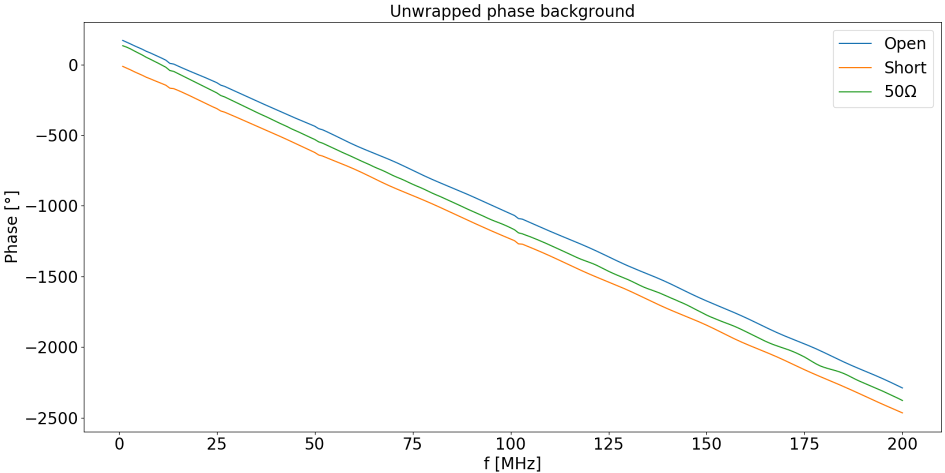


Background measurement

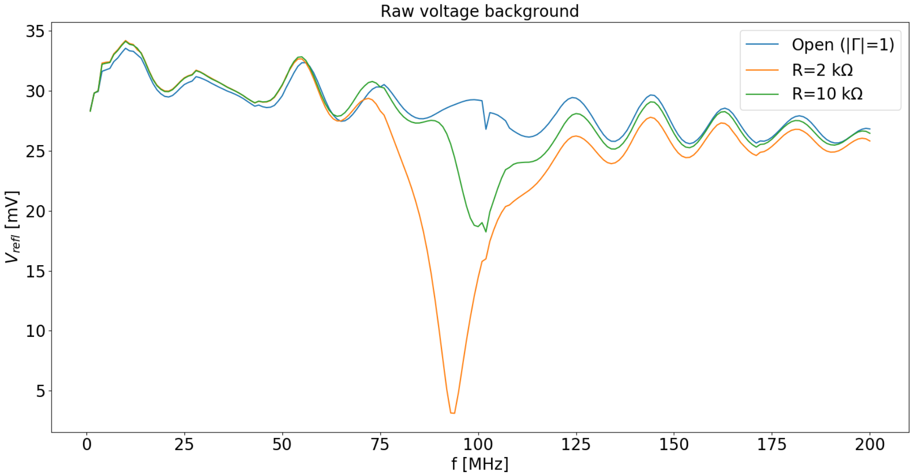


$\Delta f \approx 34\,\mathrm{MHz}$
$\rightarrow d \approx 3\,\mathrm{m}$
Cable lenght from sample:
$l \approx 120 + 200\,\mathrm{cm}$

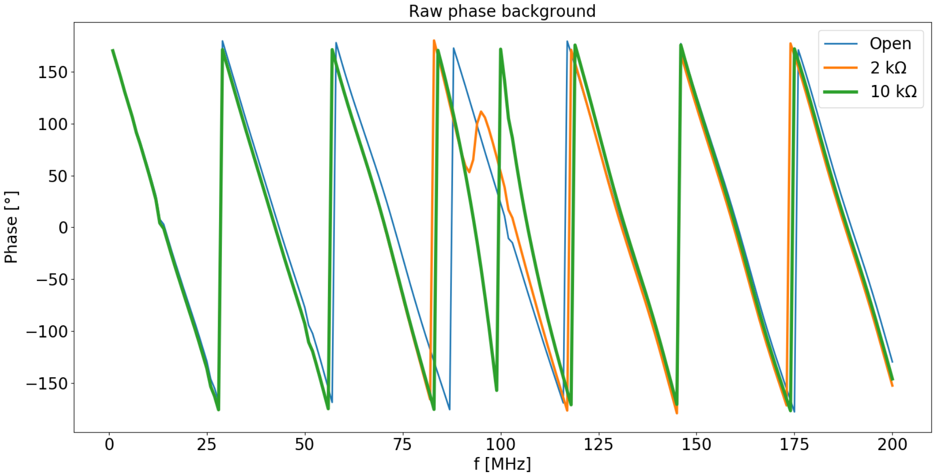
Background measurement



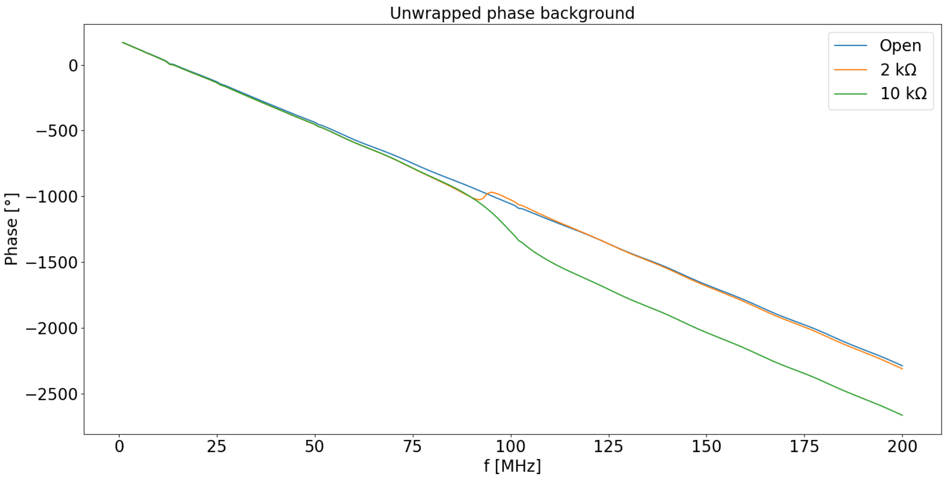
Raw sample data



Raw sample data

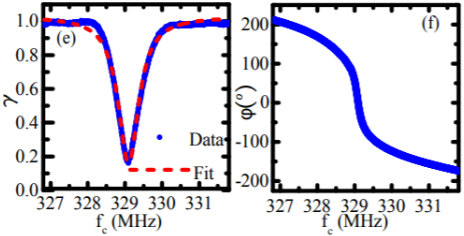


Raw sample data



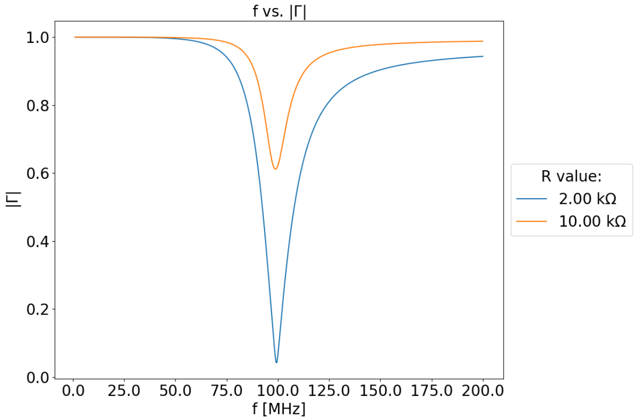
Normalization

- Inhomogeneous input to sample
- What happens if we have a "small" ($|\Gamma| \approx 0$) resonance at a background peak?
- We need to normalized the raw measured data, but how?



Fernando Gonzalez-Zalba
(1801.09759v1 [physics.app-ph] 29 Jan 2018)

Simulation

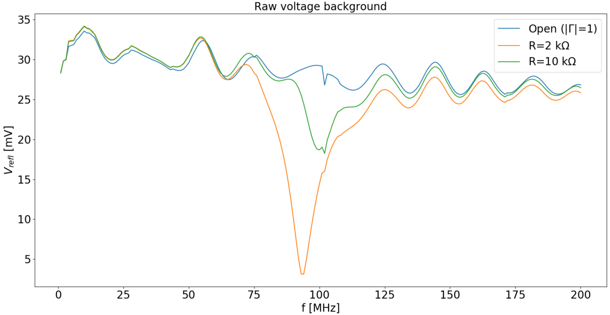


Numerically solved $\Gamma = \frac{Z-Z_0}{Z+Z_0}$ at given frequency points

For the 10k and 2k peaks $(f, |\Gamma|)$:

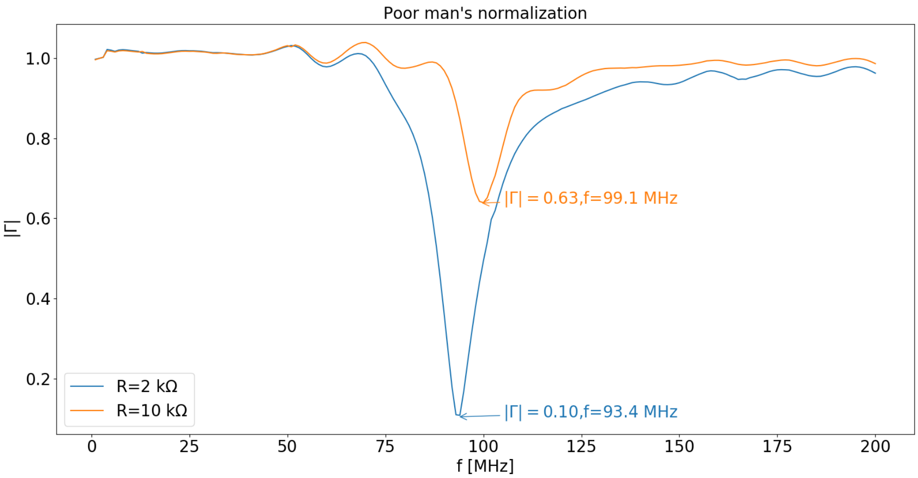
- $10\,\mathrm{k}\Omega$:$(98{,}6\,\mathrm{MHz}, 0.60)$
- $2\,\mathrm{k}\Omega$:$(99{,}3\,\mathrm{MHz}, 0.04)$

Poor man's normalization

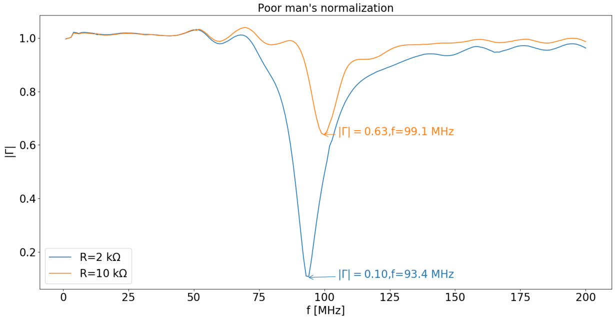


- $|\Gamma| \leq 1$
- Let's divide the full reflection dataset with the sample dataset!
- $|\Gamma(f_i)| = \frac{V_{Sample}(f_i)}{V_{Open}(f_i)}$

Poor man's normalization



Poor man's normalization

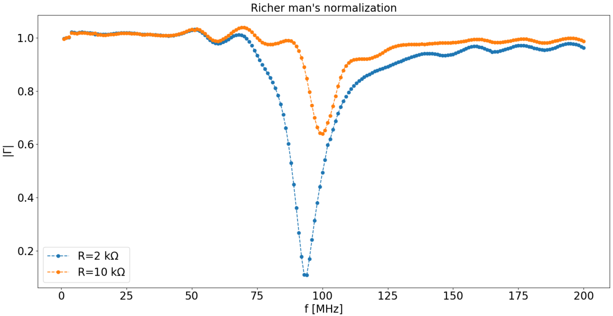


Notes:

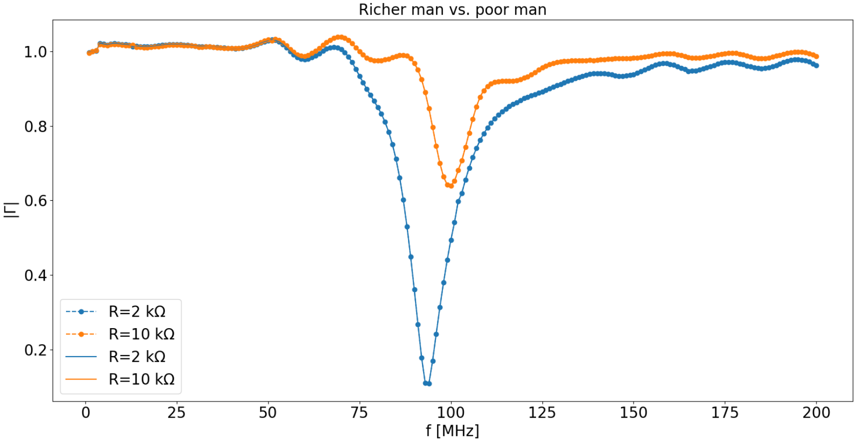
- After resoldering the resistance capacitence changed (shorter leg, more soldering lead, geometry...)
- 10k: $\Delta|\Gamma| = \frac{||\Gamma_{sim}(f_0)|-|\Gamma_{norm}(f_0)||}{|\Gamma_{sim}(f_0)|} = 5\,\%$
- 2k: $\Delta|\Gamma| = 150\,\%!$

Richer man's normalization

- Previously only calculated with $V_{refl} \sim |\Gamma|$
- Transform it back to $\Gamma = |\Gamma| e^{i \cdot \varphi}$
- Divide the complex numbers!

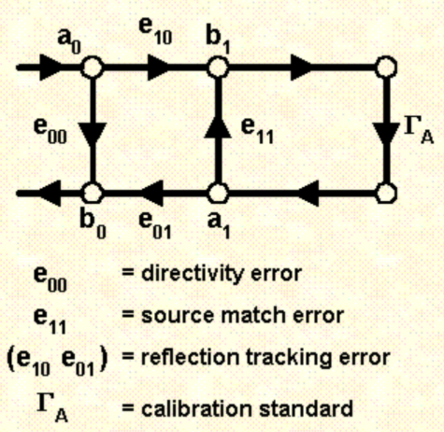


Richer man's normalization



There is no difference!

One port error modell



- These errors are constant at given frequency
- If we know the response for well-defined $|\Gamma|$, we can calculate these errors, and from it we can know the true $|\Gamma|$
- We need 3 standard for 3 parameters.

Millionare's normalization

Measured

$$\Gamma_M = \frac{b_0}{a_0} = \frac{e_{00} - \Delta_e \Gamma}{1 - e_{11}\Gamma}$$

Actual

$$\Gamma = \frac{\Gamma_M - e_{00}}{\Gamma_M e_{11} - \Delta_e}$$

$$\Delta_e = e_{00}e_{11} - (e_{10}e_{01})$$

For ratio measurements there are 3 error terms
The equation can be written in the linear form

$$e_{00} + \Gamma\Gamma_M e_{11} - \Gamma\Delta_e = \Gamma_M$$

With 3 different known Γ, measure the resultant 3 Γ_M
This yields 3 equations to solve for e_{00}, e_{11}, and Δ_e

$$e_{00} + \Gamma_1\Gamma_{M1}e_{11} - \Gamma_1\Delta_e = \Gamma_{M1}$$

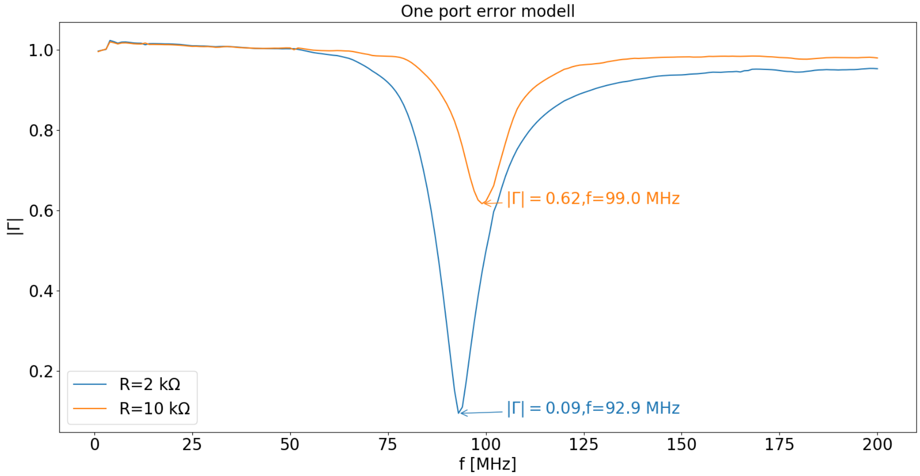
$$e_{00} + \Gamma_2\Gamma_{M2}e_{11} - \Gamma_2\Delta_e = \Gamma_{M2}$$

$$e_{00} + \Gamma_3\Gamma_{M3}e_{11} - \Gamma_3\Delta_e = \Gamma_{M3}$$

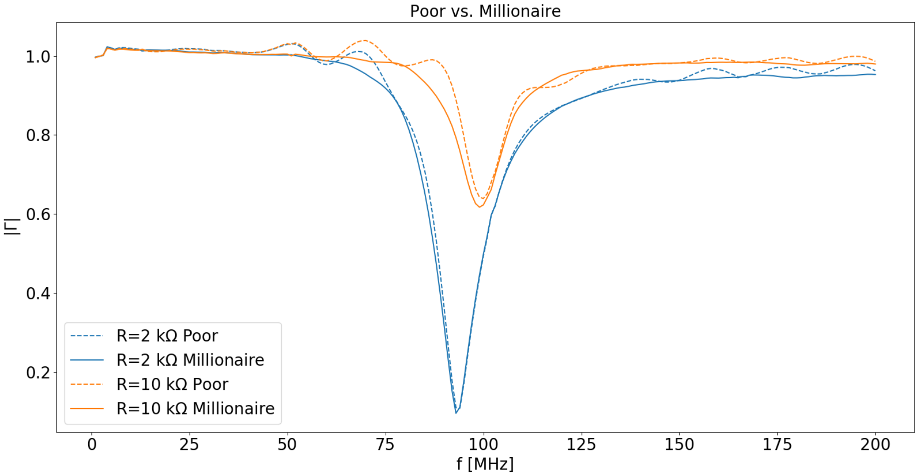
Any 3 independent measurements can be used

http://emlab.uiuc.edu/ece451/appnotes/Rytting_NAModels.pdf

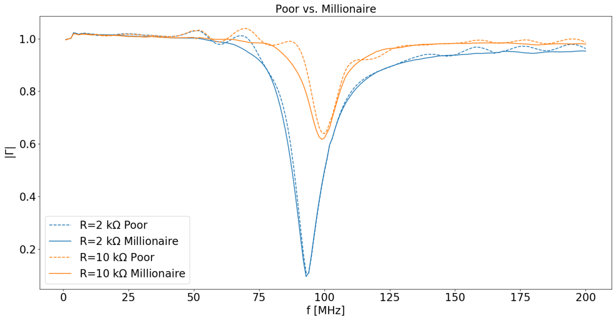
Millionare's normalization



Comparison

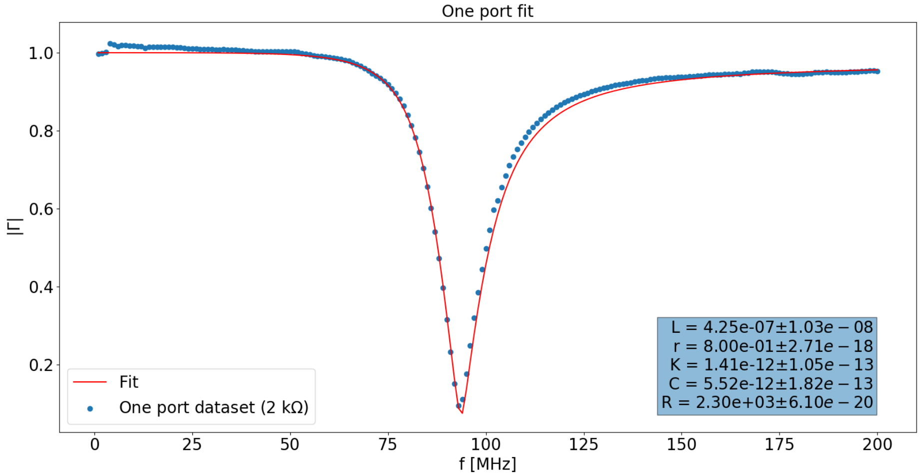

Poor vs. Millionaire
1.0
0.8
0.6
0.4
0.2
|Γ|
0
25
50
75
100
125
150
175
200
f [MHz]
R=2 kΩ Poor
R=2 kΩ Millionaire
R=10 kΩ Poor
R=10 kΩ Millionaire

Comparison

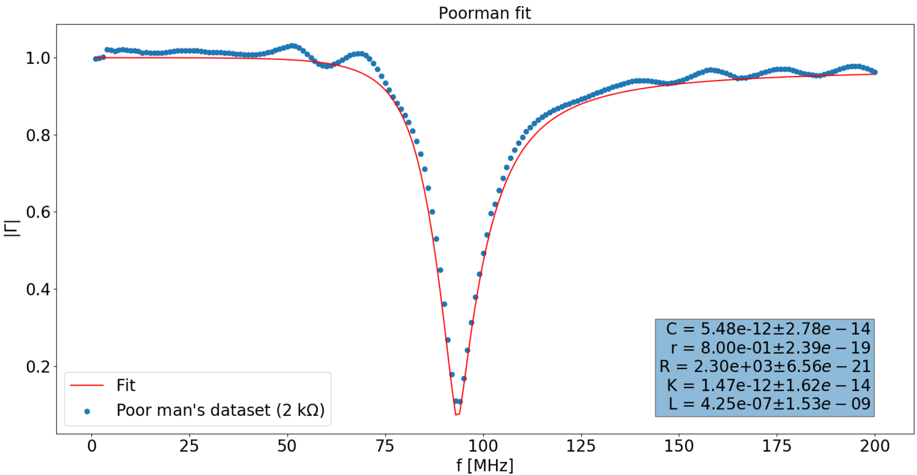


- The difference in $|\Gamma(f_0)|$ is around 0,01!
- In frequency $\sim$ 0,2 - 0,5 MHz
- Measurement time is twice as much for the one port modell! (take into consideration cooling)
- Let's see what happens if we try to fit on the dataset

Comparison

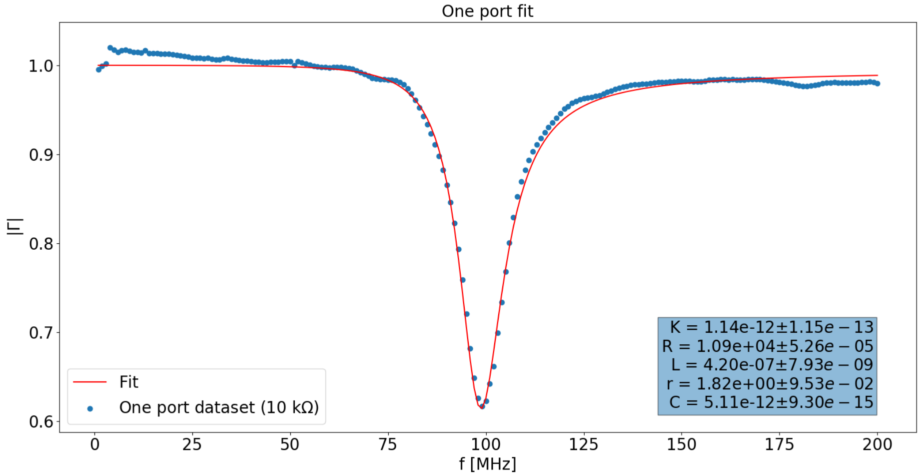

One port fit
1.0
0.8
0.6
0.4
0.2
|Γ|
0
25
50
75
100
125
150
175
200
f [MHz]
Fit
One port dataset (2 kΩ)
L = 4.25e-07±1.03e − 08
r = 8.00e-01±2.71e − 18
K = 1.41e-12±1.05e − 13
C = 5.52e-12±1.82e − 13
R = 2.30e+03±6.10e − 20

Comparison



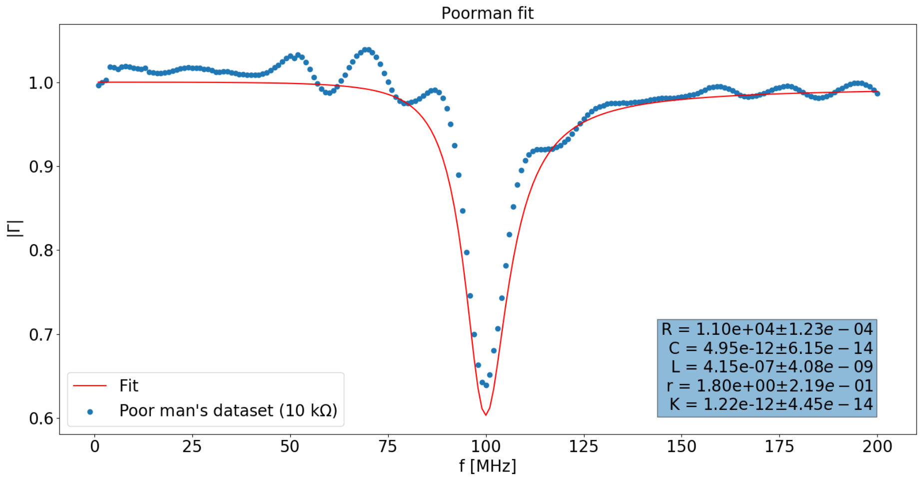
Poorman fit
1.0
0.8
0.6
0.4
0.2
|Γ|
0
25
50
75
100
125
150
175
200
f [MHz]
Fit
Poor man's dataset (2 kΩ)
C = 5.48e-12±2.78e − 14
r = 8.00e-01±2.39e − 19
R = 2.30e+03±6.56e − 21
K = 1.47e-12±1.62e − 14
L = 4.25e-07±1.53e − 09

Comparison



One port fit
1.0
0.9
0.8
0.7
0.6
|Γ|
0
25
50
75
100
125
150
175
200
f [MHz]
Fit
One port dataset (10 kΩ)
K = 1.14e-12±1.15e − 13
R = 1.09e+04±5.26e − 05
L = 4.20e-07±7.93e − 09
r = 1.82e+00±9.53e − 02
C = 5.11e-12±9.30e − 15

Comparison



Poorman fit
1.0
0.9
0.8
0.7
0.6
|Γ|
0
25
50
75
100
125
150
175
200
f [MHz]
Fit
Poor man's dataset (10 kΩ)
R = 1.10e+04±1.23e − 04
C = 4.95e-12±6.15e − 14
L = 4.15e-07±4.08e − 09
r = 1.80e+00±2.19e − 01
K = 1.22e-12±4.45e − 14

Thanks for your attention!