Noise Model for Charge Signal

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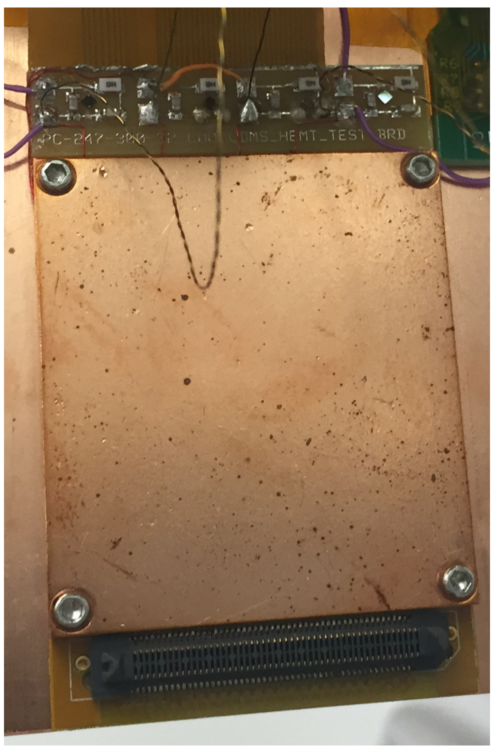
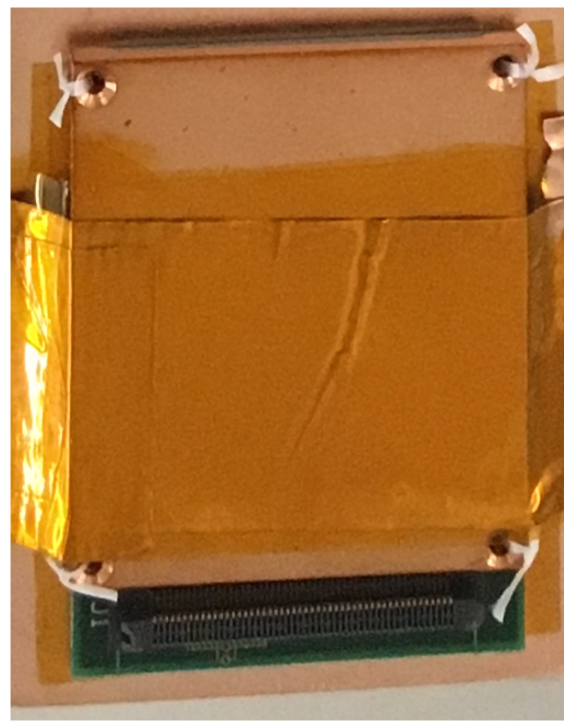
Outline

- Noise model was updated based on Gary's note
- New HEMT chips were tested with simplified setup
  - No additional board to avoid unknown stray capacitance etc.
  - V_{gs} ~ -170mV (was ~0mV) for I_d ~ 0.9mA as expected

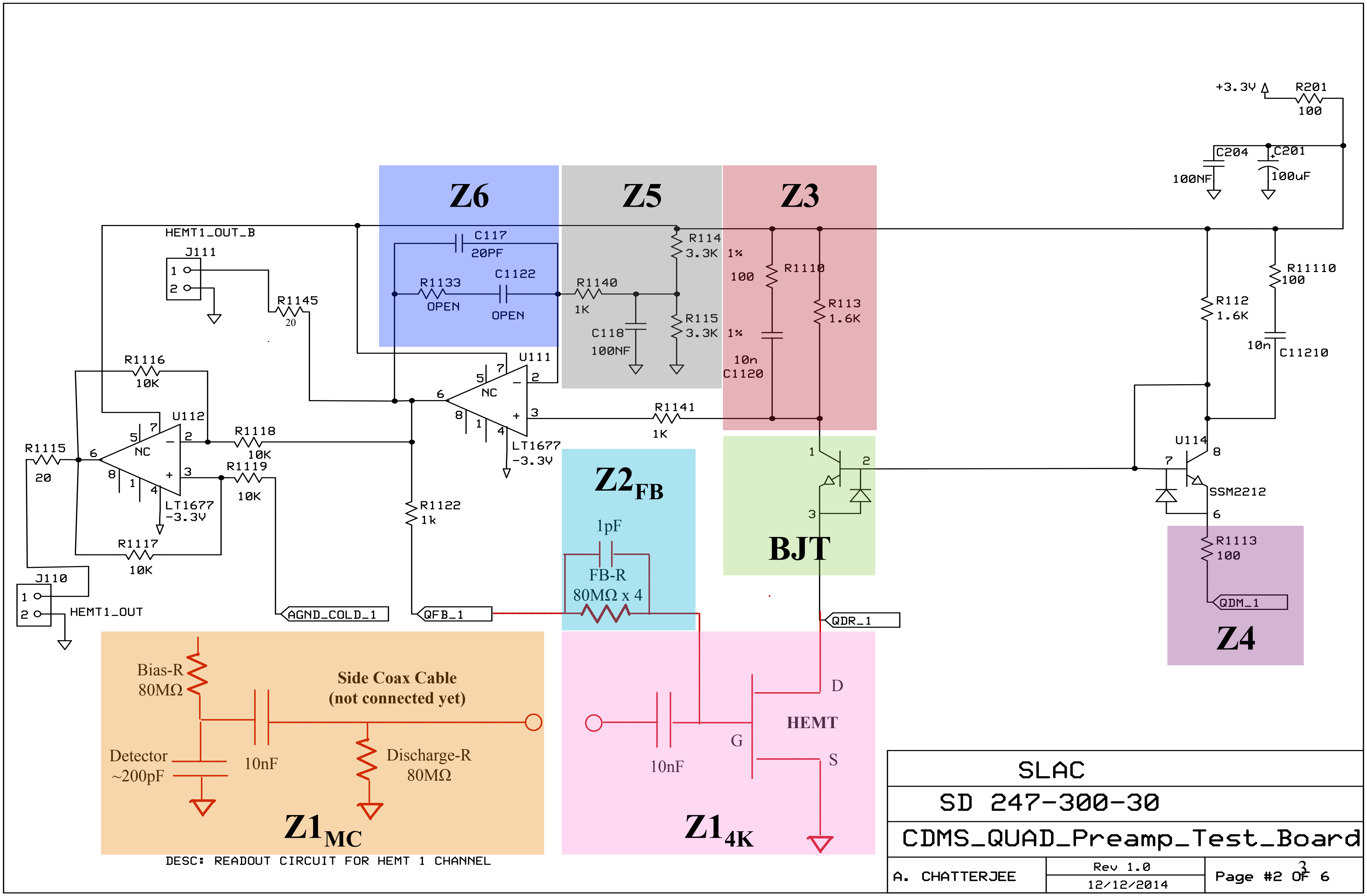
Old (VFC#1)



New (VFC#2)



Schematics


Z6
Z5
Z3
Z2FB
BJT
Z4
Z1MC
Z1 4K
HEMT1_OUT_B
J111
R1145
20
R1116
10K
U112
R1118
10K
R1119
10K
R1115
20
R1117
10K
LT1677
-3.3V
J110
HEMT1_OUT
C117
20PF
R1133
OPEN
C1122
OPEN
U111
NC
LT1677
-3.3V
R1140
1K
C118
100NF
R114
3.3K 1%
R115
3.3K 1%
R1141
1K
R1122
1k
100
R1110
R113
1.6K
10n
C1120
AGND_COLD_1
QFB_1
QDR_1
1pF
FB-R
80MΩ x 4
+3.3V
R201
100
C204
C201
100NF
100uF
R11110
100
R112
1.6K
10n
C11210
U114
SSM2212
R1113
100
QDM_1
Bias-R
80MΩ
Side Coax Cable
(not connected yet)
Detector
~200pF
10nF
Discharge-R
80MΩ
10nF
G
D
S
HEMT
DESC: READOUT CIRCUIT FOR HEMT 1 CHANNEL
SLAC
SD 247-300-30
CDMS_QUAD_Preamp_Test_Board
A. CHATTERJEE
Rev 1.0
12/12/2014
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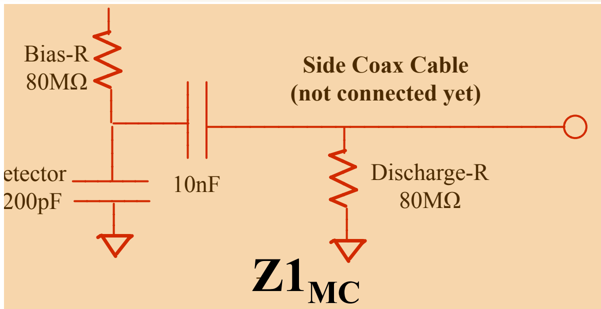
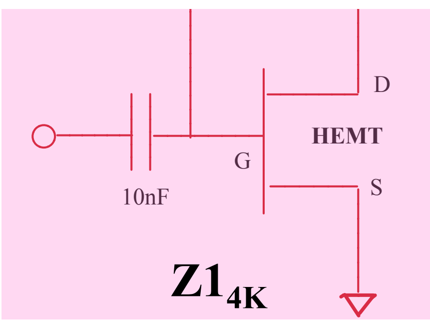
Impedance Calculation

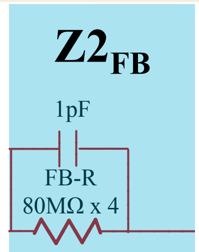


$$Z1_{MC} = \left(\left(\left(i\omega C_{det} + \frac{1}{R_{bias}} \right)^{-1} + \frac{1}{i\omega C_{cc}} \right)^{-1} + \frac{1}{R_{dis}} \right)^{-1}$$

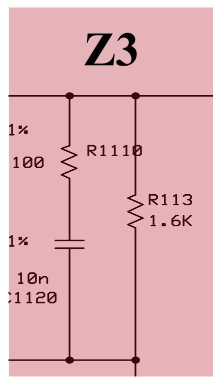


$$Z1_{4K} = \left(\left(R_{open} + \frac{1}{i\omega C_{cc}} \right)^{-1} + i\omega C_{HEMT} \right)^{-1}$$

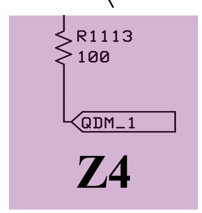
$$Z1_{total} = \left(\frac{1}{Z1_{MC}} + \frac{1}{Z1_{4K}} \right)^{-1} \qquad C_{HEMT} = 100\text{pF}$$



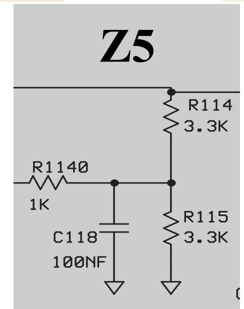
$$Z2_{FB} = \left(i\omega C_{FB} + \frac{1}{R_{FB}} \right)^{-1}$$



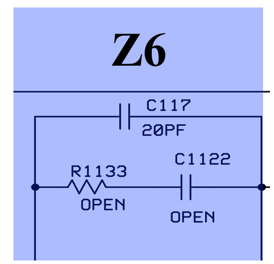
$$Z3 = \left(\frac{1}{R_{113}} + \left(R_{1110} + \frac{1}{i\omega C_{1120}} \right)^{-1} \right)^{-1}$$



$$Z4 = R_{1113}$$



$$Z5 = R_{1140} + \left(i\omega C_{118} + \frac{1}{R_{115}} + \frac{1}{R_{114}} \right)^{-1}$$

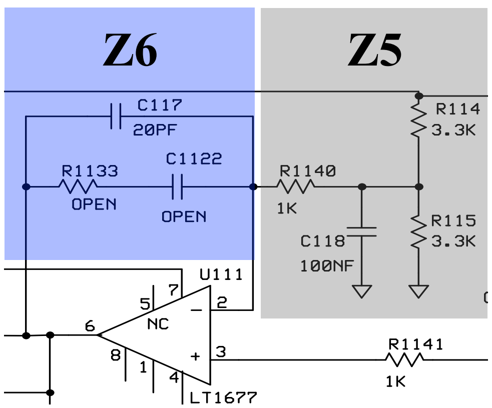


$$Z6 = \left(i\omega C_{117} + \frac{1}{R_{open}} \right)^{-1}$$

$$R_{open} \sim 10^{15}\,\Omega$$

Gain Calculation

Op-Amp gain



$$A = \frac{A_{open}}{1 + A_{open} B_1}$$

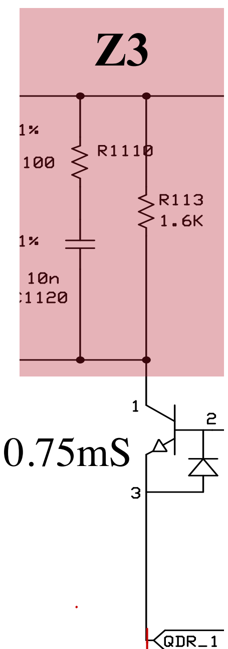
$$A_{open} = \frac{2 \cdot 10^7}{\left(1 + i\frac{\omega}{\omega_1}\right)\left(1 + i\frac{\omega}{\omega_2}\right)}$$

$$\cancel{f_1 = 0.2\text{Hz}, \quad f_2 = 100\text{kHz}}$$

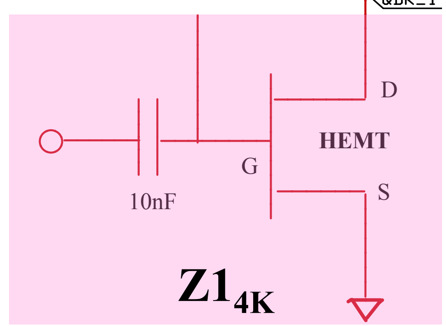
$$f_1 = 1\text{Hz}, \quad f_2 = 1\text{MHz}$$

$$B_1 = \frac{Z5}{Z5 + Z6}$$

HEMT gain



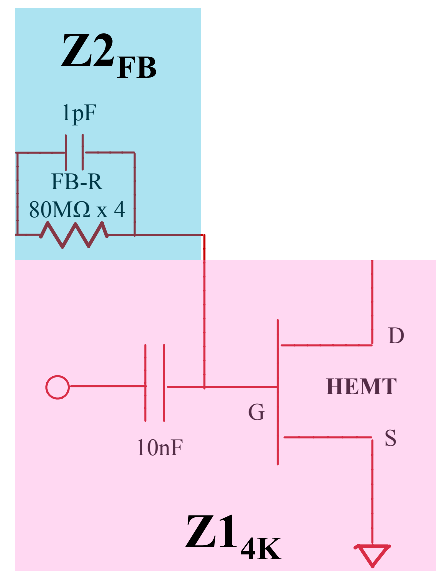
$$g_d = 0.75\text{mS}$$



$$A_{HEMT} = g_m Z3$$

$$g_m = 35\text{mS}$$

Total gain



$$gain = -\frac{A_{total}(1 - B_2)}{1 + A_{total} B_2}$$

$$B_2 = \frac{Z1}{Z1 + Z2}$$

$$A_{total} = A_{HEMT} A$$

Gain vs. Frequency

No detector, discharge-R, bias-R, T_{4K} = 5.5K

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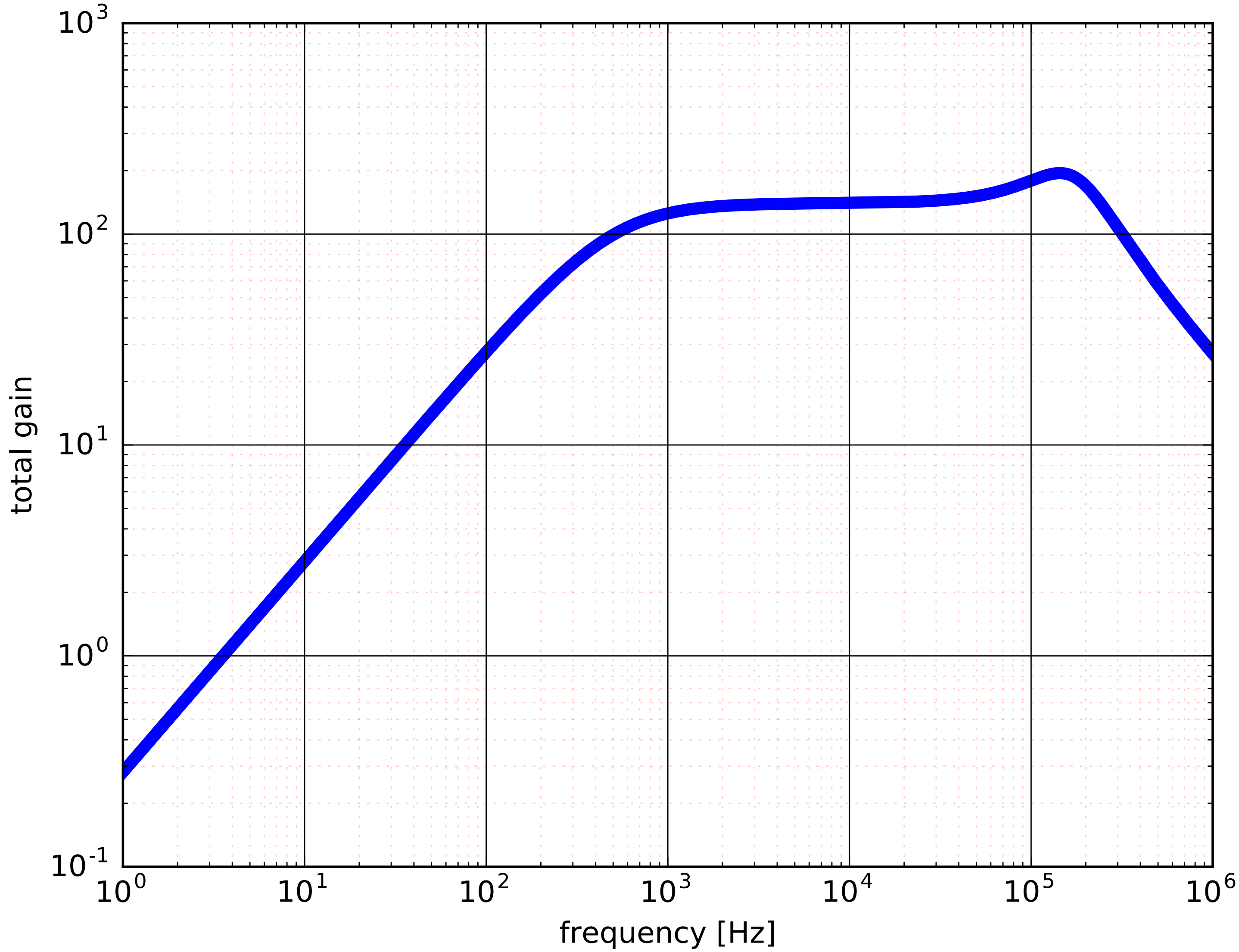
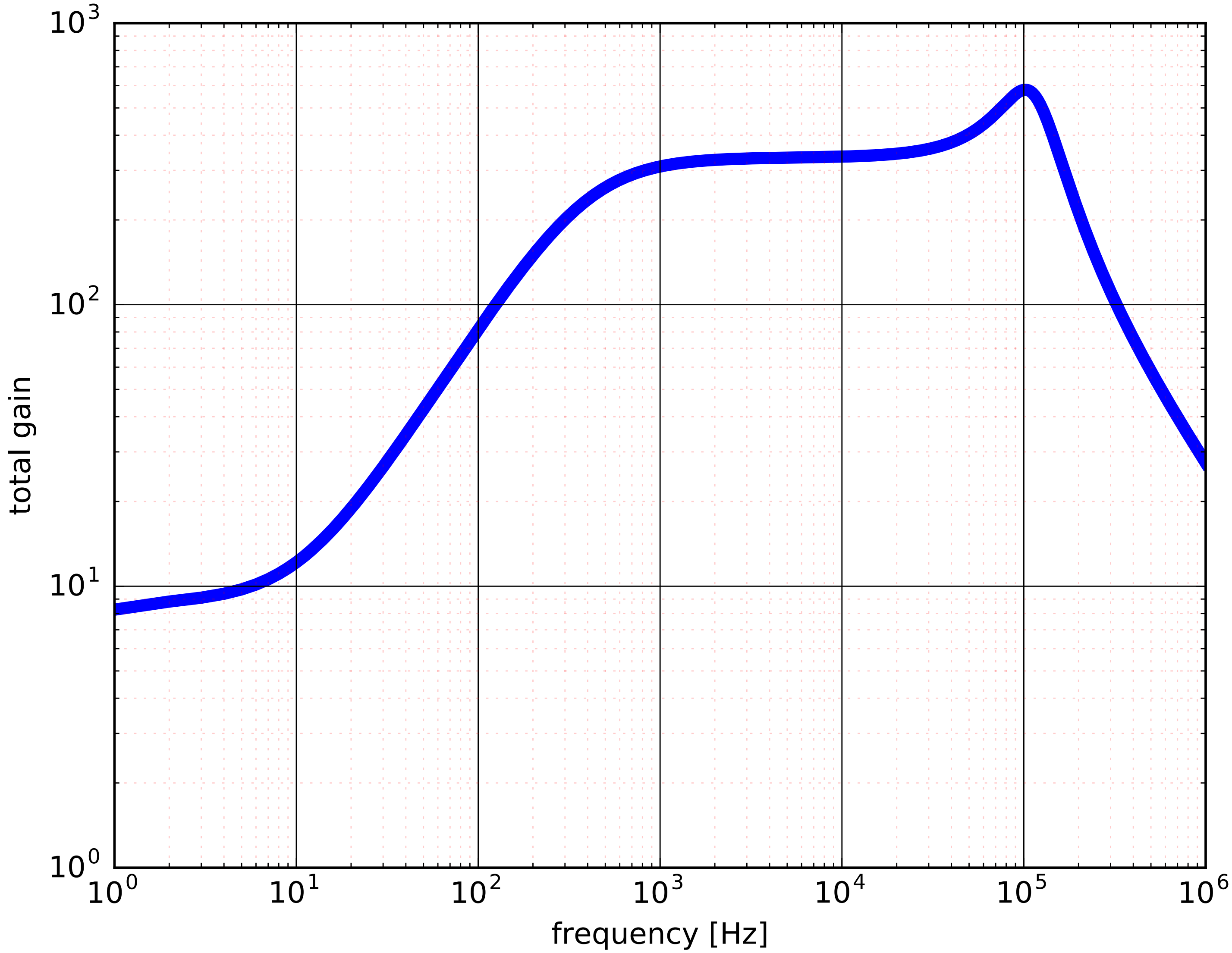


Gain vs. Frequency

C_{det} = 200pF R_{dis} = 80MΩ, R_{bias} = 80MΩ, T_{4K} = 4K, T_{MC} = 30mK



Noise Calculation (at HEMT input)

Thermal Johnson Noise at Z1 $$v_1 = \sqrt{4kT_{MC}\,\mathrm{Re}(Z1_{MC}) + 4kT_{4K}\,\mathrm{Re}(Z1_{4K})}$$

Thermal Johnson Noise at Z2_FB $$v_2 = \frac{\sqrt{4kT_{MC}\,\mathrm{Re}(Z2_{FB})}}{|gain|}$$

Thermal Johnson Noise at Z3 $$v_3 = \frac{\sqrt{4kT_{MC}\,\mathrm{Re}(Z3)}}{|A_{HEMT}|}$$

Thermal Johnson Noise at Z4 $$v_4 = \frac{g_d}{g_m}\sqrt{4kT_{MC}\,\mathrm{Re}(Z4)}$$

Op-amp (LT1677) noise $$v_{amp} = \sqrt{\left(1.8\cdot 10^{-9}\right)^2 + \left(30\cdot 10^{-9}\right)^2 \frac{2\pi}{\omega}}$$

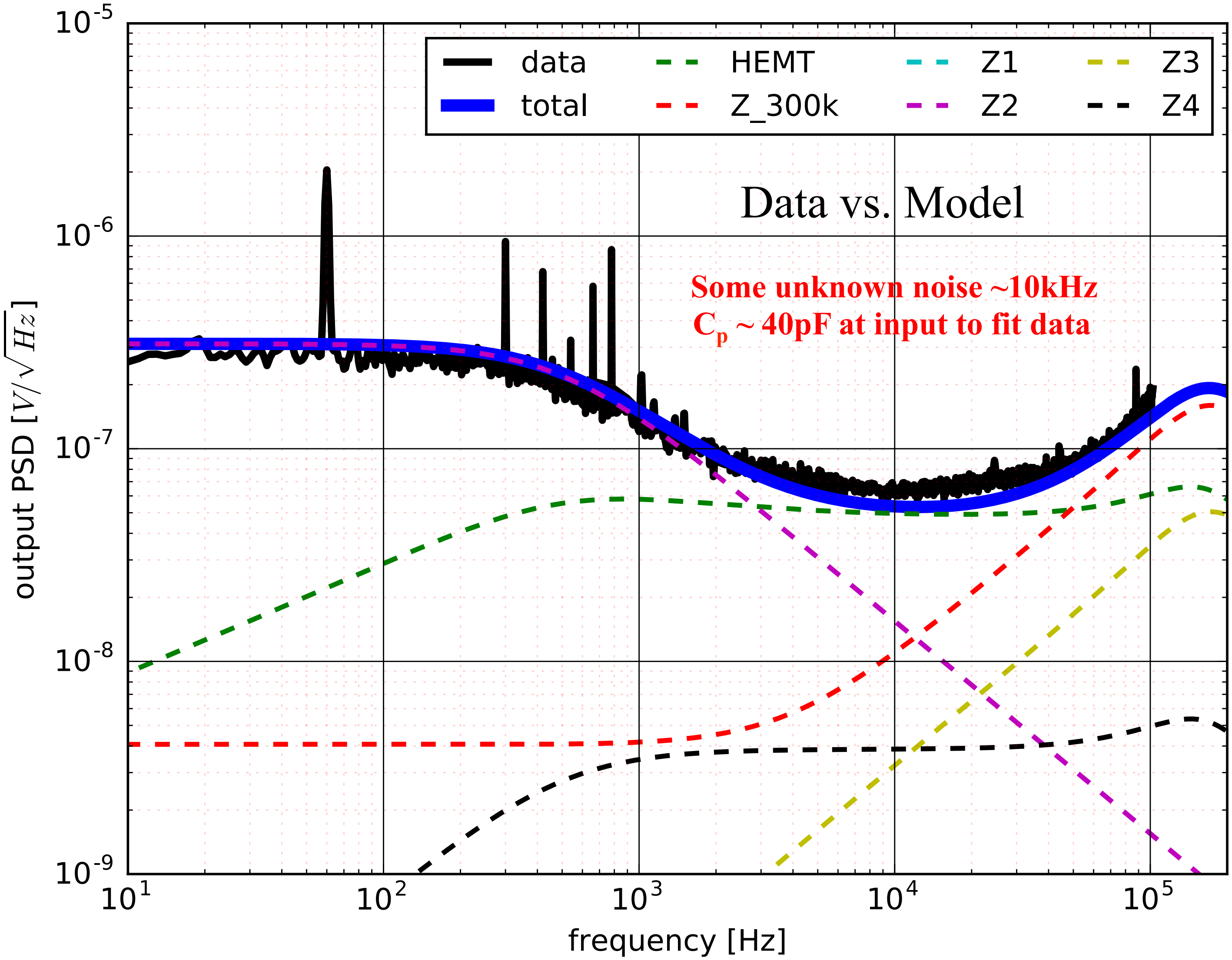
~~Shot noise at BJT~~ $$\cancel{v_{shot} = \frac{\sqrt{2qI_d}}{g_m}}$$

$R_{emitter}$ ~ 26Ω, R_{drain} ~ a few kΩ -> most no Shot noise going through HEMT (by Sten)

HEMT noise
(fit to Yon Jin's plot by Gary) $$v_{HEMT} = 0.24\cdot 10^{-9}\sqrt{2\left(1+850\frac{2\pi}{\omega}\right)}$$

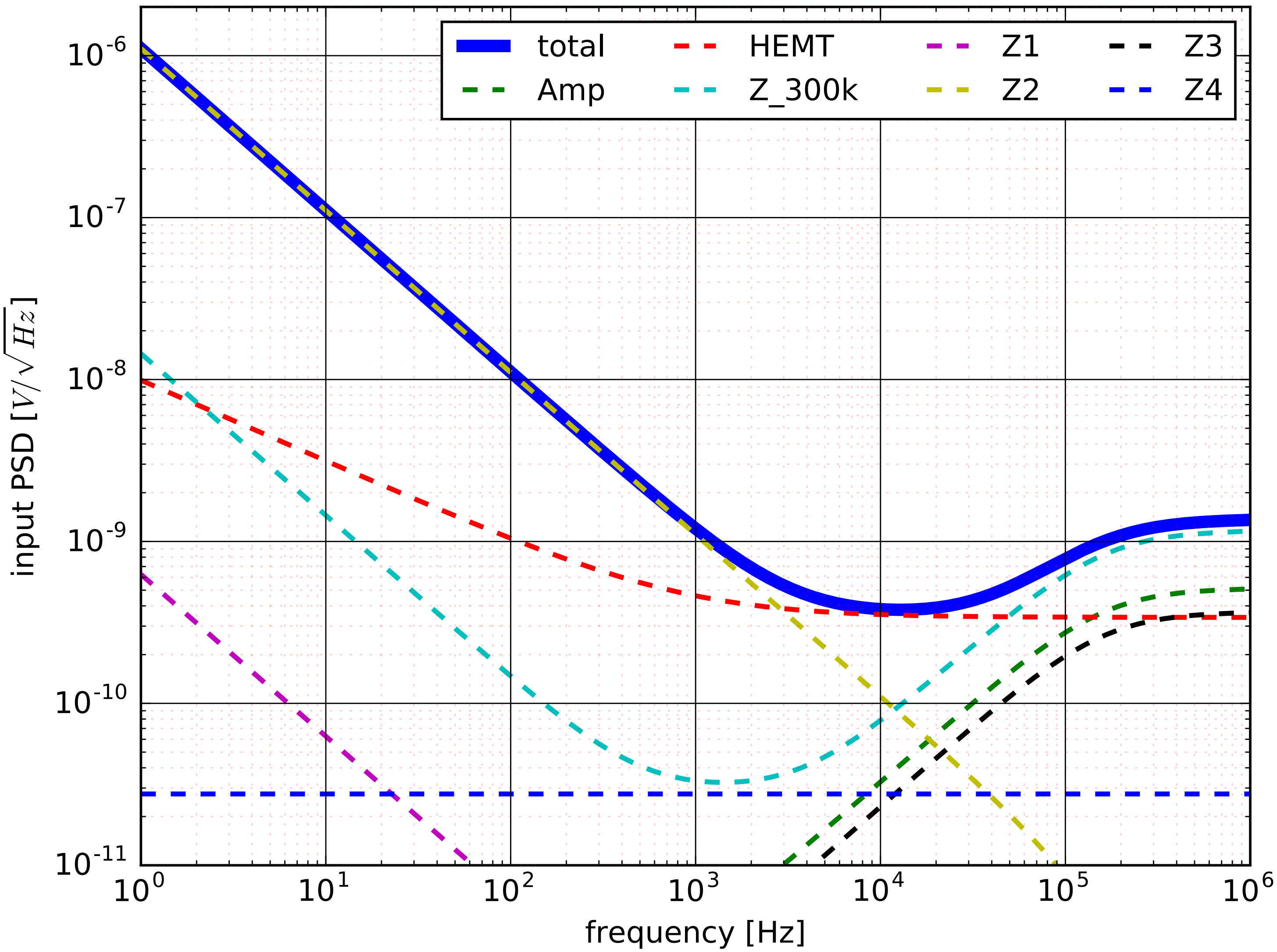
Output Noise

No detector, no $R_{discharge}$, no R_{bias}, T_{4K} = 5.5K



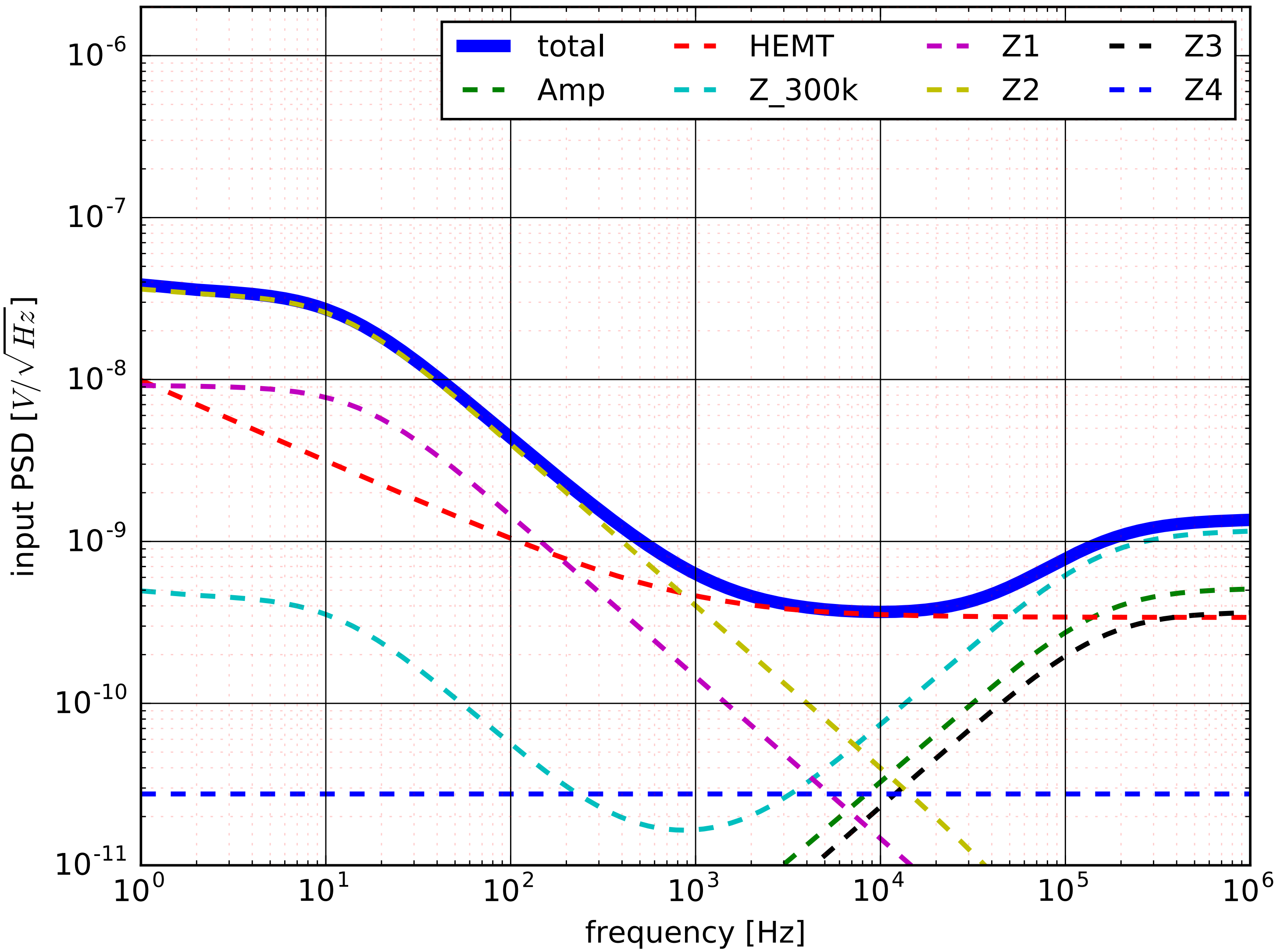
Input Noise

No detector, no $R_{discharge}$, no R_{bias}, T_{4K} = 5.5K



Input Noise with Detector

C_{det} = 200pF $R_{discharge}$ = 100MΩ, R_{bias} = 100MΩ, T_{4K} = 4K, T_{MC} = 30mK

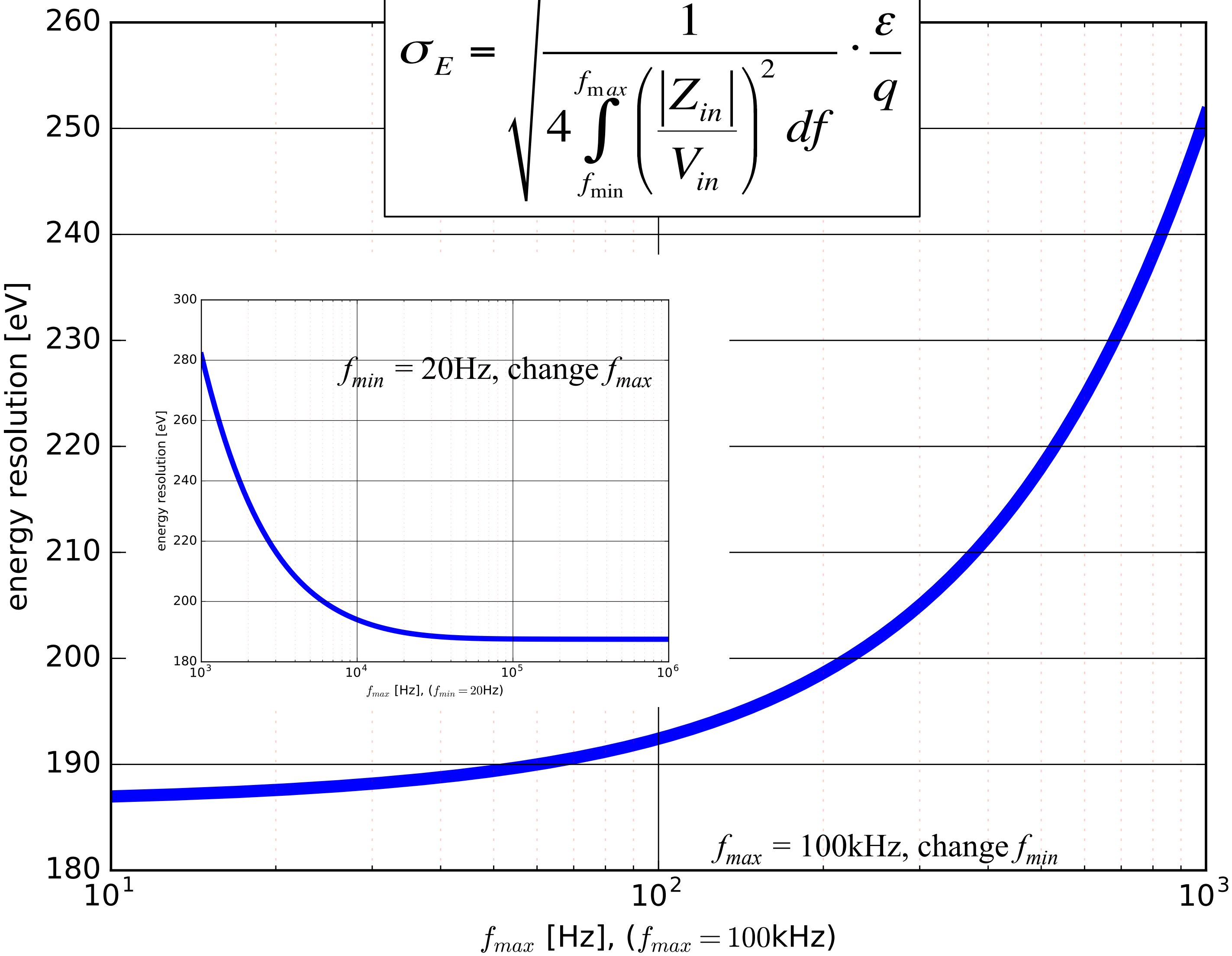


Optimal Filter

$C_{det} = 200pF$ $R_{discharge} = 100M\Omega$, $R_{bias} = 100M\Omega$, $T_{4K} = 4K$, $T_{MC} = 30mK$

$$\sigma_E = \sqrt{\frac{1}{4\int_{f_{\min}}^{f_{max}} \left(\frac{|Z_{in}|}{V_{in}}\right)^2 df}} \cdot \frac{\varepsilon}{q}$$

$\sigma_{OF} \sim 190$ eV



Summary

- With a HEMT chip (and no additional board), we obtained a consistent noise result with the calculated model.
  - Some unknown noise around 10kHz, which is equivalent with ~40pF parasitic capacitance at input.

-> Noise for HEMTs on Mezzanine board (C_{FB} = 0.25pF, C_p = 1pF) showed good agreement with the model (see next page)

- Future plan
  - Add more components (C_{det}, R_{dis}, R_{bias}) on the HEMT card and compare the noise with the model
  - Measure noise with Vacuum Coax Cable
    - Vibration susceptibility test
    - Vacuum Coax Cable vs. Twisted Pair of Wires
  - Active reset test

HEMTs at Mezzanine Board

No detector, no $R_{discharge}$, no R_{bias}, T_{4K} ~ 4.0K, C_{FB} = 0.25pF