Radiation hardness of the ZEUS MVD frontend chip
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Appendix A

Frontend transfer functions

A.1 Transfer function of the preamp

In figure A.1(a) the schematic of the preamp is shown. Using current conservation the following set of equations is obtained

\[ I_{in} = I_2 + I_3 \]
\[ I_1 = \frac{V_{in}}{Z_1} \]
\[ V_{in} - V_{out} = I_2 Z_2 \]
\[ I_2 = g_m V_{in} + \frac{V_{out}}{Z_3} \]

Combining these equations, the transfer function of the preamp is obtained as

\[ \frac{V_{out}}{I_{in}} = \frac{\frac{1}{Z_2} + g_m}{\frac{1}{Z_3} \left( \frac{1}{Z_2 + g_m} \right) + \left( \frac{1}{Z_2} + \frac{1}{Z_3} \right) \left( \frac{1}{Z_1} + g_m \right)} \]

where

\[ Z_1 = \frac{1}{s \left( C_{det} + C_{ir} \right)} \]
\[ Z_2 = \frac{R_f}{1 + sC_f R_f} \]
\[ Z_3 = \frac{R_i}{1 + sC_i R_i} \]

Inserting the impedances and neglecting the small terms, the transfer function can be written as

\[ \frac{V_{out}(s)}{I_{in}(s)} = \frac{-g_m}{\frac{g_m}{R_f} + sg_m C_f + s^2 C_{in} C_{out}} \]
The signal from the silicon, $I_{in}(s)$ can be approximated by a $Q\delta(t)$. The LaPlace transform of the $\delta$-function is 1. The output signal of the preamplifier in the time domain is obtained by an inverse LaPlace transform of equation (A.9) after inserting $I_{in}$. The output signal of the preamplifier is then

$$v_{out}(t) = \frac{Q\tau_1}{C_{fb}(\tau_1 - \tau_2)} \left( e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}} \right)$$

with

$$\frac{1}{\tau_1} = \frac{1}{R_{fb}C_{fb}} \quad \text{and} \quad \frac{1}{\tau_2} = \frac{g_mC_{fb}}{(C_{det} + C_{tr} + C_{fb})(C_{fb} + C_l)}$$

When adjusting $I_{pre}$ the value of $V_{gs}$ of M2 is changed. The $V_{gs}$ of M2 determines the value of $g_m$. The register $V_{jp}$ determines the $V_{gs}$ of M7. This determines the value of $R_{fb}$.

Figure A.1: Schematic of the preamp (a) and the corresponding small signal model (b).
Figure A.2: Schematic of the shaper (a) and the corresponding small signal model (b).

A.2 Transfer function of the shaper

Making use of Kirchhoff's laws the transfer function of the shaper can be obtained analytically using a LaPlace transform. Current conservation yields

\[
\begin{align*}
I_1 &= I_2 + I_3 \\
I_3 &= I_4 + g_m V_1 \\
V_{in} - V_1 &= I_1 Z_1 \\
V_1 &= I_2 Z_2 \\
V_1 &= I_3 Z_3 + V_{out} \\
V_{out} &= I_4 Z_4
\end{align*}
\]

(A.12) \hspace{1cm} (A.13) \hspace{1cm} (A.14) \hspace{1cm} (A.15) \hspace{1cm} (A.16) \hspace{1cm} (A.17)

The transfer function follows from combining these equations

\[
\begin{align*}
\frac{V_{out}}{V_{in}} &= \frac{(1 - g_m Z_3) \frac{1}{Z_1}}{(\frac{1}{Z_3} + \frac{1}{Z_4}) \left(\frac{1}{Z_1} + \frac{1}{Z_2} + g_m\right) Z_3 + (1 - g_m Z_3) \frac{1}{Z_4}}
\end{align*}
\]

(A.18)
which reads after inserting the impedances

\[
Z_1 = \frac{1}{sC_c} \\
Z_2 = \frac{1}{sC_tr} \\
Z_3 = \frac{R_{fb}'}{1 + sC_{fb}R_{fb}'} \\
Z_4 = \frac{R_l}{1 + sC_lR_l}
\]

\[
A.19 \quad A.20 \quad A.21 \quad A.22
\]

\[
V_{out} = \frac{V_m}{V_{in}} = \frac{sC_c \left(1 - \frac{g_mR_{fb}'}{1 + sC_{fb}R_{fb}'}\right)}{\left(1 + \frac{sC_{fb}R_{fb}'}{R_l} + \frac{1 + sC_{fb}R_{fb}'}{R_l}\right)\frac{R_{fb}'}{1 + sC_{fb}R_{fb}'} (sC_c + SC_{tr} + g_m) + \frac{1 + sC_lR_l}{R_l} \left(1 - \frac{g_mR_{fb}'}{1 + sC_{fb}R_{fb}'}\right)}
\]

\[
A.23
\]

After removal of the negligible terms, the transfer function of the shaper is approximately:

\[
V_{out} = \frac{V_{in}}{V_{in}} = \frac{g_mC_c s}{\frac{g_m}{R_{fb}'} + s g_m C_{fb} + s^2 (C_c C_l + C_{tr} C_l + C_c C_{fb} + C_{fb} C_{tr})}
\]

\[
A.24
\]

When the signal from the preamp is indeed a voltage step, \(V_{in}(s) = \frac{1}{s}\). Inserting \(V_{in}(s)\) yields the output voltage of the preamp, which is of the form

\[
V_{out}(s) = \frac{K}{(s + a)^2 + b^2}
\]

\[
A.25
\]

This is in the time domain

\[
v_{out}(t) = \frac{K}{b} e^{-at} \sin(bt)
\]

\[
A.26
\]

Inserting \(K\), \(a\) and \(b\) yields

\[
v_{out}(t) \approx \frac{Q}{C_{fb}^{pre} R_{fb}'} \frac{g_m C_{fb}}{\sqrt{(C_{fb} + C_l)(C_c + C_{tr}) - \frac{C_{fb}^2}{4C_c^2}}} \sin \left(\sqrt{\frac{g_m R_{fb}'}{(C_{fb} + C_l)(C_c + C_{tr}) - \frac{C_{fb}^2}{4C_c^2}}} t\right)
\]

\[
A.27
\]

The register \(V_{fs}\) determines the value of the \(V_{gs}\) of M7 and hence the value of \(R_{fb}\) of the shaper. The value of \(I_{sha}\) determines the value of the \(V_{gs}\) of M2. This determines the \(g_m\) of the shaper.