Charge Pre-Amplifier.

Introduction.

The schematic of the charge Pre-Amplifier is drawn in figure 1. In a charge amplifier the main feedback is a capacitor.

In the ideal case the capacitor is the only feedback. All input charge will flow into this capacitor. This gives an output voltage of:

\[ U = \frac{Q}{C}. \]

The demands for the amplifier, to get all input charge on the capacitor, are:

1. Very high gain,
2. Very high bandwidth,
3. No leakage of charge.

This amplifier cannot been made within the design limits, so we will have to compromise on all three points.

1. Very high gain:
   When the gain is infinitive the input of the amplifier becomes the so-called virtual ground. When the gain of the amplifier is smaller an error signal appears on the input of the amplifier. This signal will cause some of the input charge to stay on the detector- and input- capacitor. This charge is not used to produce output signal and therefore lost.

2. Very high bandwidth:
   When the bandwidth is infinitive the output will follow the input without distortion. The bandwidth however is limited. The pulse shape at the output has distortion due to this limitation. The settling time of the signal on the output is longer. An other result of this being slower is the fact, that part of the input charge is gone already before the output is on it's end value. It makes the end value lower as it could be.

3. No leakage of charge:
   It's impossible to build an amplifier without any charge leakage, because without it's impossible to control the DC set point of the amplifier. For signals with a known timing it's possible to make the leakage switched. In our case the timing of the input signal is random, so a continuous leakage is needed. The disadvantaged of this circuit is the fact that some input charge is lost into the resistor without giving any contribution to the output signal.
The schema of the amplifier:

Figure 1: The schema of the amplifier.
The schema of the amplifier is drawn in figure 1. Used for the amplifier is the folded cascode principal. Reason for this principal is to give the amplifier two different sides.

1. The input side:
   On the input the FET must be big, to keep the amplifier noise contribution low, and realise a high $g_m$.
2. The output side:
   The FET on the output must be small, to make high speeds possible.

The input FET M0 converts the input signal into a current change. The current source M1 does not allow this change, so the only way this $\Delta i$ can flow is into the source of M16. The load of M16 is the second current source M13. Between these point (net73) the output voltage ($\Delta v$) appears.

All feedback should be realised from this point. The DC set point on the gate of the input FET however is about -1 V. To realise a nice symmetrical output the DC set point on net 73 should be around 0 V. FET M28 and a small current source makes this voltage step.

### The component sizes.

When a certain technology is chosen the only way to control the way a component behaves in the circuit is by changing size of a component.

One of the important parameters of a FET is the transconductance $g_m$. The formula for the $g_m$ is:

$$g_m = \sqrt{2 \cdot \mu_{eff} \cdot C_{ox} \cdot \frac{W}{L} \cdot I_{DS}}$$

In this formula 3 design parameters, which we, within limit, control, influence directly the value of $g_m$. These parameters are $W$ (width of the FET), $L$ (length of the FET) and $I_{DS}$ (drain source current through the FET). The trick now is to choose the best values for a certain FET.

This start with deducting what you expect of a FET? What is the value of $g_m$ you need? Are their limits to the parameters?

With the values then chosen simulation starts. By varying the value's one by one an optimum can be found. In our case I tried to reach the best signal noise figure on the equivalent input noise.

To deduct this figure the simulation must calculate the gain of the amplifier and the rms. noise on the output.

A charge amplifier has a charge as input signal and a voltage as output. The gain therefor has the dimension $V/Q$. The minimal input signal is one MIP (12000 electrons), which is a charge of 1.92 fQ. The noise contribution of the amplifier should be calculated in electrons at the input to make a good evaluation of the circuit possible.

This is called the Electrical Noise Charge. The formula is:

$$ENC = \frac{V_{rms} \cdot V_s \cdot C_s}{q \cdot V_{op}}$$
The simulations.

The first simulation calculates the transient response. This is the output voltage caused by a signal of 1 MIP on the input. To simulate 1 MIP I used a current source of 500 nA during 3.84 nsec. The charge of this pulse is about 12000 electrons.

A current source is chosen, because a detector is also a current source. Second a voltage source short-circuits the input for a certain part of the frequency spectrum through the capacitor. This makes the output of the noise calculations not correct.

The charge pulse from a detector does not arrive instantly, therefore the input pulse is made lower (500 nA) and longer (3.84 nsec).

In figure 2 the output pulse due to 1 MIP input charge at the moment 10 nsec is drawn.

![Figure 2: The transient Response.](image)

50 nsec after the input pulse starts the output reaches his maximum value of 16.5 mV. The rise time of the signal is 23 nsec (10% - 90%). The difference between those two numbers can be declared by:

1. The delay time of the circuit, about 1 nsec.
   The signal needs some time to travel through the circuit.
2. The time to reach the 10% point, about 4 nsec.
   This part of the edge is fast, because the signal on the gate of M0 is big and the signal on the output is small, so almost no leakage jet.
3. The time from 90% to the end value, about 22 nsec.
   This part of the edge is slow, because the signal on the gate of M0 is smaller and the signal on the output is relatively big, so the leakage is almost maximal for this situation. The major part of the \( \Delta i \) is flowing into the resistor instead of into the capacitor.
The AC response.

In figure 3 the AC response is drawn. This simulation is needed for the noise simulation. The graphic is the result of the amplifier with a signal of 1 A on the input. Normally this signal would be much too big but the simulator ignores in this case the power supply limits. Due to using a current of 1 A as the input signal the graphic represents the gain-bandwidth characteristic. The characteristic is a little bit misleading, because on first side the bandwidth looks small. By using a shaper later on only the part around 15 MHz is used. The gain there is not 3 M but about 50 k.
**The Noise Response.**

In the simulator the noise spectrum at the output of the amplifier can be calculated. This spectrum is given in figure 4.

![Figure 4: The noise response.](image)

The noise response drawn in figure 4 falls down from low frequencies up until around 1 MHz a peak appears. This peak is caused by the detector capacitor. To illustrate this in figure 5, 5 diagrams are drawn with the detector capacitor going from 0 pF to 20 pF in 5 pF steps.

The diagram however tells us little about the signal noise ratio. Therefore the noise must be calculated to the input as electrons. As shown before, calculating the $\text{ENC}$ does this.

$$\text{ENC} = \frac{v_{rms} \cdot V_s \cdot C_s}{q \cdot V_{op}}$$

To make it easier to find the optimum in component sizes I used several special functions of the calculator to calculate the $\text{ENC}$. These functions are:

1. **RmsNoise** (10M, 30M).
   - This function calculates the rms. value of the noise at the output of the amplifier.
2. **YMAX**.
   - Gives the maximum value of a signal back.
3. **YMIN**.
   - Gives the maximum value of a signal back.
Figure 5: The noise dependency of the detector capacitor.

In the formula for $ENC$ the value $v_{rms}$ is calculated by function 1. The value $V_s \cdot C_s$ is the input charge, in this case $1.92 \cdot 10^{-15}$. The value of $q$ in the formula is $1.6021 \cdot 10^{-19}$. The last value $V_{op}$ is calculated by subtracting function 2 and 3.

This gives the formula in the calculator:

$$ENC = \frac{rms\text{Noise}(10M, 30M) \cdot 1.92 \cdot 10^{-15}}{(YMAX(net73)) - (YMIN(net73))] \cdot 1.6021 \cdot 10^{-19}}$$

The result of this formula is given in the table below for all 5 given detector capacitors.

<table>
<thead>
<tr>
<th>Capacitor (pF)</th>
<th>Number of electrons</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>292</td>
</tr>
<tr>
<td>5</td>
<td>457</td>
</tr>
<tr>
<td>10</td>
<td>588</td>
</tr>
<tr>
<td>15</td>
<td>694</td>
</tr>
<tr>
<td>20</td>
<td>785</td>
</tr>
</tbody>
</table>

These numbers are also plotted in figure 6.

As you can see in this figure, the relation between capacitor and noise is almost linear. With 5 pF the difference is 33 electrons/pF while for 20 pF it's 25 electrons/pF.
Figure 6: The ENC dependence of the detector capacitor.