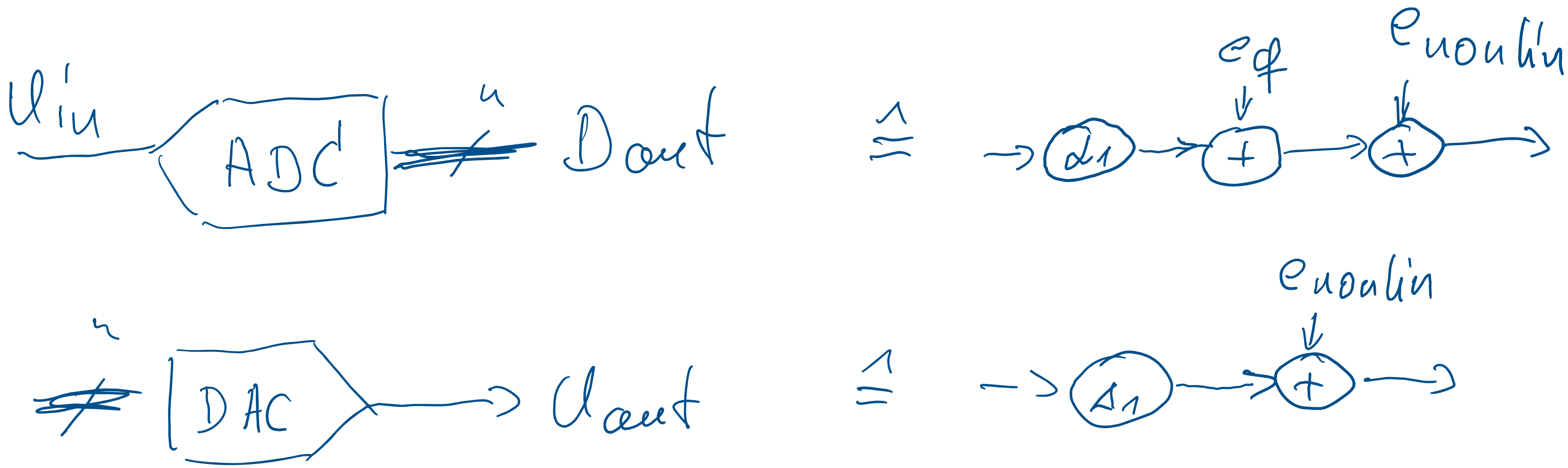
# Delta-Sigma Modulation Theory and Practical Setup

In the ADA Master Course

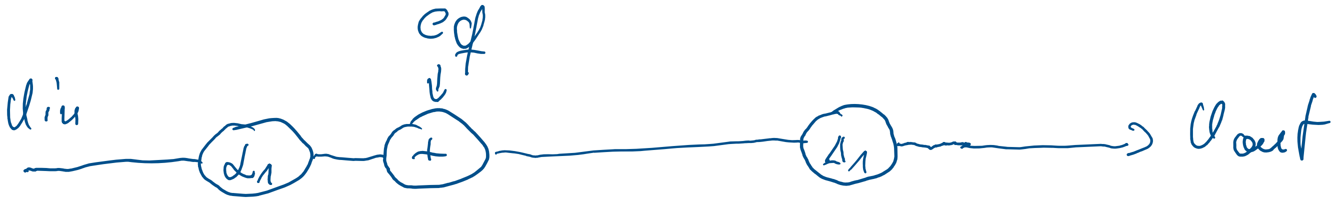
# A/D- and D/A Converter Most Simple Models



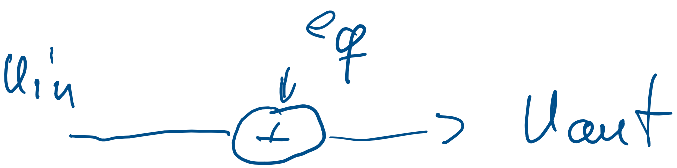
# A/D and D/A –Converter in Series, 1

mit $\Delta_1 \cdot \alpha_1 = 1$ and $e_{nonlin} = 0$


q Level = ld (q) = 3,17 bit

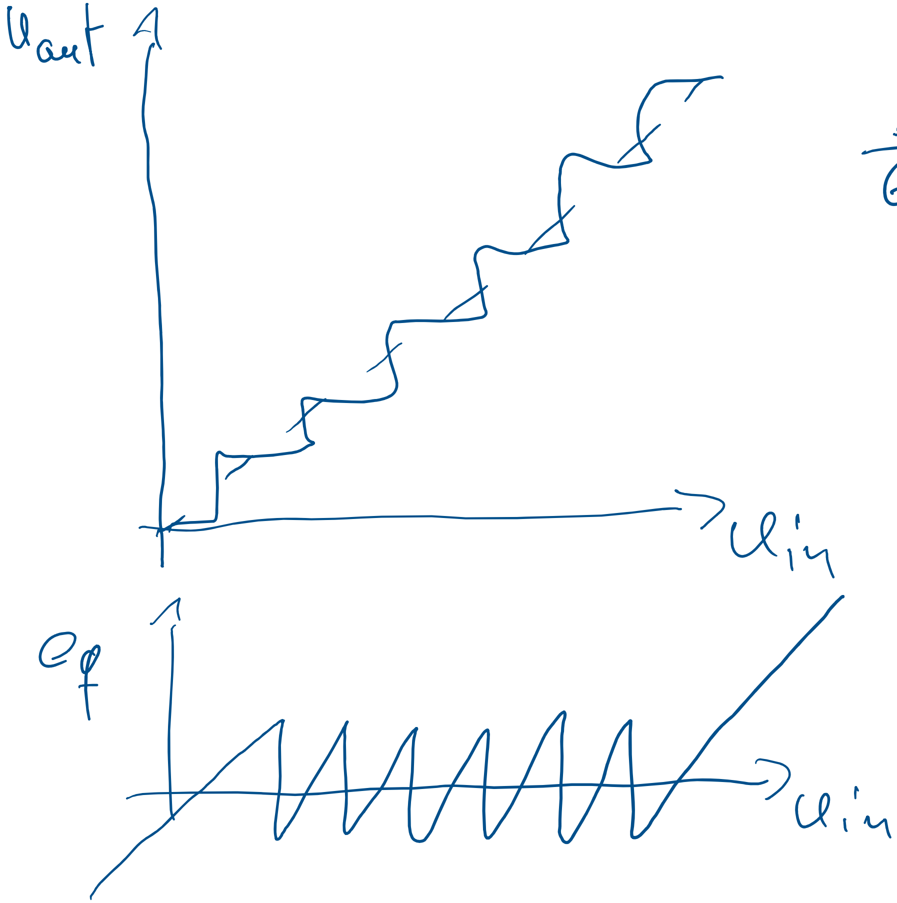


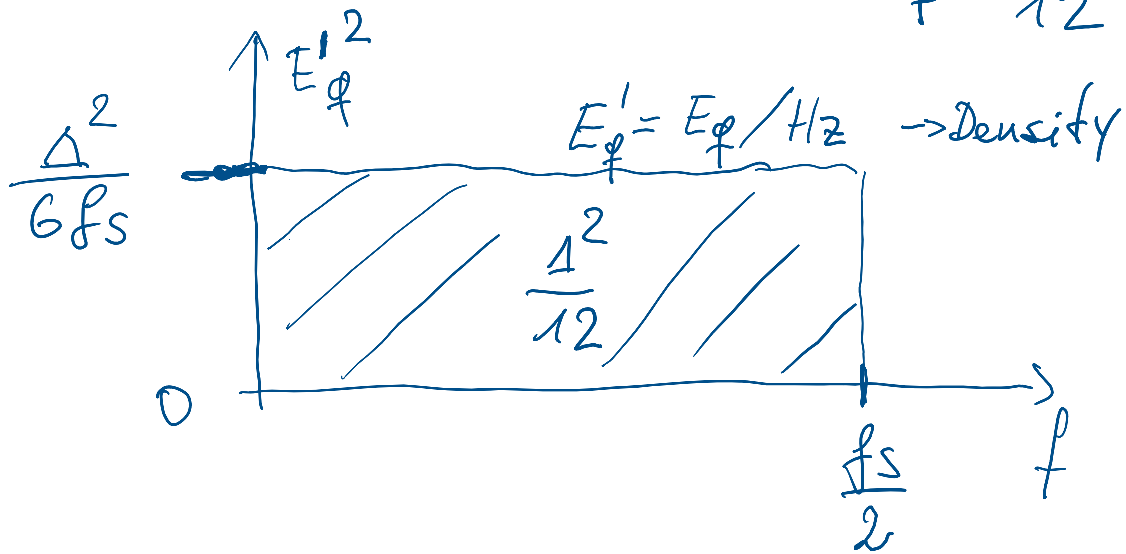

$\alpha_1 \cdot \Delta_1 = 1$ :



# A/D and D/A –Converter in Series, 2

Total $E_q^2$: $\frac{\Delta^2}{12}$

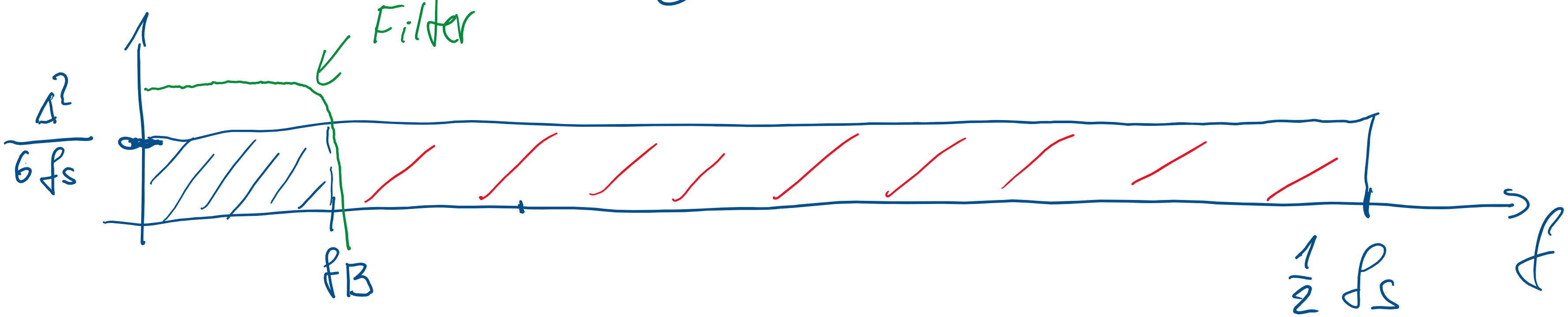



Quantization noise is white, in input signal sufficiently busy

# Principle of Noise Reduction in PWM

1 Oversampling




Quantization noise in Baseband $0 \ldots f_B$

$$\overline{E_{q}}_{B}^{2} = \frac{E_q^2}{OSR} \quad \text{with } OSR = \frac{f_s}{2 f_B} \text{ : oversampl. Ratio}$$

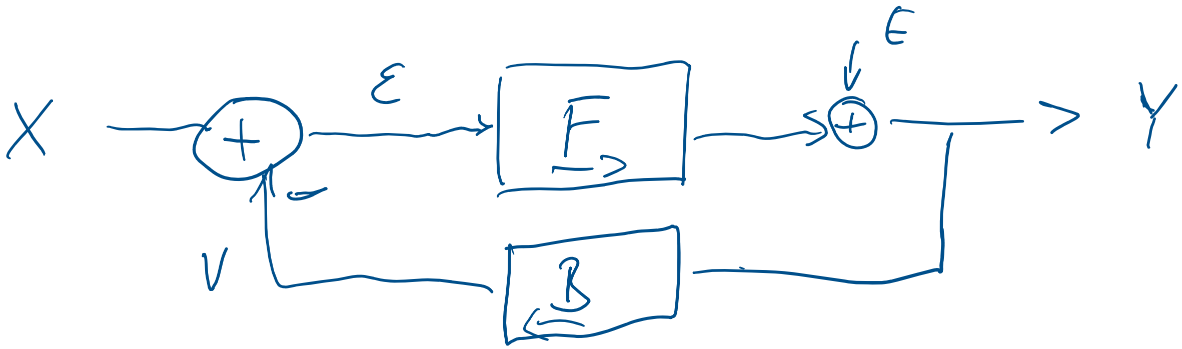
# PWM corresponds to a Delta-Sigma Modulator of Order 0:

Rauschleistung im Basisband

$$E_{qB}^2 = \frac{E_q^2}{OSR}$$

$$E_{qB} = \frac{E_q}{\sqrt{OSR}} = \frac{E_q}{OSR^{1/2}}$$

# Lineare Feedback Loops

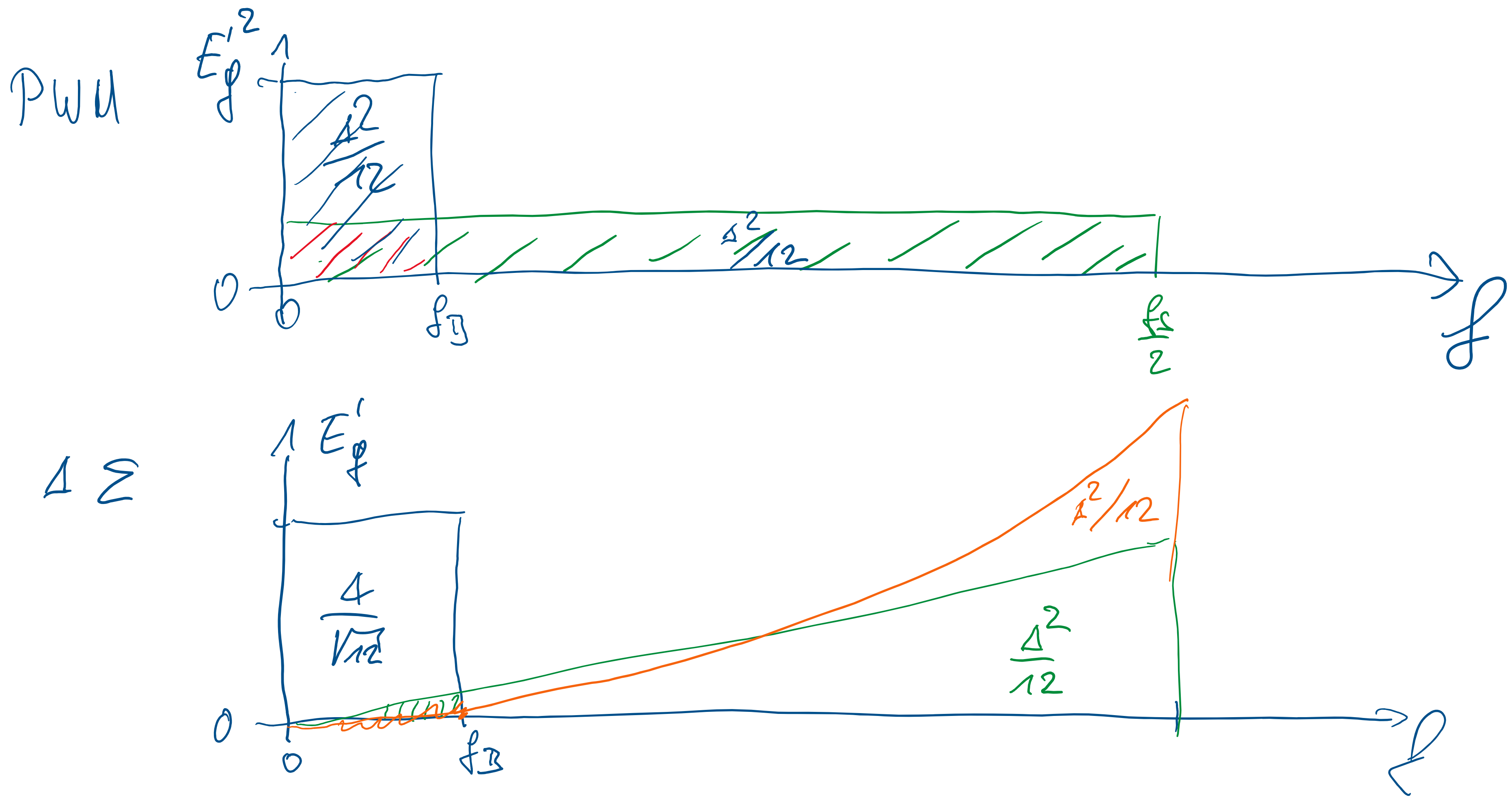



$$E = 0: \quad Y = \varepsilon F = (X - V) F = (X - BY) F$$

$$STF = \frac{Y}{X}\Big|_{E=0} = \frac{F}{1 + FB} \xrightarrow{|FB| \to \infty} B^{-1}$$ } Signal Transfer Func.

$$NTF = \frac{Y}{E}\Big|_{X=0} = \frac{1}{1 + FB} \xrightarrow{|FB| \to \infty} 0$$ } Noise Transfer Function

# Shaping Quantization Noise out of the Baseband



# Power of Noise Shaping: Reduction of $E_q^2$ in the Baseband 0…$f_B$ as a Function of Oversampling Ratio OSR = $f_S/(2f_B)$

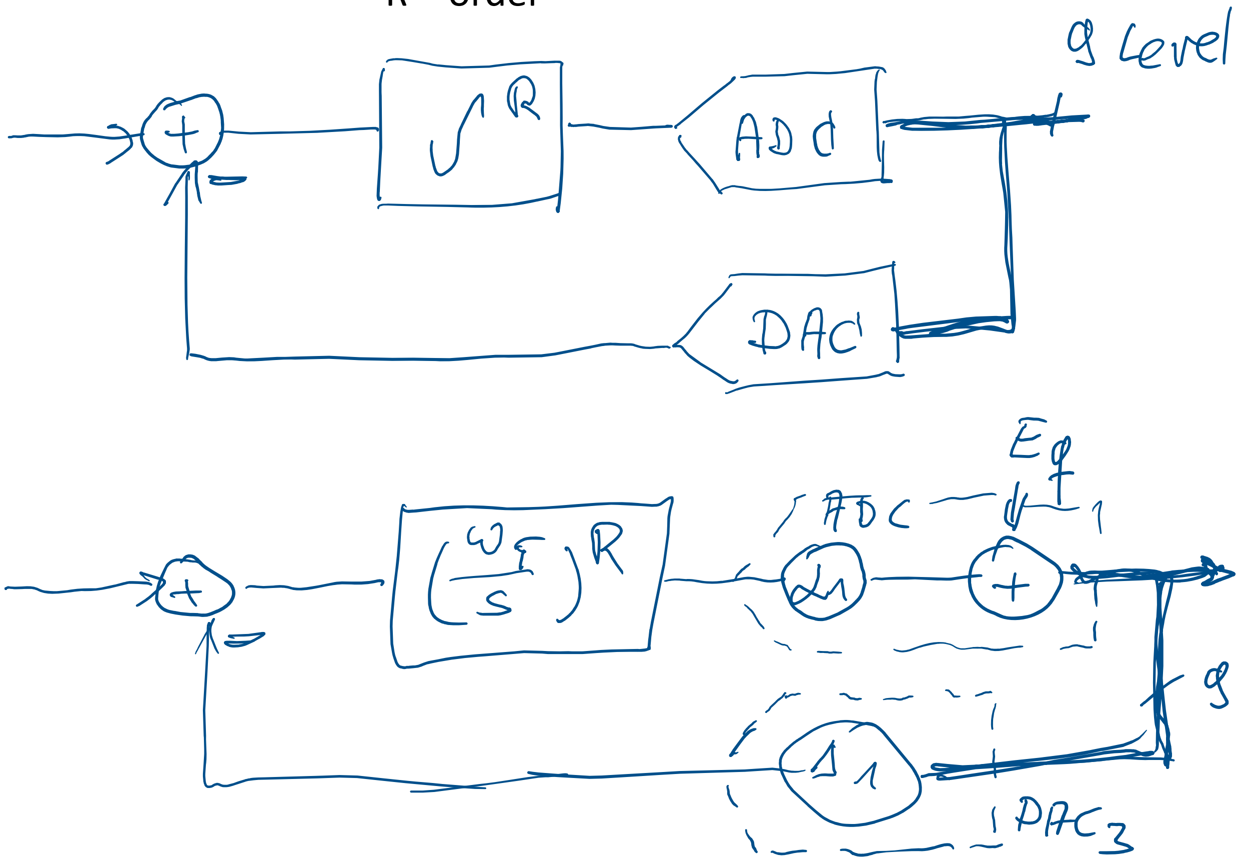
**Table 5.4.3.4:** Theoretically obtainable *SNR* improvements. Taken from [Leme, PhD...]

| ***SNR$_{dB}$*** | **20 dB** | **40 dB** | **60 dB** | **80 dB** | **100 dB** |
|---|---|---|---|---|---|
| *OSR*(*order* =2) | 5 | 11 | 27 | 67 | 168 |
| *OSR*(*order* =1) | 6 | 28 | 126 | 578 | 2657 |
| *OSR*(*order*=0) | 100 | 10322 | 1,05E6 | 106E6 | 1,08E10 |

Consider: The total noise power remains constant. Reduction of $E_q^2$ in the baseband is achieved by pushing noise power to higher frequencies. To get the quality figures shown in the table above, we have to assume (i) an infinitely good filter with cut-off frequency $f_B$, and (ii) there are no other noise sources.

# Delta-Sigma Modulator in the Practical Training

R = order



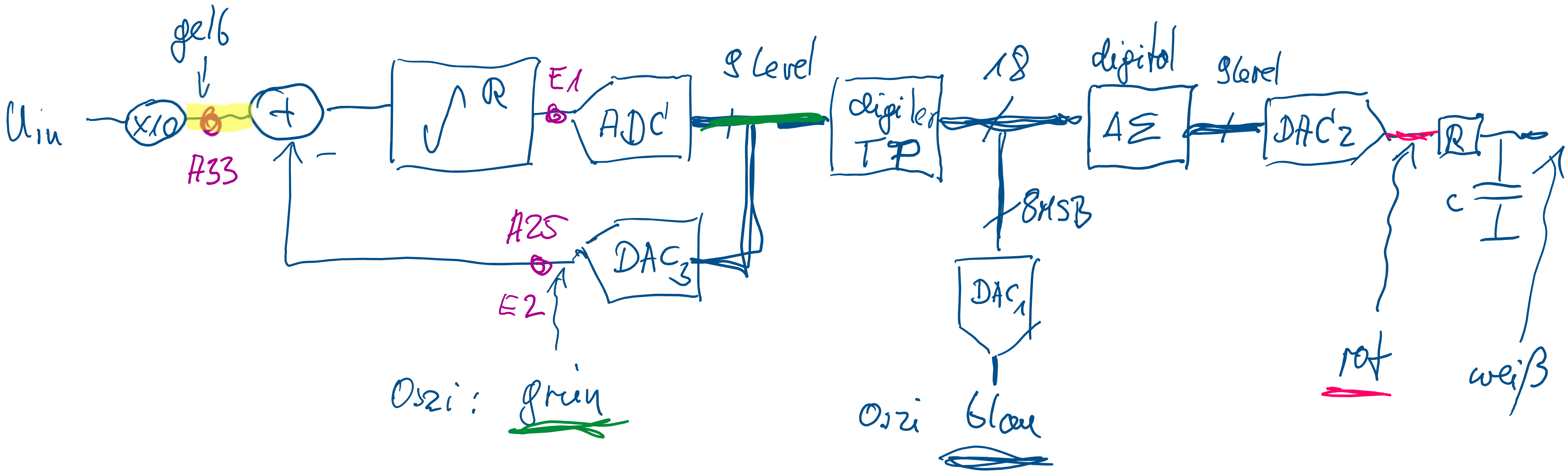

$$NTF = \frac{1}{1 + FB}$$

$$= \frac{1}{1 + \alpha_1 \left(\frac{\omega_T}{s}\right)^R \cdot \Delta_1}$$

$$= \frac{s^R}{s^R + const} \approx s^R$$

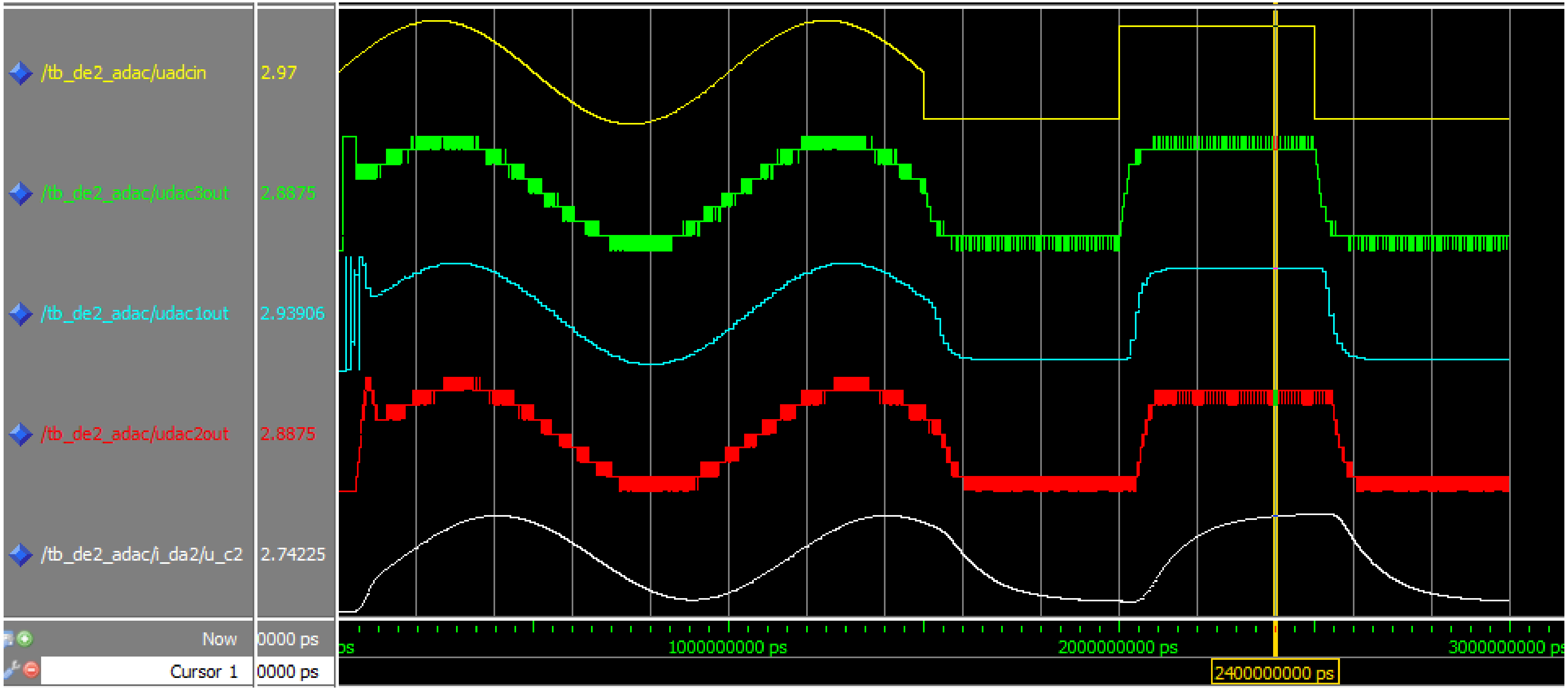
$\approx 0$ bei großen OSR

# Building Delta-Sigma in the Practical Training

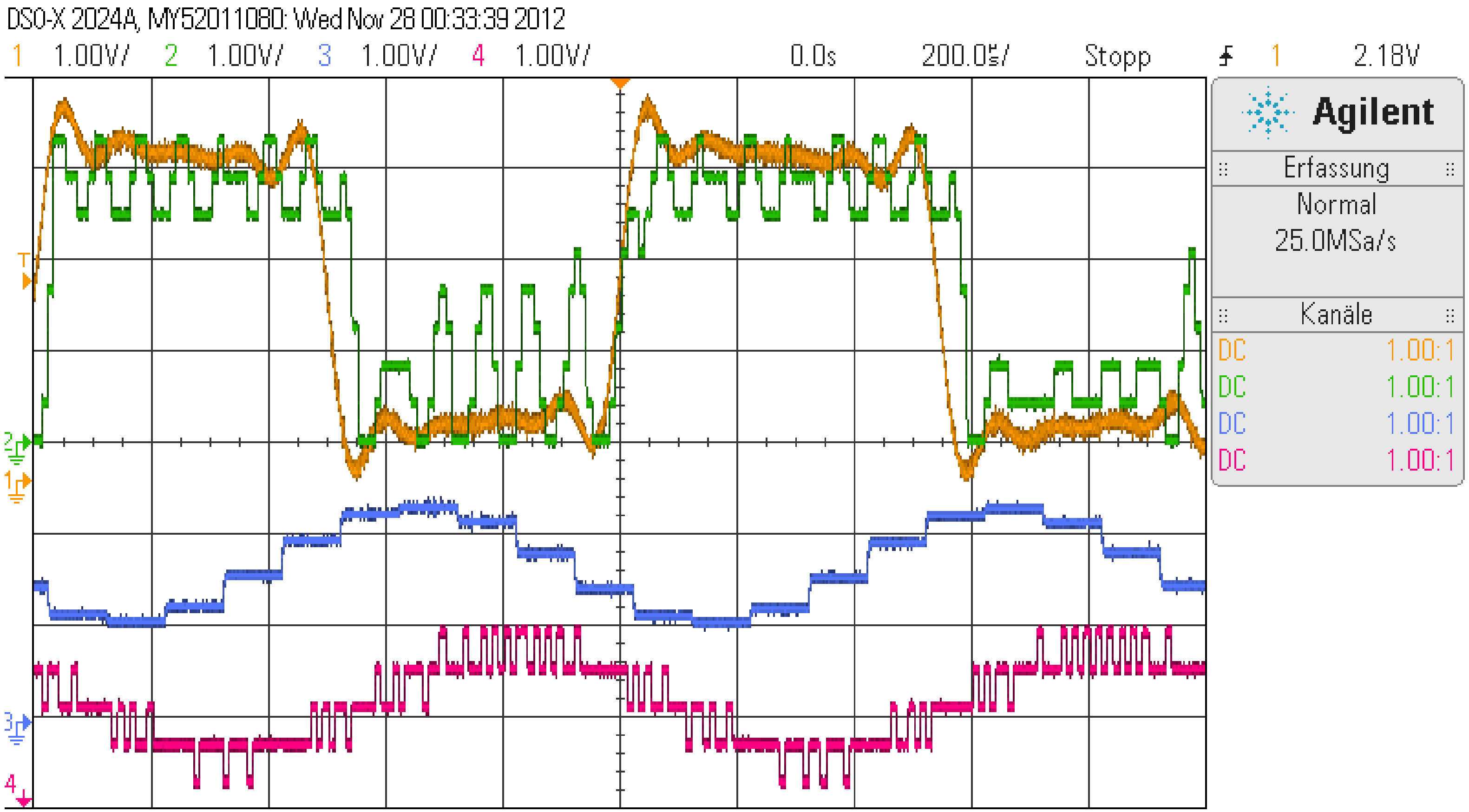



See also simulation plot next page

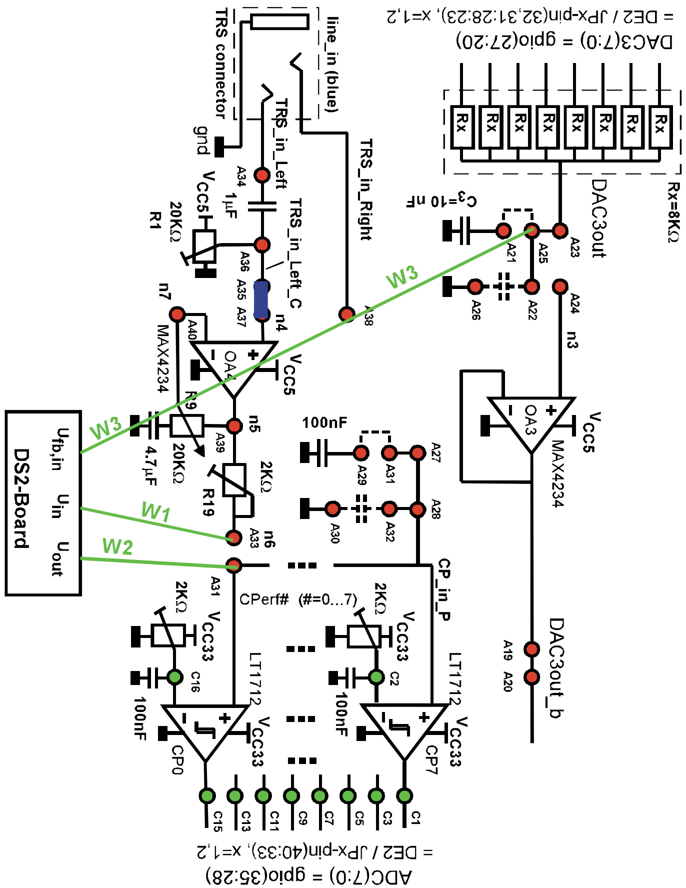
# A/D and D/A Delta-Sigma Simulation using ModelSim

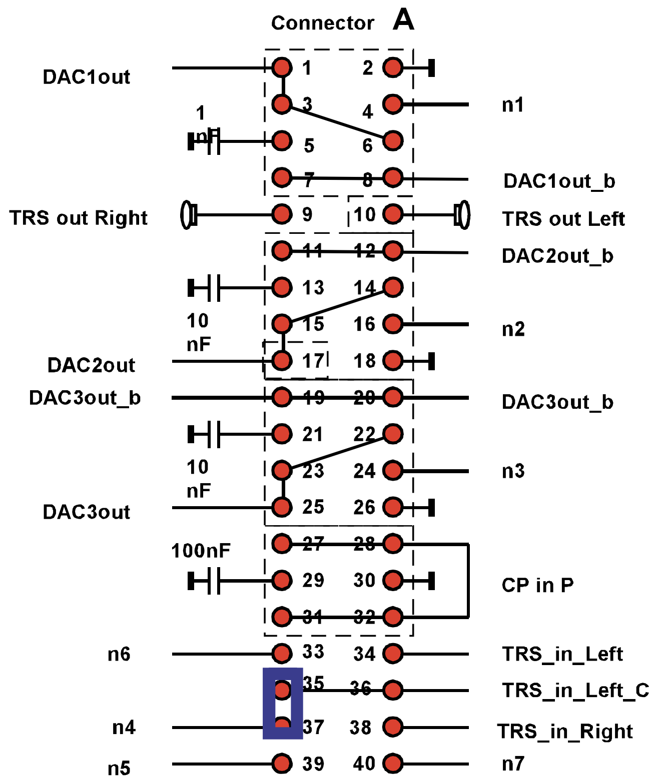


# A/D and D/A Delta-Sigma Simulation Measured



# A/D and D/A Delta-Sigma Simulator on DA2 Board



# Integrator on DA2 Board