# Building the SAR ADC Simulation Model

## TIPL 4403
## TI Precision Labs – ADCs

**Created by Tim Green, Art Kay**

**Presented by Peggy Liska**

# Agenda

1. SAR Operation Overview
2. Select the data converter
3. Use the Calculator to find amplifier and RC filter
4. Find the Op Amp
5. Verify the Op Amp Model
6. Building the SAR Model
7. Refine the Rfilt and Cfilt values
8. Final simulations
9. Measured Results
10. SAR Drive Calculator Algorithm

# Equivalent Circuit: Translate to TINA

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **ANALOG INPUT** | | | | | | |
| | Full-scale input span(1) | AINP – AINN | 0 | | $V_{REF}$ | V |
| | Operating input range(1) | AINP | –0.1 | | $V_{REF}$ + 0.1 | V |
| | | AINN | –0.1 | | + 0.1 | V |
| $C_I$ | Input capacitance | AINP and AINN terminal to GND | | 59 | | pF |
| | Input leakage current | During acquisition for dc input | | 5 | | nA |

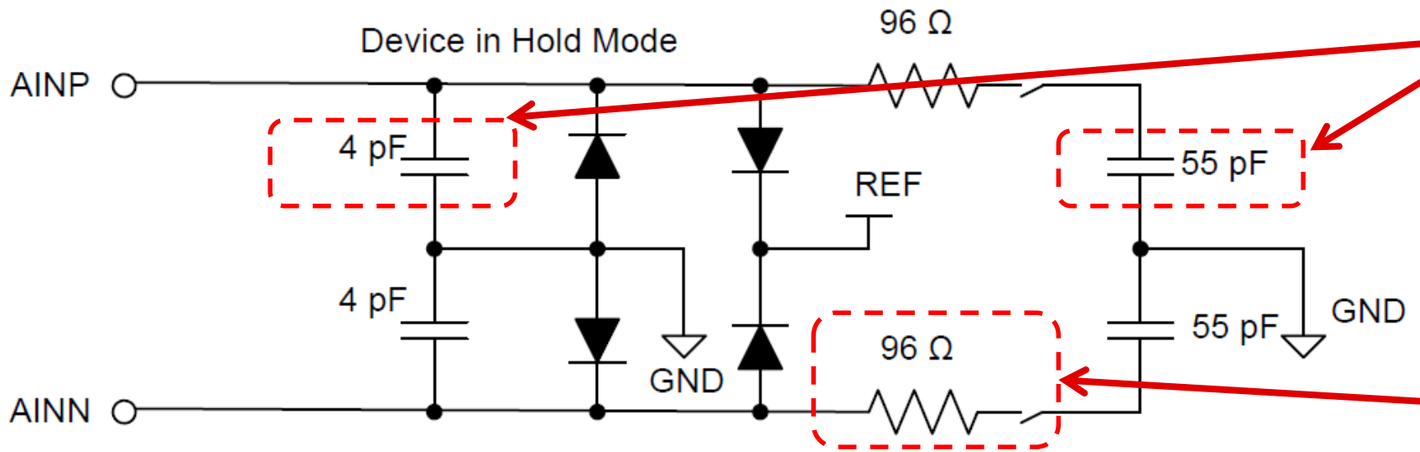



**Figure 45. Input Sampling Stage Equivalent Circuit**

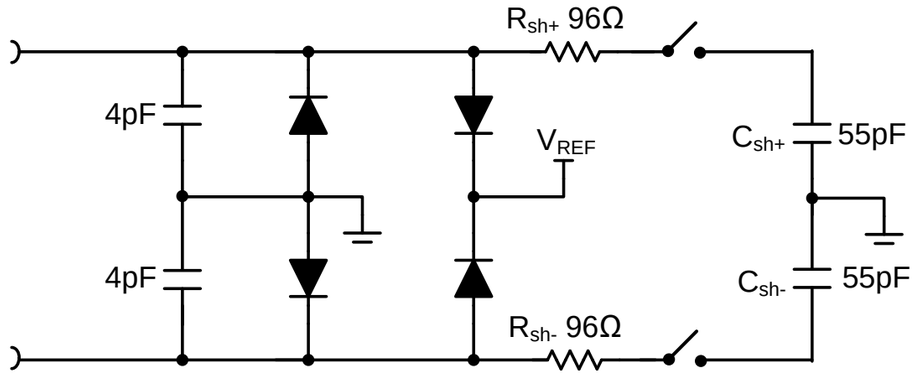
59pF = 55pF + 4pF

$$R_{sh} \approx \frac{t_{acq\_min}}{100 \cdot C_{sh}}$$

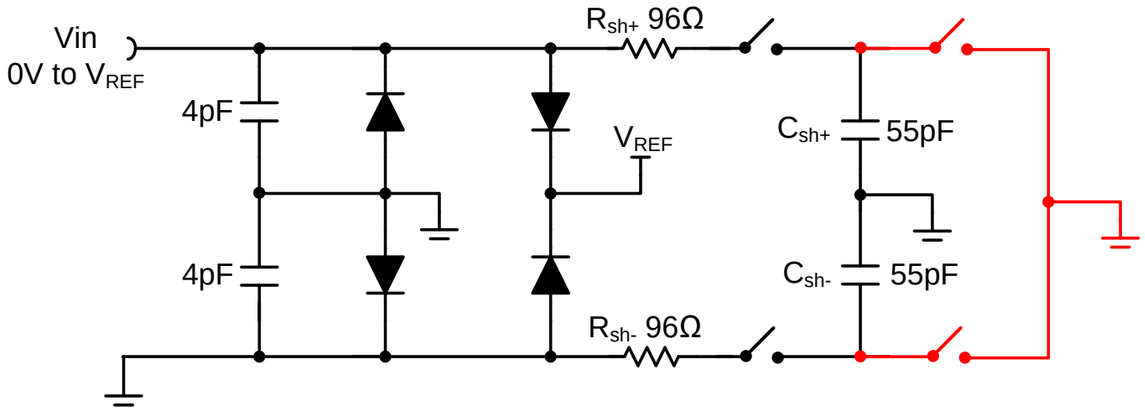
$$R_{sh} \approx \frac{290ns}{100 \cdot 55pF} = 53\Omega$$

# Simplifying the input model

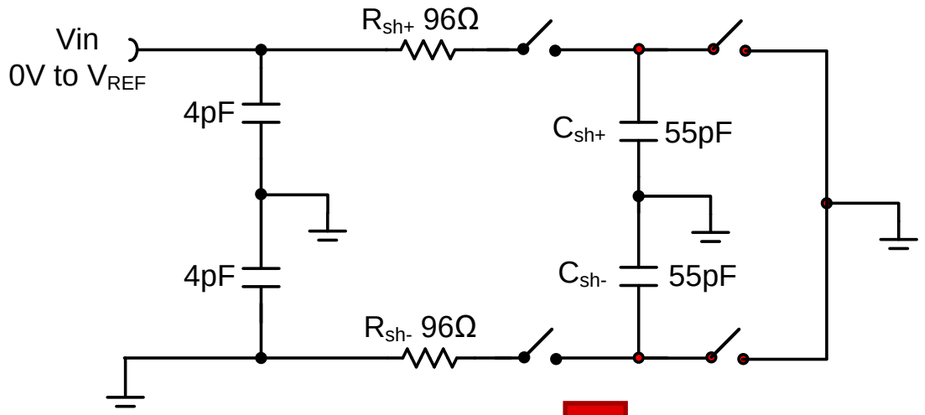
1) Input Circuit from the data sheet



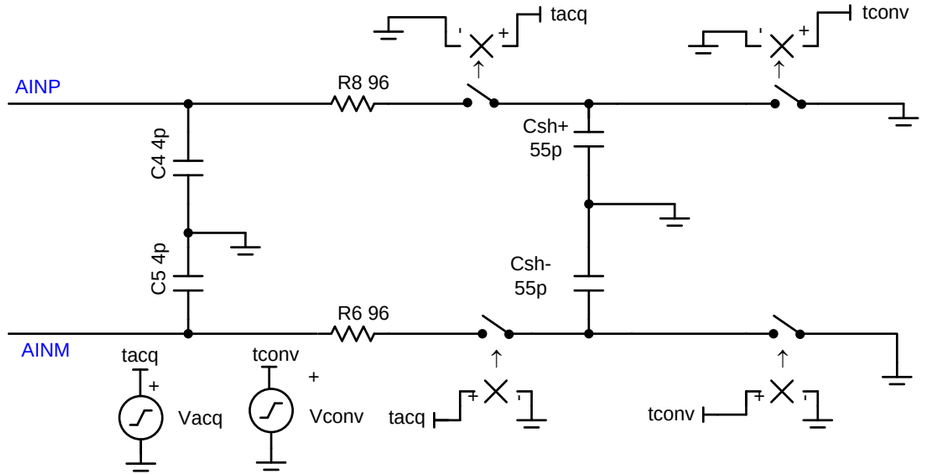

2) Add the sample and hold reset circuit



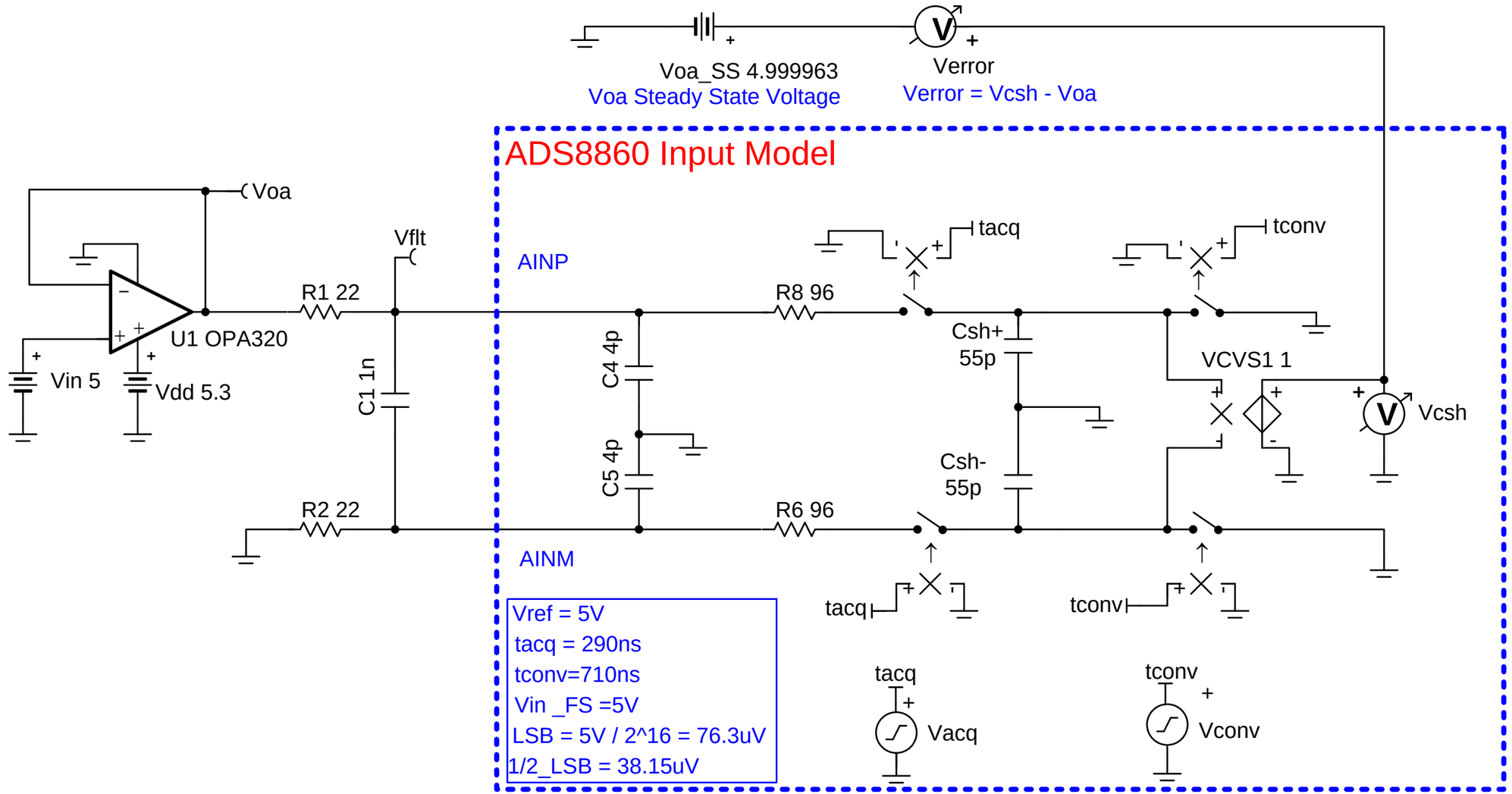

3) Diodes are reverse bias



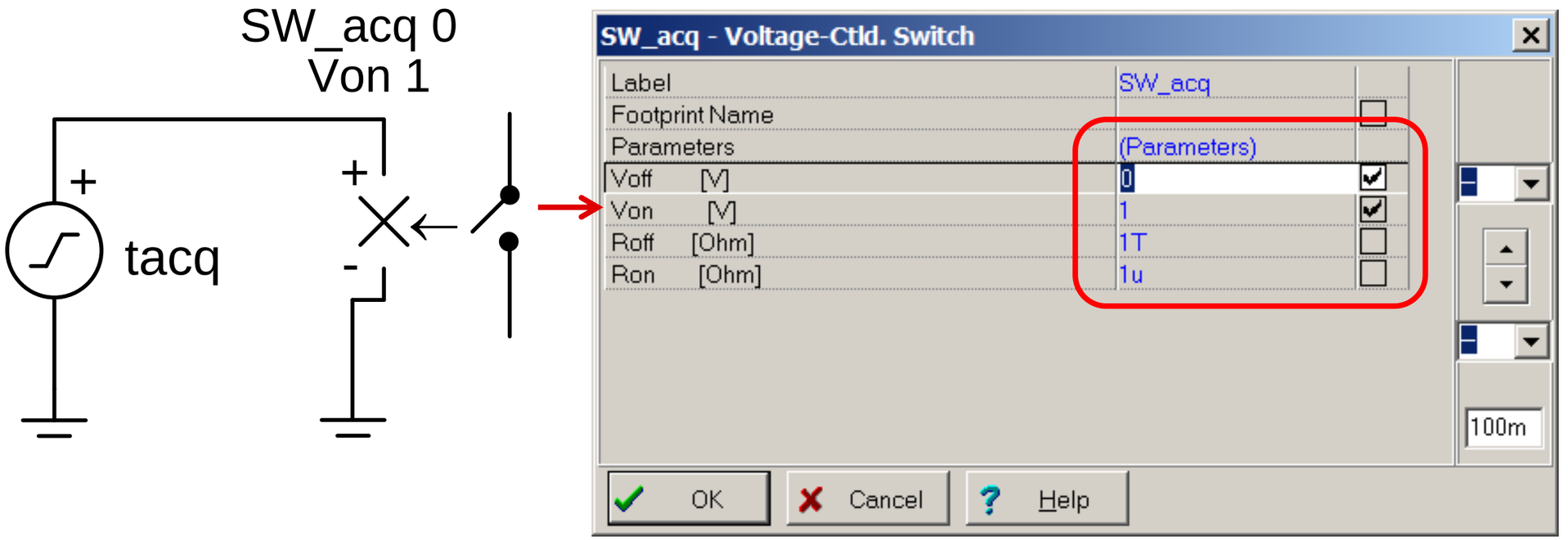

4) TINA Spice Model



# TINA SPICE Equivalent Model



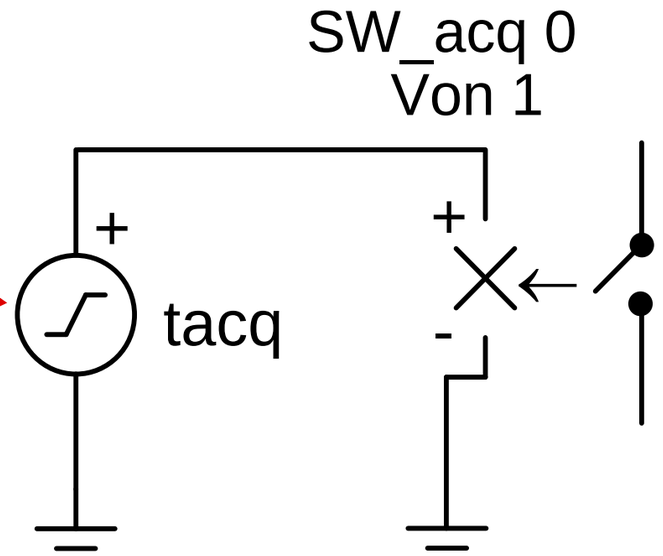
# Configure the voltage controlled switch



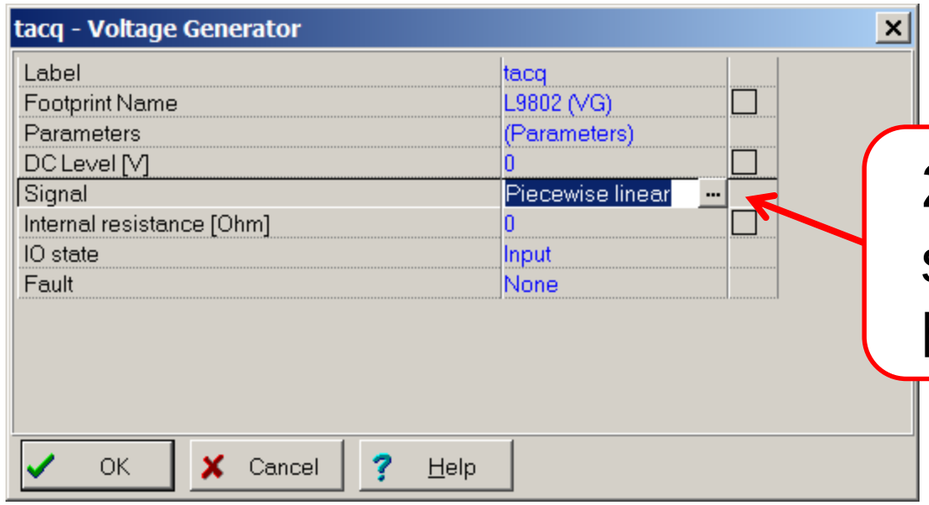

**Set all parameters as shown.**

Default Roff=1GΩ and Ron=0Ω will impact accuracy.

# Configure the signal source to control the switch

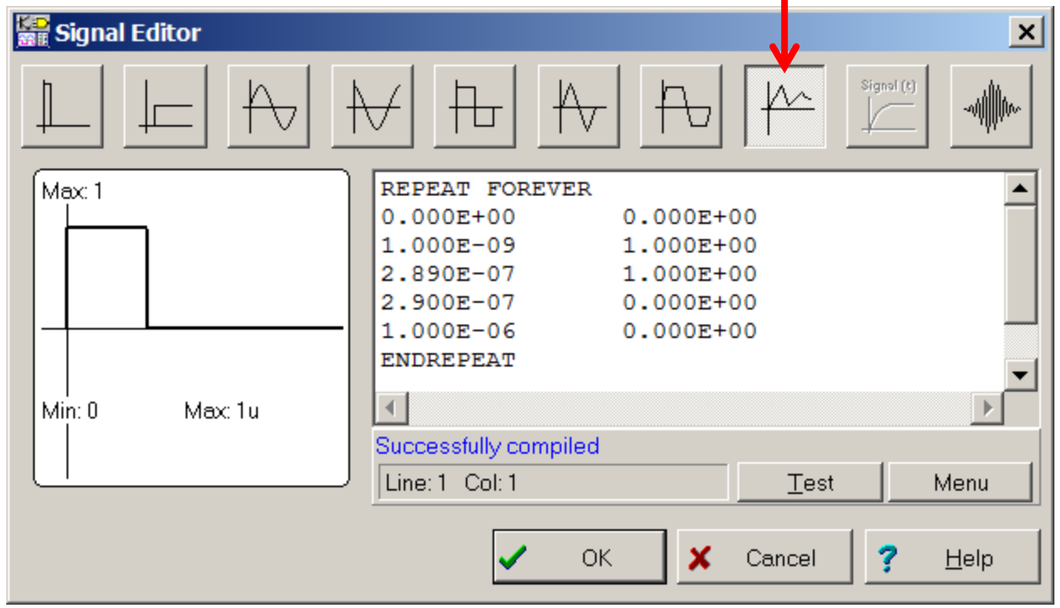



1. Click on source to select and edit switch control signal




2. Under signal, click here to edit.

3. Select “Piecewise linear”



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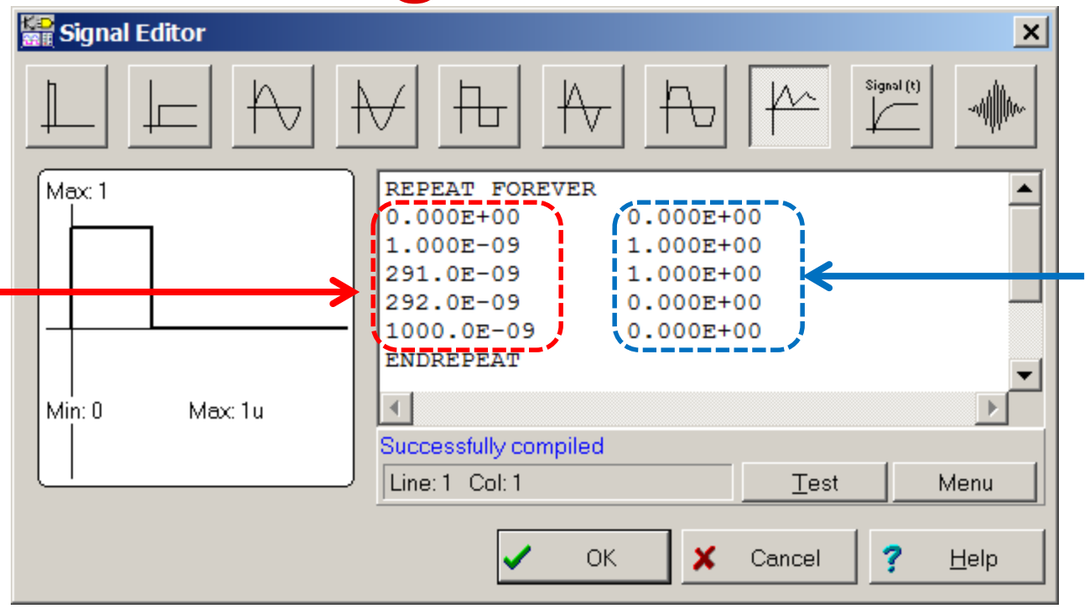
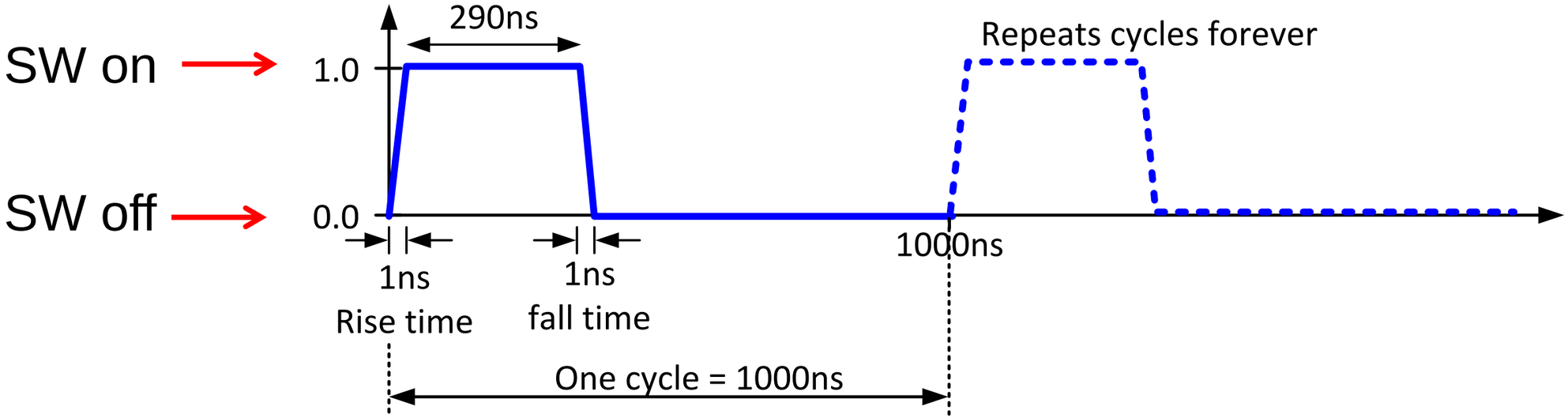
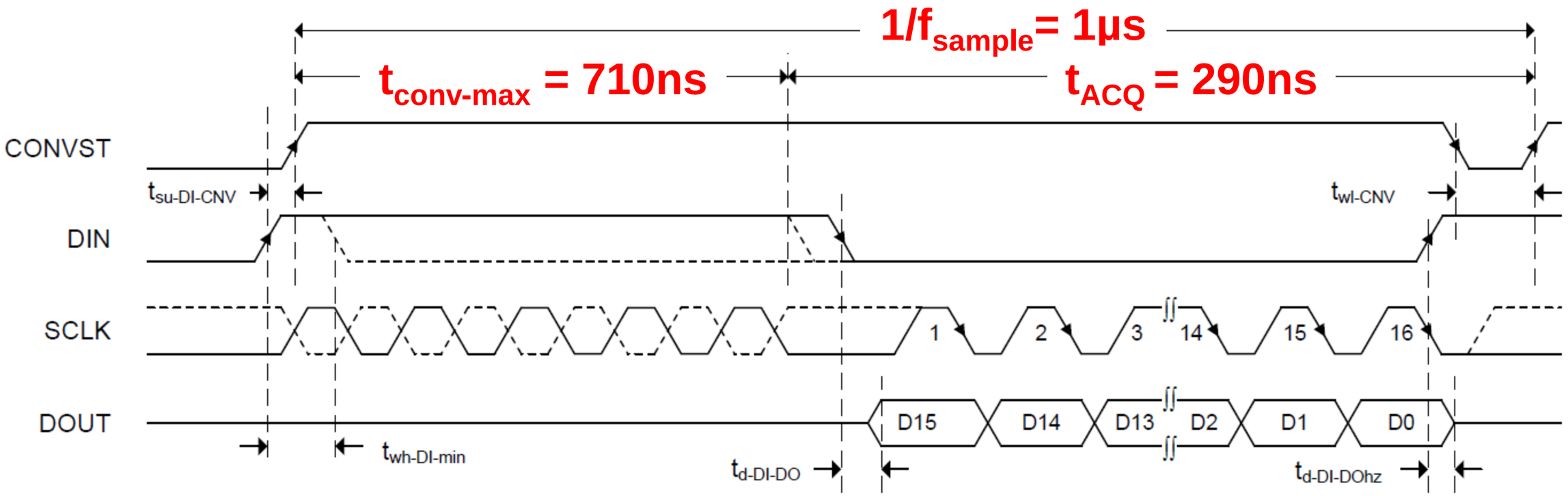



Time

Voltage levels
On: V ≥ 1V
Off: V ≤ 0V



# Timing diagram



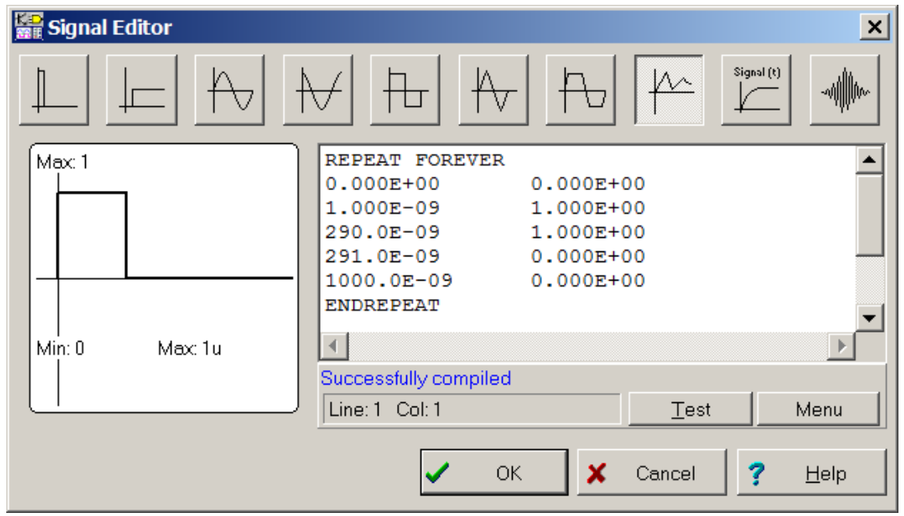

| Parameter | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| $t_{acq}$ | Acquisition time | 290 | | | ns |
| $t_{conv}$ | Conversion time | 500 | | 710 | ns |

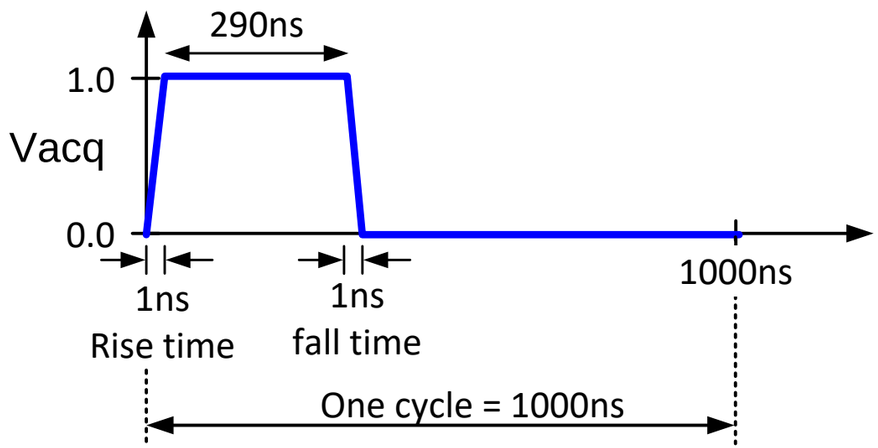
$1/f_{sample} = 290ns + 710ns$

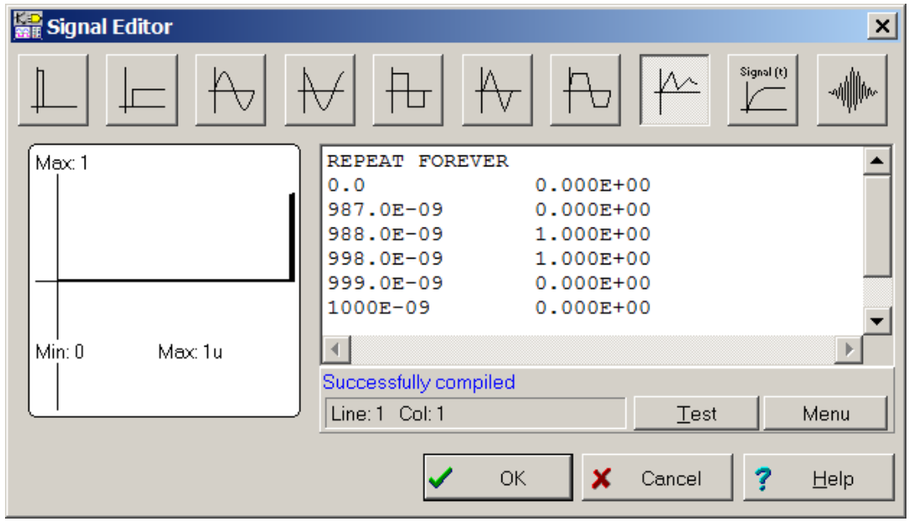
$1/f_{sample} = 1µs$

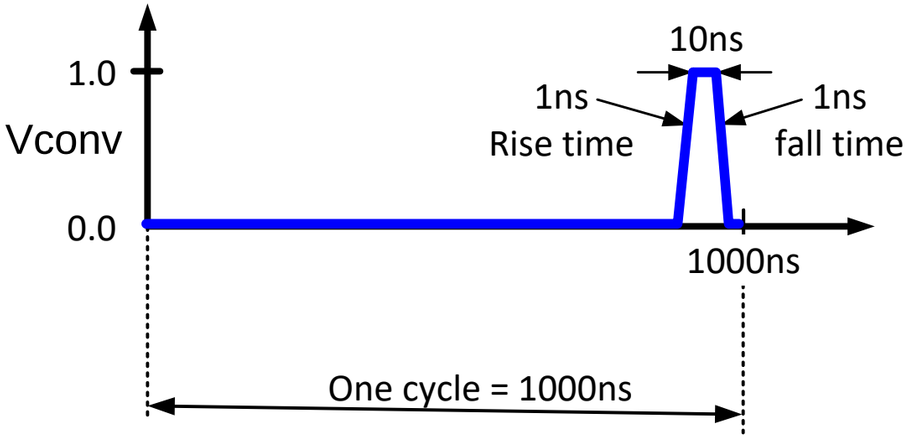
$f_{sample} = 1MHz$

# Example simulation: simulator settings

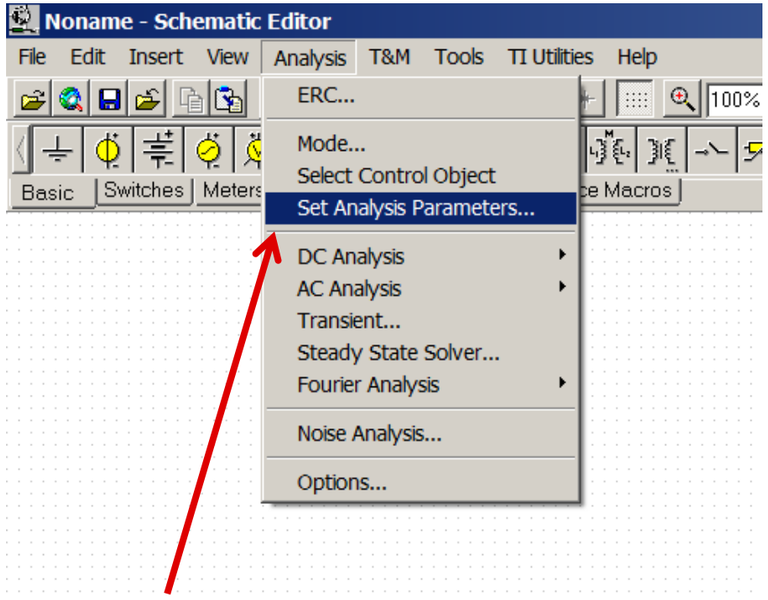


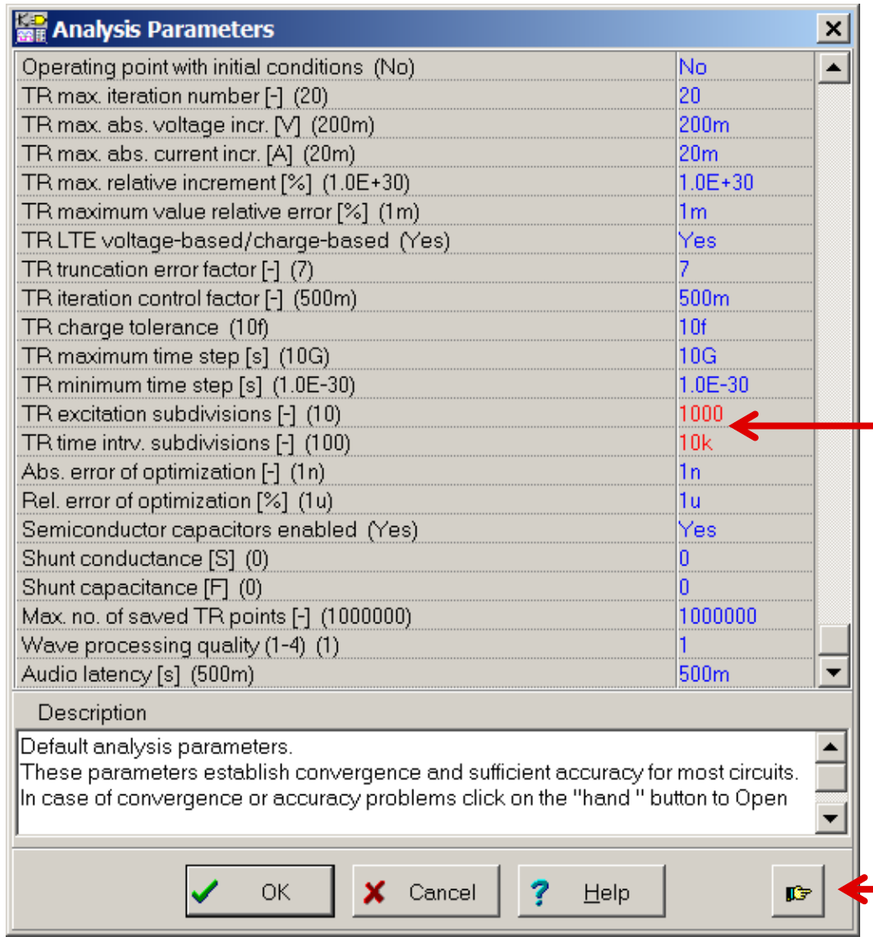



# Optimizing Simulation Results



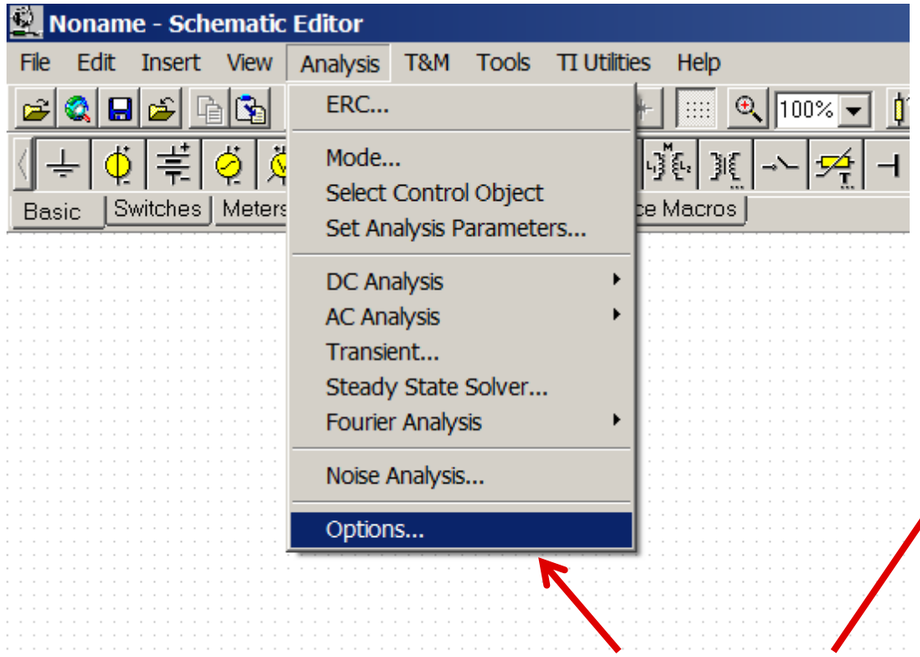

"Set Analysis Parameters" adjusts how the simulator math engine operates.

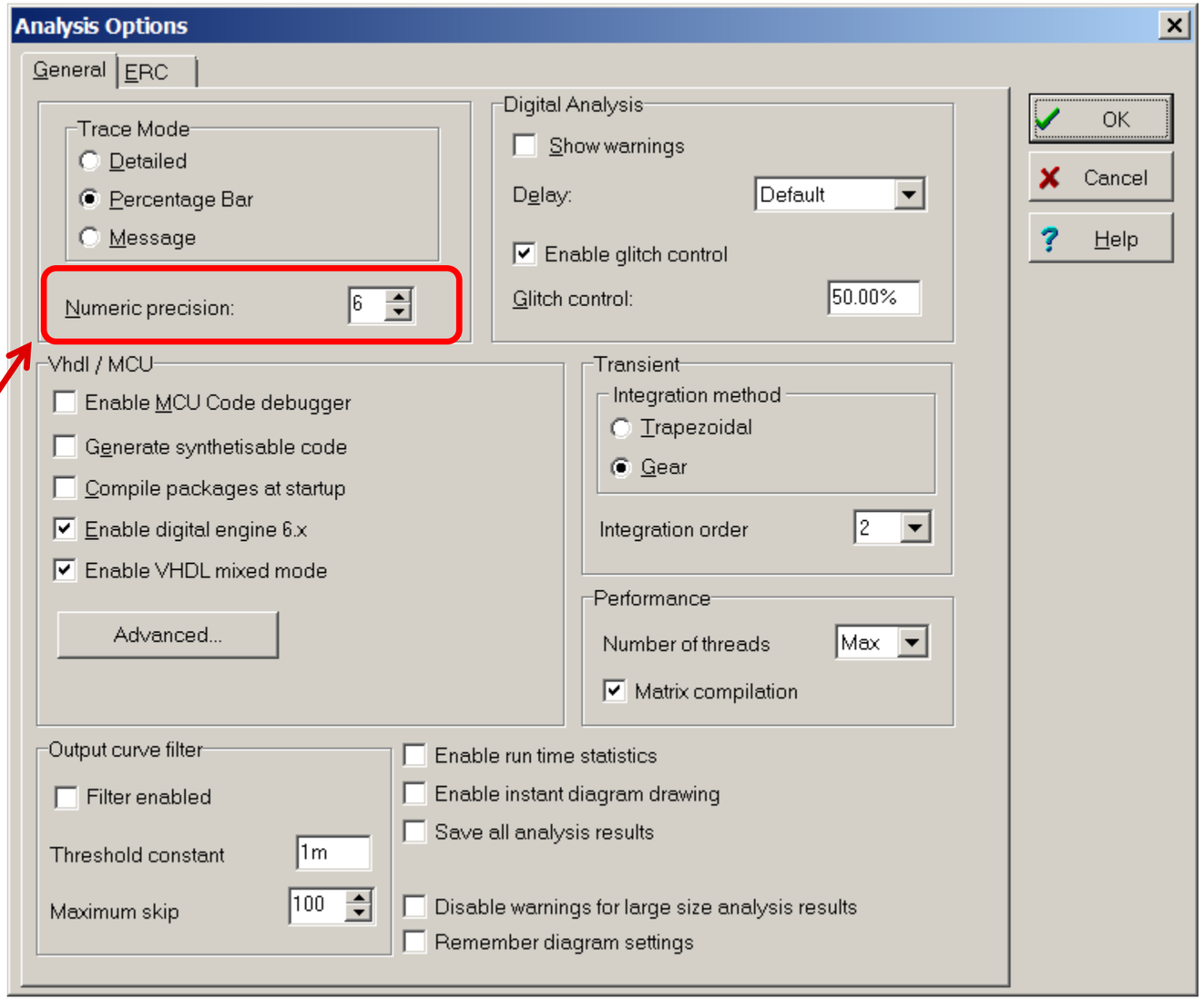



TR excitation subdivisions = 1000
TR time intrv. subdivisions = 10k
This increases the number of points vs time so that transient behaviors aren't obscured.

Press this button to expand the list.

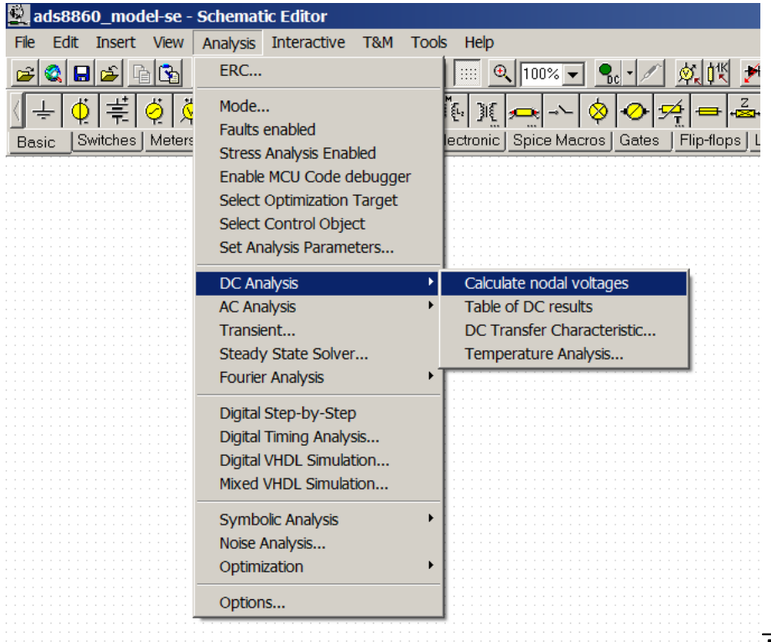
# Optimizing Simulation Results



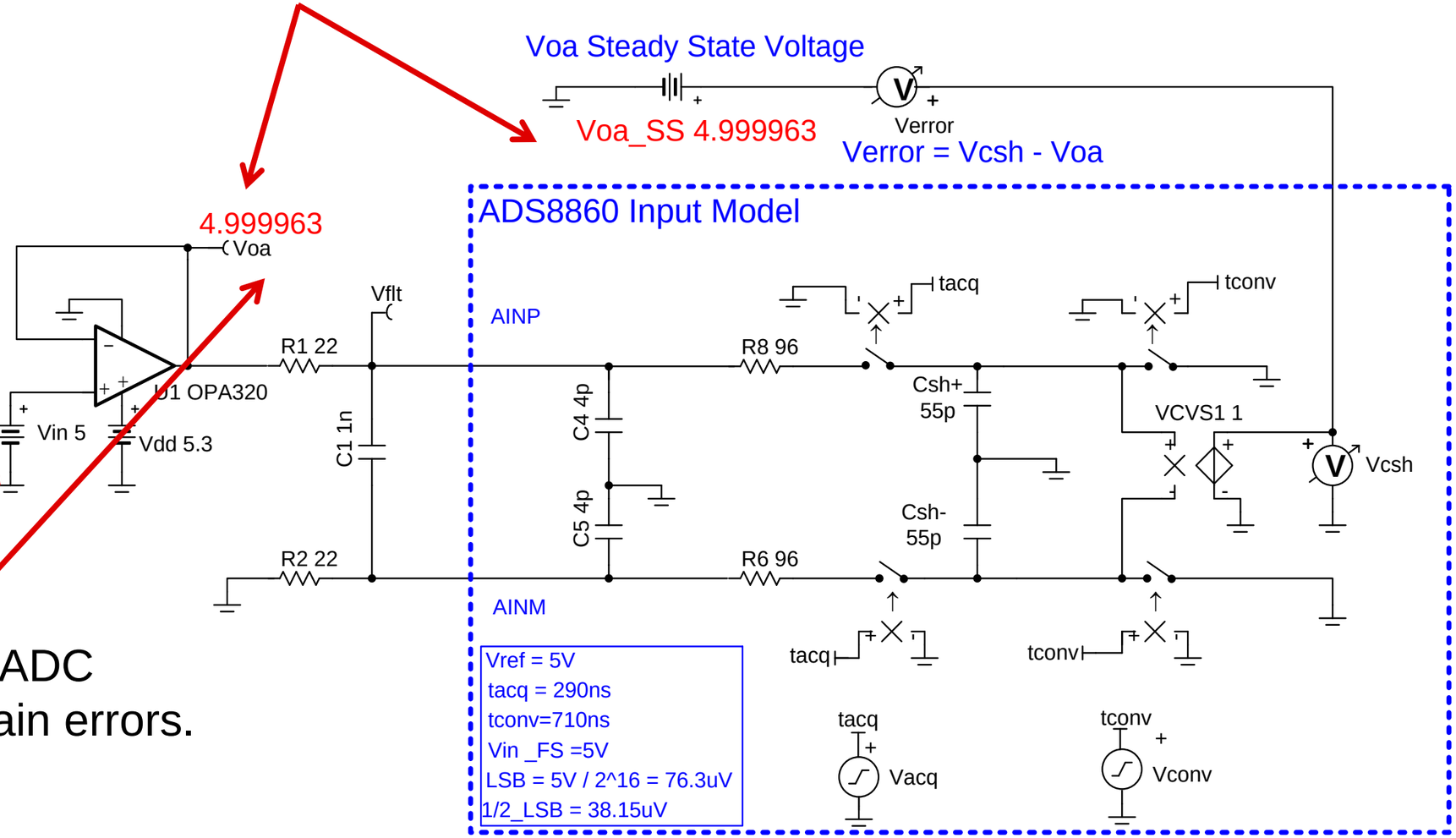




Set the “numeric precision” to 6 digits. This will allow us to see dc operating points to six digits. The importance of this is highlighted on the next slide.

# Steady State Simulation Results

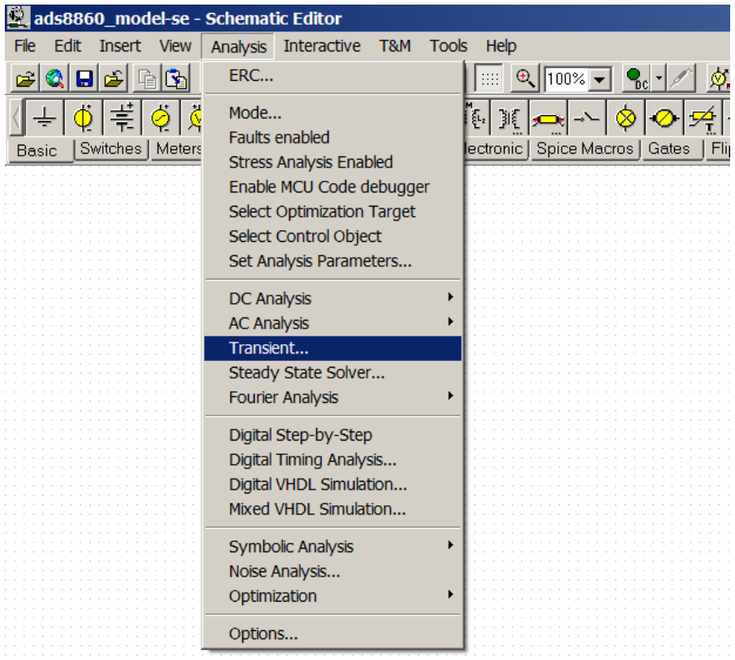


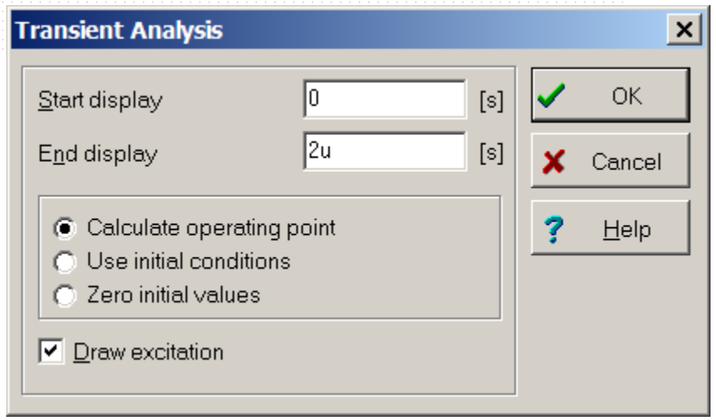

Set the output source to match the steady state ADC input.

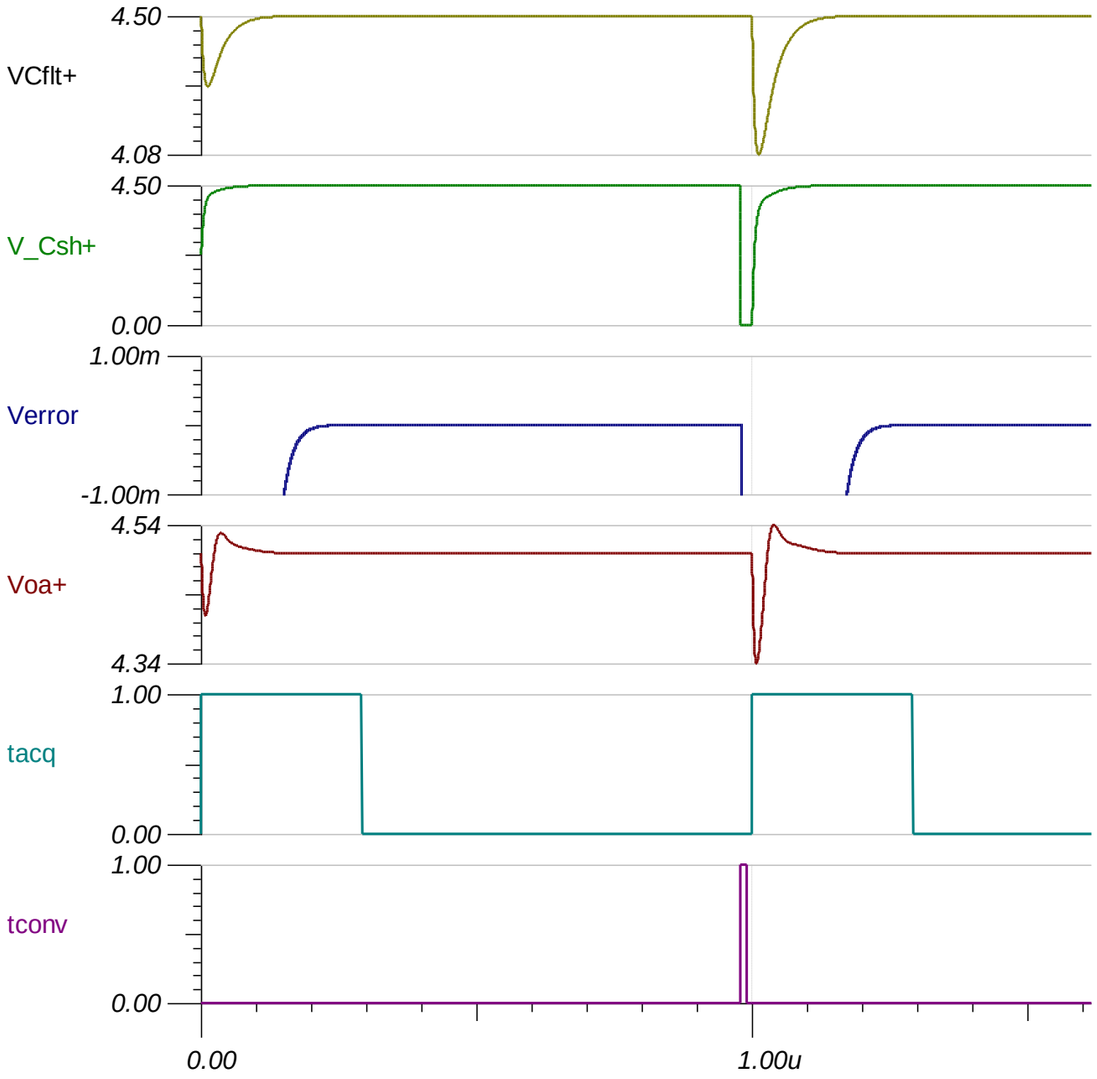



The steady state input to the ADC includes amplifier offset an gain errors.

# Example simulation: simulator results




Input to ADC across Charge bucket filter

Internal ADC sample and hold capacitor

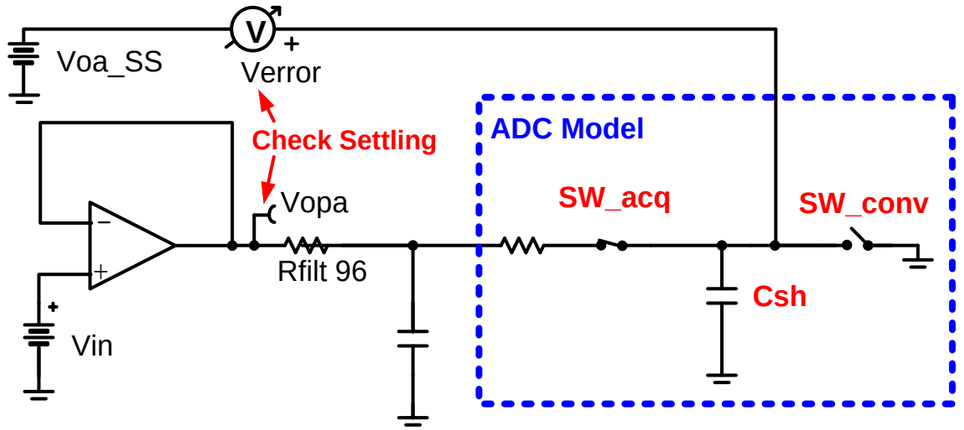
Error in ADC settling sampled signal

Op amp output

Acquisition switch control

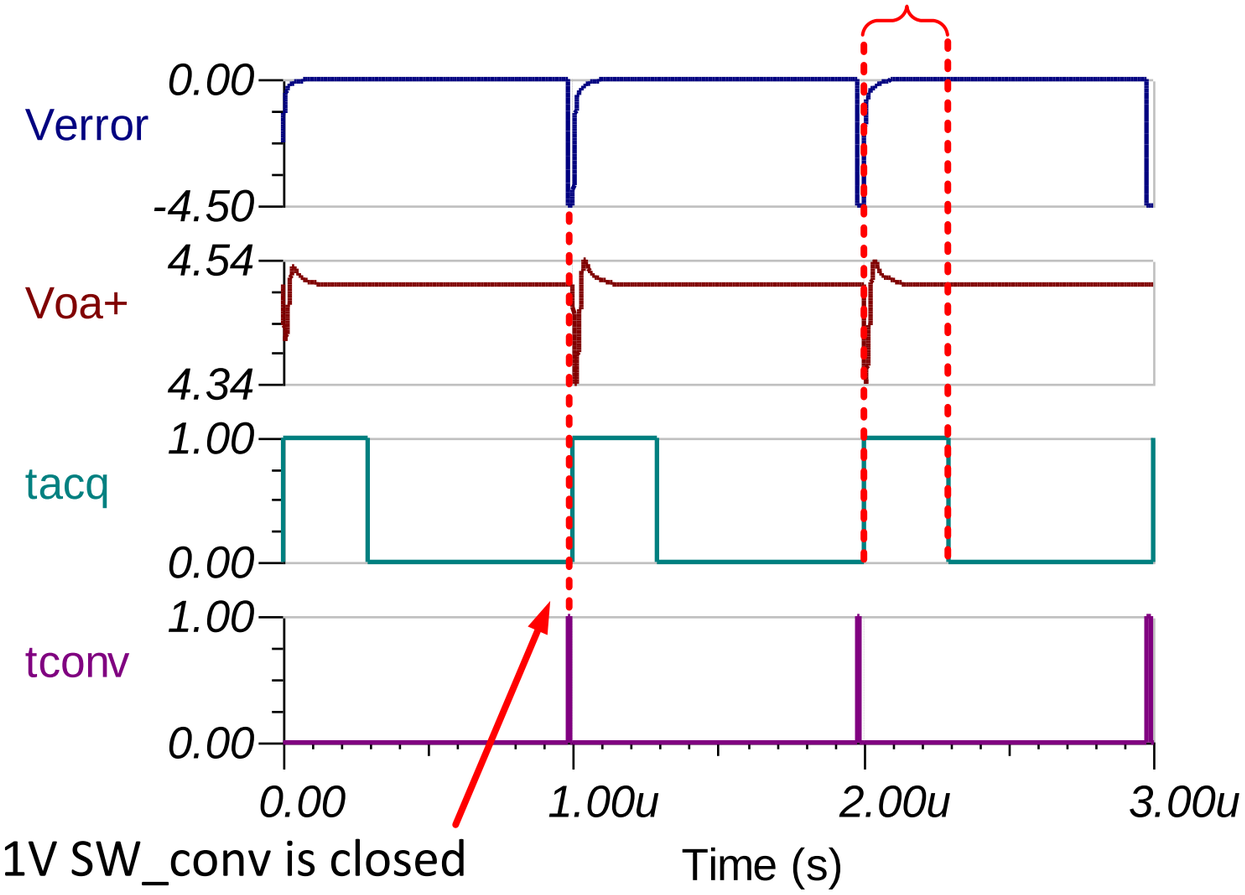
Conversion switch control

# Key Result: Error Signal




When tacq = 1V SW_acq is closed

Verror and Vopa must settle in this window




When tconv = 1V SW_conv is closed

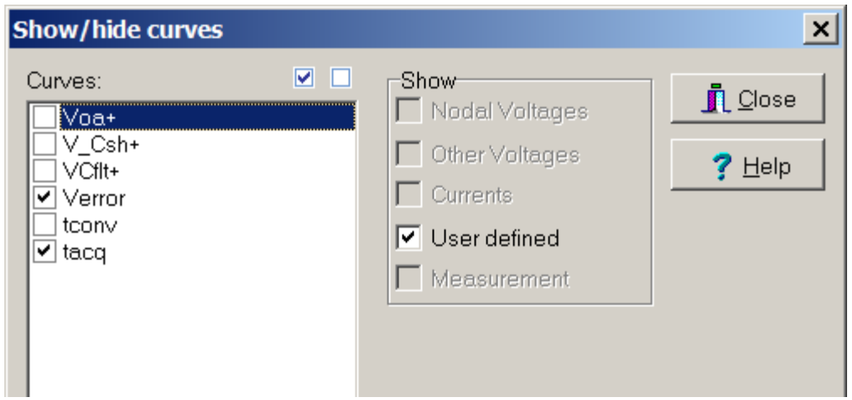
This resets the internal S &H Capacitor Csh

# Zoom in on Error Signal

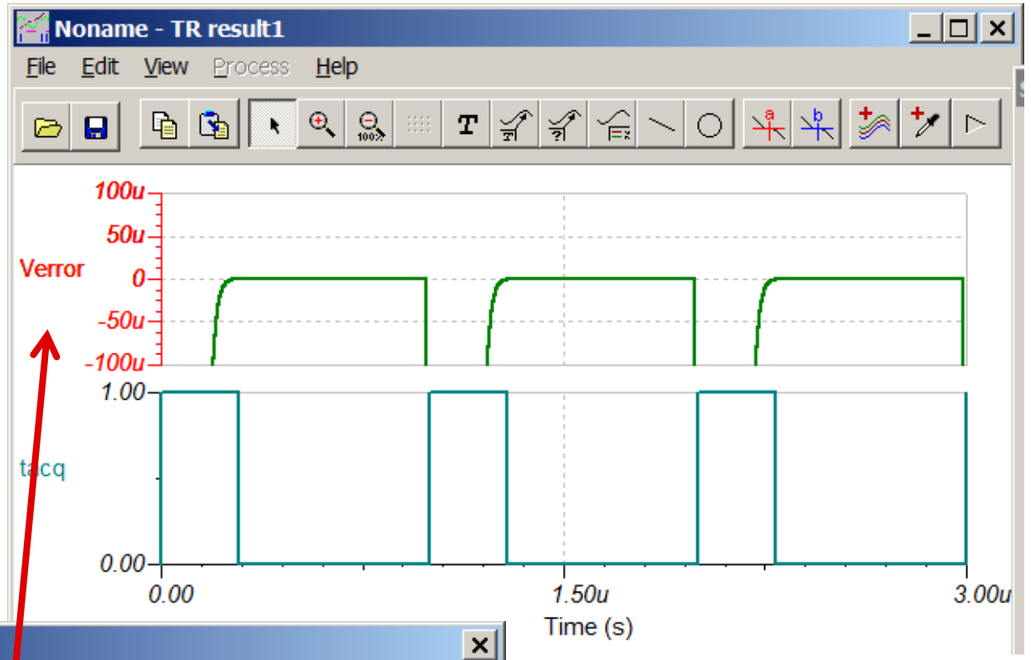
$N = 16$ Number of bits

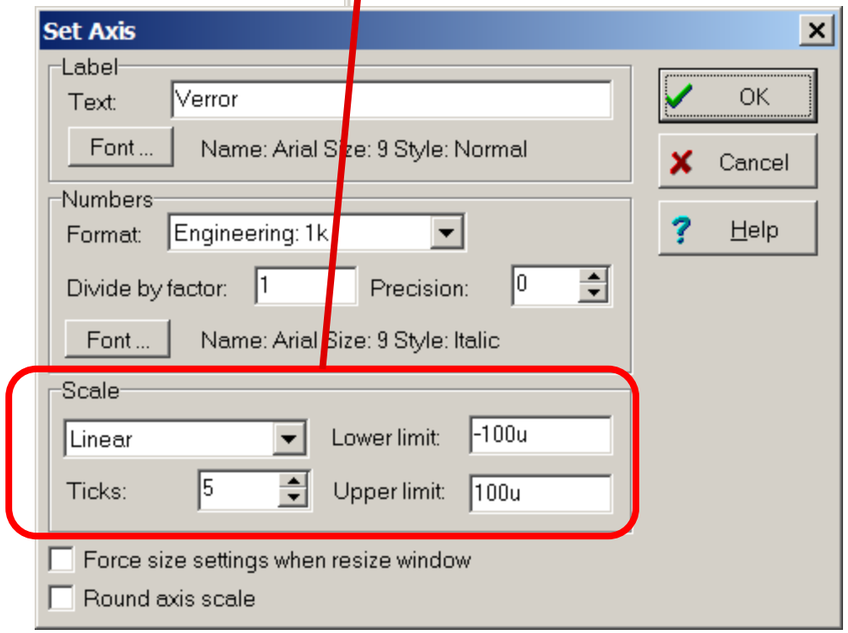
$\mathrm{LSB} = \frac{FSR}{2^N} = \frac{5.0V}{2^{16}} = 76.3\mu V$ Resolution

$0.5 \cdot \mathrm{LSB} = 38.1\mu V$ Target Error




Use “view>show / hide curves” to focus on most important curves.




Click on axis and adjust the scale relative to LSB resolution.

# Agenda – next video…

1. SAR Operation Overview
2. Select the data converter
3. Use the Calculator to find amplifier and RC filter
4. Find the Op Amp
5. Verify the Op Amp Model
6. Building the SAR Model
7. Refine the Rfilt and Cfilt values
8. Final simulations
9. Measured Results
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# Thanks for your time!
# Please try the quiz.

# Building the SAR ADC Simulation Model

## TIPL 4403

## TI Precision Labs – ADCs

**Created by Art Kay**

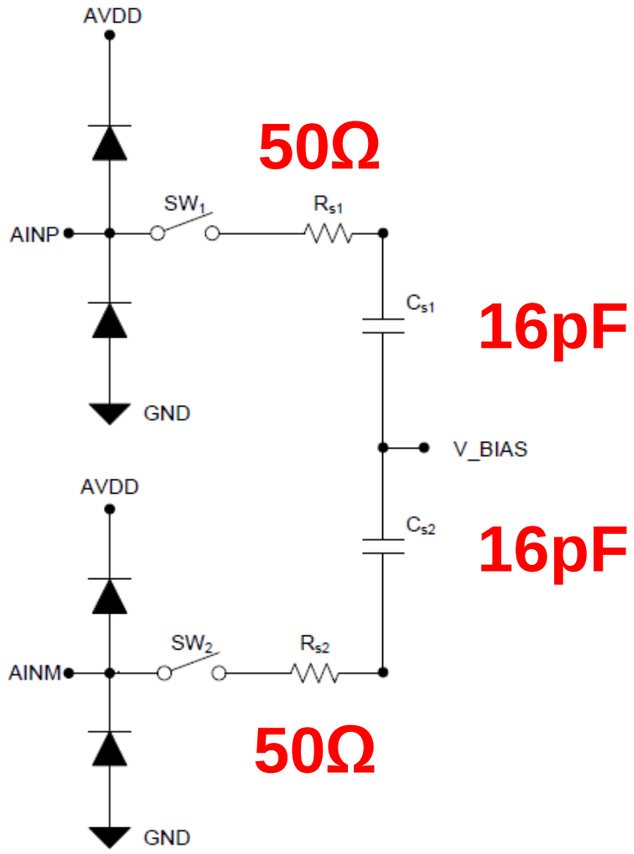
# Quiz: Building the SAR ADC Simulation Model

1. Build the model for ADS7056.

# Solutions

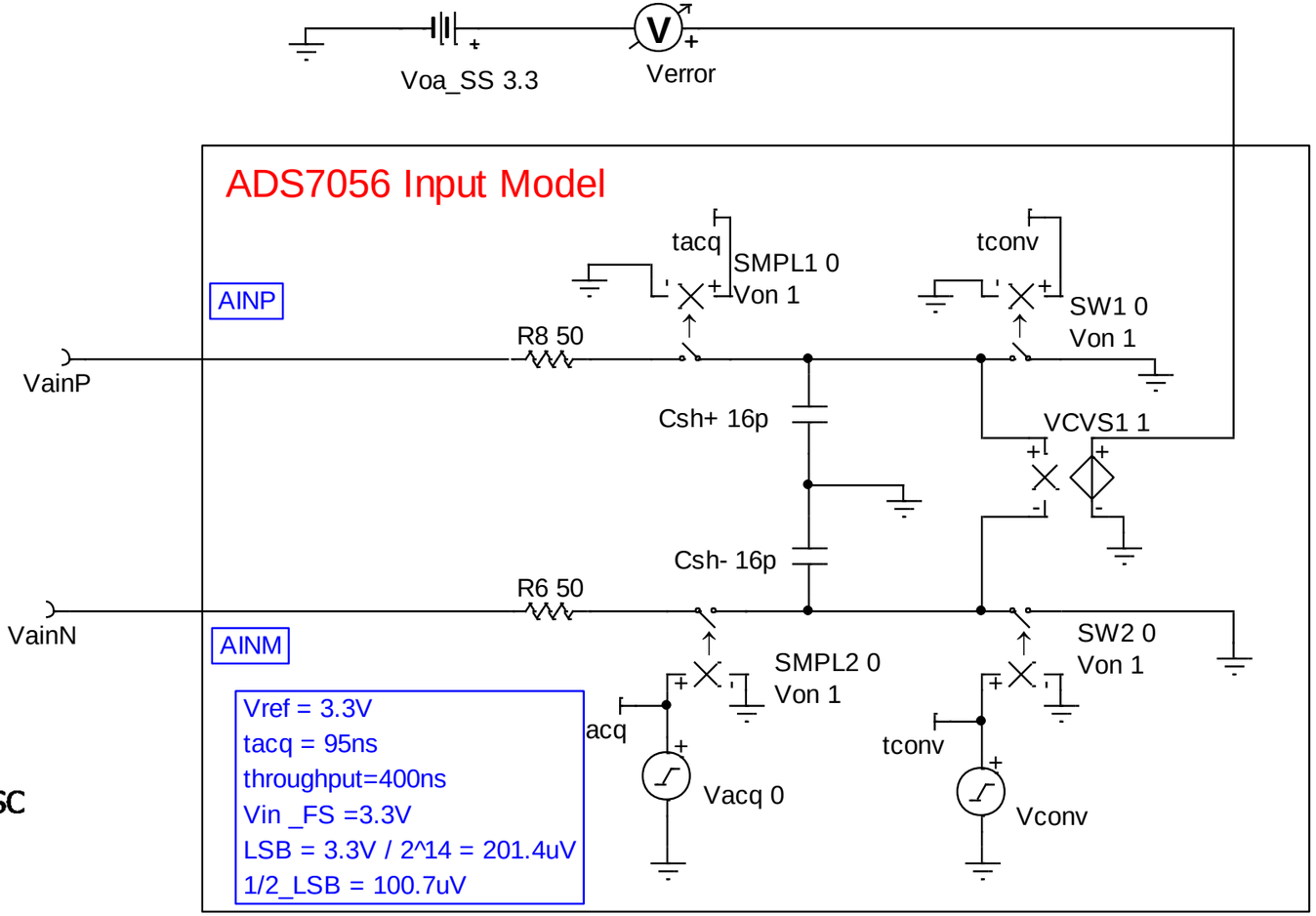
# Quiz: Building the SAR ADC Simulation Model

1. Build the model for ADS7056.




ads7056 model.TSC

Click here for the TINA file



# Quiz: Building the SAR ADC Simulation Model

1. Build the model for ADS7056.