The Math Behind the R-C Component Selection

TIPL 4406
TI Precision Labs – ADCs

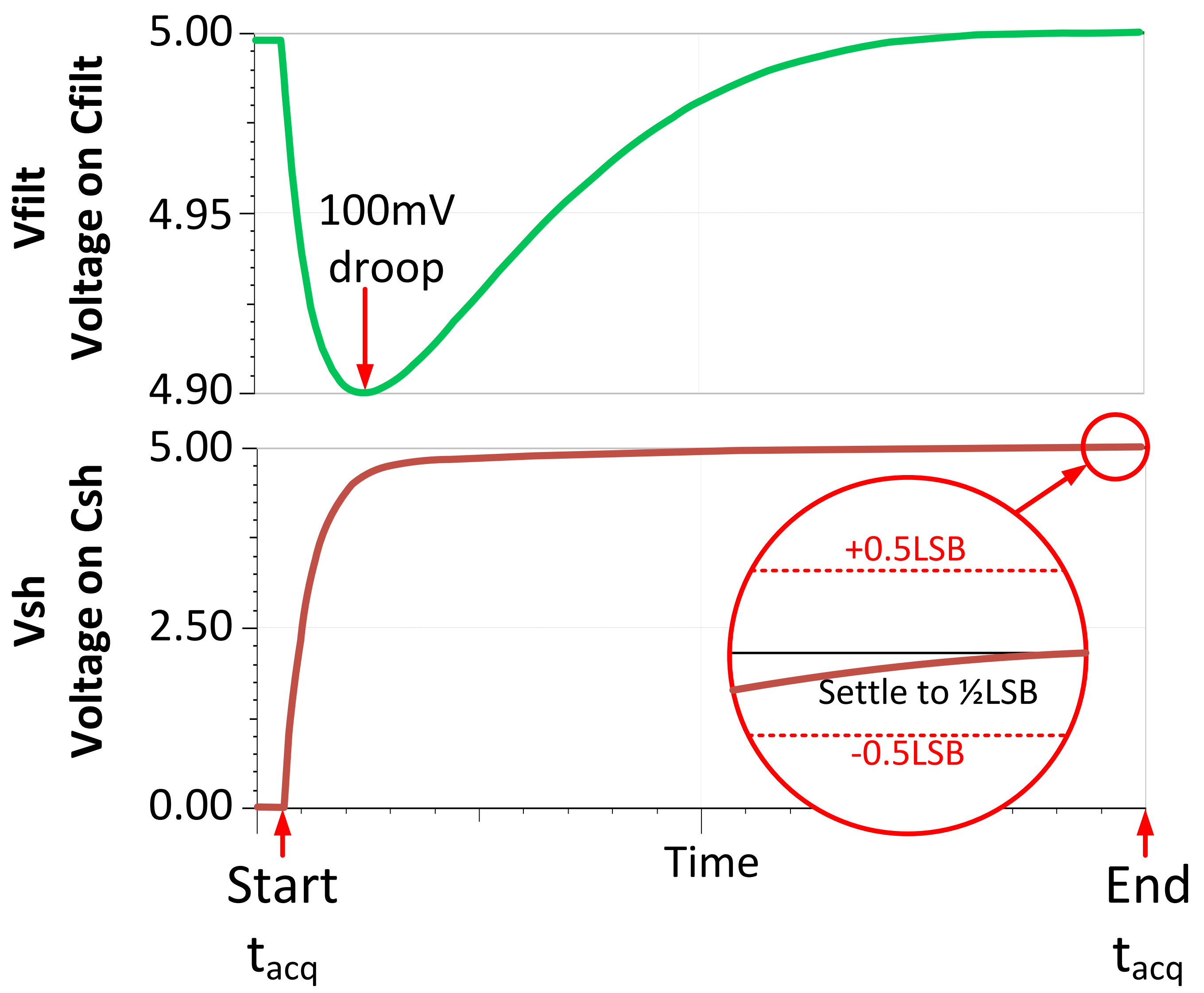
Created by Tim Green, Art Kay

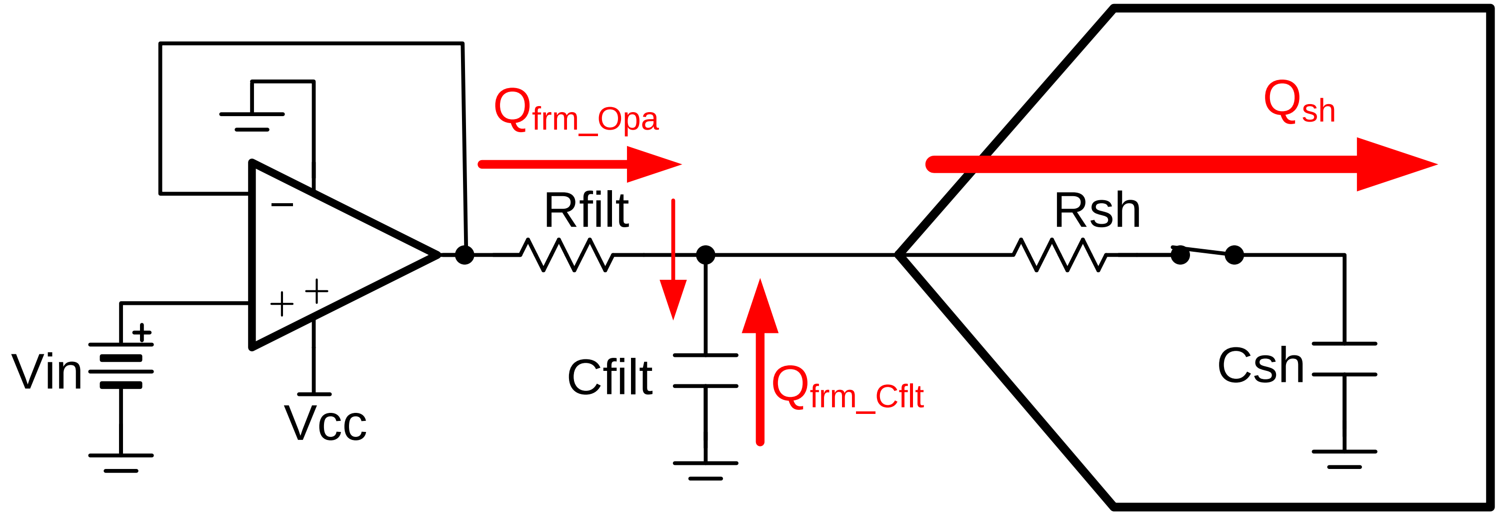
Presented by Peggy Liska

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

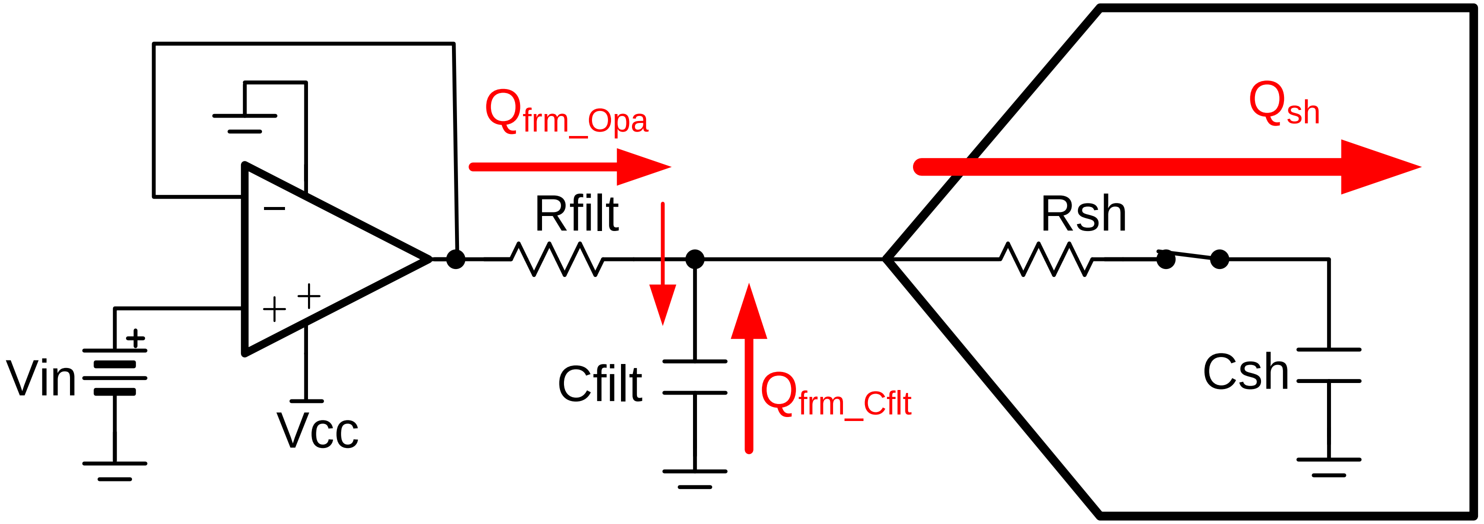
Concept behind the math





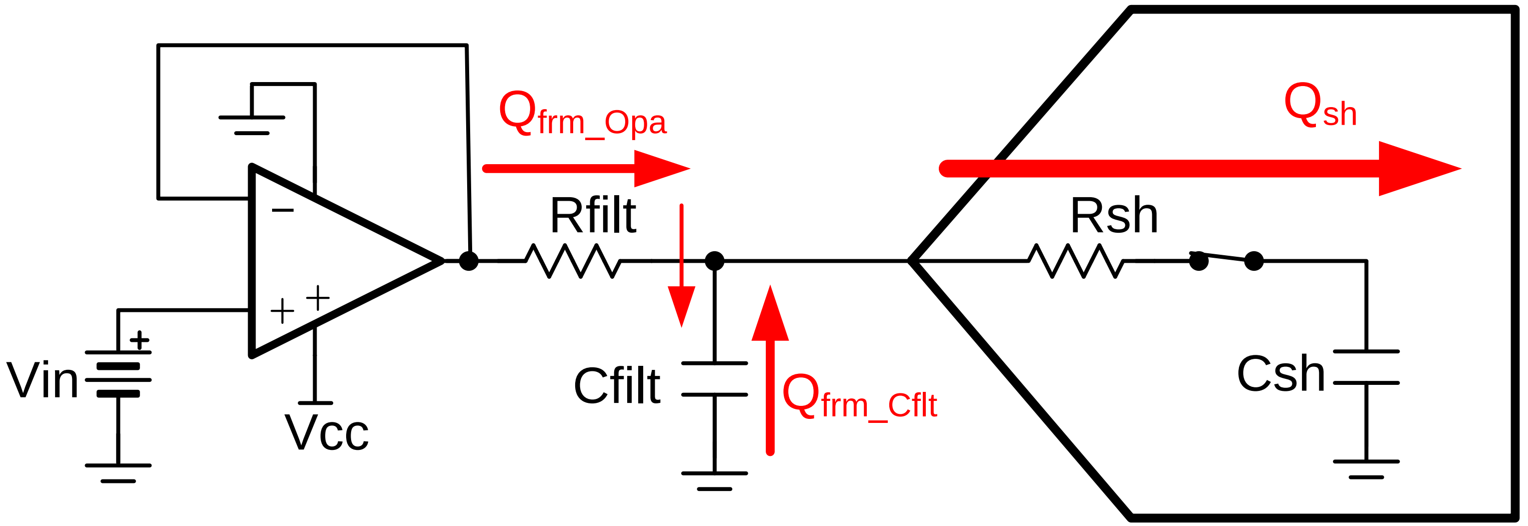
- Assumptions based on multiple designs
- Vin = Full Scale
- ½ of Q_{sh} is from C_{filt} & ½ from Op Amp
- 100mV Droop – small signal response
- Error target = 0.5·LSB
- Op amp approximated as second order system
- Op amp four times faster than filter

C_{filt} Selection



$Q_{sh} = V_{FSR} \cdot C_{sh}$	(1)	Total Charge in Csh and the end of acquisition period.
$Q_{sh} = Q_{frmOpa} + Q_{frmCfilt}$	(2)	Charge is from amplifier and filter capacitor
$\Delta Q_{Cfilt} = 0.5 \cdot Q_{sh}$	(3)	Half the sample and hold charge (Q_{sh}) is delivered from the filter. This results in a change in the charge on Cfilt.
$\Delta Q_{Cfilt} = 0.5 \cdot V_{FSR} \cdot C_{sh}$	(4)	From (1), and (3)
$\Delta Q_{Cfilt} = \Delta V_{filt} \cdot C_{filt}$	(5)	The change in charge on Cfilt will cause a droop in voltage. ΔV_{filt}
$C_{filt} = \left(\frac{0.5 \cdot V_{FSR}}{\Delta V_{filt}}\right) C_{sh}$	(6)	From (4), and (5). This is the general relationship for scaling Cfilt, given a droop in filter voltage (Vfilt)

C_{filt} Scaling Continued



$C_{filt} = \left(\frac{0.5 \cdot V_{FSR}}{\Delta V_{filt}}\right) C_{sh}$	(6)	From previous slide: This is the general relationship for scaling Cfilt, given a droop in filter voltage (Vfilt).
Assume $V_{FSR} = 4\text{V},\ \Delta V_{filt} = 100\text{mV}$		
$\boldsymbol{C_{filt} = 20 \cdot C_{sh}}$	(7)	**Typical value for Cfilt**
$C_{filt} = 30 \cdot C_{sh}$	(8)	Maximum value for Cfilt
$C_{filt} = 10 \cdot C_{sh}$	(9)	Minimum value for Cfilt

Note 1: Experience shows that using the fixed factors of 20 yields good results.

Note 2: In rare cases, you may need to sweep Cfilt. Thus the factors of 10 and 30.

Time constant required for settling to error target

$V_{filt} = (V_{init} - V_{final}) \cdot e^{-t/\tau_c} + V_{final}$	(10)	This is the standard RC charge equation. τ_c = time constant for charging C_{sh}. V_{init} = initial voltage at start of t_{acq} V_{final} = final voltage for fully charged C_{filt}
$0.5 \cdot LSB = V_{final} - V_{filt}$	(11)	Error is less than ½ LSB
$V_{init} - V_{final} = 100mV$	(12)	Droop is 100mV
$0.5 \cdot LSB = (100mV) \cdot e^{-t/\tau_c}$	(13)	Substitute 11 and 12 into 10
$\tau_c = \dfrac{-t_{acq}}{\ln\left(\dfrac{0.5 \cdot LSB}{100mV}\right)}$	(14)	Solve (13) for τ_c Note: τ_c includes effects from Op Amp and C_{filt} The op amp is being modeled as a second order system (RC circuit)

Find Rfilt and Amplifier Bandwidth

$\tau_c = \sqrt{(\tau_{RC})^2 + (\tau_{OA})^2}$	(15)	τ_c can be approximated as the RSS of the time constant of the filter and the op amp.
$\tau_{RC} = 4 \cdot \tau_{OA}$	(16)	Rule of thumb for good settling
$\tau_c = \sqrt{(4 \cdot \tau_{OA})^2 + (\tau_{OA})^2}$	(17)	Substitute (16) into (15)
$\tau_{OA} = \frac{\tau_c}{\sqrt{17}}$	(18)	Solve (17)
$\tau_{RC} = 4 \cdot \left(\frac{\tau_c}{\sqrt{17}}\right)$	(19)	Substitute (18) into (16)
$R_{filt} = \frac{\tau_{RC}}{C_{filt}}$	(20)	Nominal filter resistance.
$\boldsymbol{R_{filt\_min} = 0.25 \cdot R_{filt}}$	**(21)**	**Minimum value of Rfilt used in SPICE iteration**
$\boldsymbol{R_{filt\_max} = 2 \cdot R_{filt}}$	**(22)**	**Maximum value of Rfilt used in SPICE iteration**
$\boldsymbol{UGBW = \frac{1}{2 \cdot \pi \cdot \tau_{OA}}}$	**(23)**	**Minimum amplifier bandwidth**

Texas Instruments

Thanks for your time! Please try the quiz.

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1. The external charge bucket capacitor is ____.
   a. Half the size of the internal sample and hold capacitor
   b. Equal to the internal sample and hold capacitor
   c. Double the size of the internal sample and hold capacitor
   d. 20 times the size of the internal sample and hold capacitor

2. The error target for settling is _______.
   a. Half the size of the LSB
   b. Equal to the LSB
   c. Double the size of the LSB
   d. 20 times the size of the LSB

The Math Behind the R-C Component Selection

3. (T/F) The algorithm determines the RC charge bucket circuit and the amplifier slew rate.
    a. True
    b. False

4. (T/F) The amplifier bandwidth is usually lower than the charge bucket filter cutoff frequency.
    a. True
    b. False

Solutions

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   d. **20 times the size of the internal sample and hold capacitor**

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   d. 20 times the size of the LSB

The Math Behind the R-C Component Selection

3. (T/F) The algorithm determines the RC charge bucket circuit and the amplifier slew rate.
    a. True
    b. **False**

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