Amplifier Settling and Charge Bucket Filter Design

TIPL 4405-L
TI Precision Labs – ADCs

by Art Kay, Dale Li
Required/Recommended Equipment

• Calculation
  – Determine initial values for RC charge bucket circuit and bandwidth using Analog Engineer’s Calculator

• Simulation
  – Optimize RC charge bucket circuit using TINA SPICE
  – Confirm final settling error is less than half of one LSB.

• Measurement
  – Verify THD and SNR for good and bad charge bucket filter design.
  – PLABS-SAR-EVM-PDK
  – Download EVM software and purchase EVM
Find amplifier and RC circuit

Amplifier:
- 5V, Rail-to-Rail I/O with Zero Crossover Distortion Required
- Find bandwidth using Analog Engineer’s Calculator
- Use parametric search to find device.
- Verify model Open Loop Gain and Open Loop Output Impedance

RC Charge Bucket Circuit:
- Use Analog Engineer’s Calculator for initial values
- Use TINA Simulation to Optimize
Find the Op Amp Bandwidth and RC Charge Bucket

1. Enter the information from the ADS8860 Data Sheet.

2. Results will be used in the simulation.
Op Amp Model: Open Loop Gain

Test Circuit for A<sub>OL</sub>

1. Test dc operating point to assure that circuit is correctly wired
2. Run ac simulation for A<sub>OL</sub> curve A<sub>OL</sub> = V<sub>out</sub>

Simulated results

Data Sheet Specification

Gain (dB)

Phase [deg]

Compare key points on simulation results to data sheet curve.
Op Amp Model: Open Loop Output Impedance

Test Circuit for A0

Simulated results

Data Sheet Specification

1. Test dc operating point to assure that circuit is correctly wired.
2. Run ac simulation for Z_o curve. 
   Z_o = Vout.
Find the Op Amp Bandwidth and RC Charge Bucket

**ADS8860 Input Model**

- **Vref** = 5V
- **tacq** = 290ns
- **tconv** = 710ns
- **Vin_FS** = 5V
- **LSB** = 5V / 2^16 = 76.3 uV
- 1/2_LSB = 38.15 uV

**Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rfit/2 Min</td>
<td>4.1 Ohm</td>
<td></td>
</tr>
<tr>
<td>Rfit/2 Max</td>
<td>32.5 Ohm</td>
<td></td>
</tr>
<tr>
<td>Gain Bandwidth</td>
<td>17.8 MHz</td>
<td></td>
</tr>
<tr>
<td>Max Error Target</td>
<td>38.15 uV</td>
<td></td>
</tr>
</tbody>
</table>
Parameter Step $R_{\text{filt}}$

Voltage (V) vs. Time (s)

$V_{\text{error}[1]}$: 26.3 [V]
$V_{\text{error}[2]}$: 19.9 [V]

$V_{\text{error}[10]}$: 32.5 [V]
$V_{\text{error}[1]}$: 4.1 [V]

Output vs. Time (s)

$V_{\text{error}[1]}$: 24.3 [V]
$V_{\text{error}[3]}$: 25.5 [V]

 ADS8860_OPA320 - 1st - iteration.TSC
 ADS8860_OPA320 - 2nd - iteration.TSC
 ADS8860_OPA320 - 3rd - iteration.TSC
Connect the hardware

- **USB Cable to Computer**
- **Set Jumpers as Shown**
- **Install Different amplifiers**
- **Plug PHI into CH2 Connector**
- **SMA Cable**
## Record results as we progress through Experiment

<table>
<thead>
<tr>
<th>Device</th>
<th>Samp. Rate</th>
<th>$V_{\text{offset}}$ (V)</th>
<th>$V_{\text{in}}$ (V)</th>
<th>$V_{\text{error}}$ (V)</th>
<th>SNR (dB)</th>
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<tbody>
<tr>
<td>ADS8860 Data Sheet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 OPA320 Good filter1</td>
<td>1M</td>
<td>2.5</td>
<td>4.9</td>
<td>28uV</td>
<td>93</td>
<td>-108</td>
<td></td>
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</tr>
<tr>
<td>2 OPA320 Bad filter</td>
<td>1M</td>
<td>2.5</td>
<td>4.9</td>
<td>-41mV</td>
<td>82.5</td>
<td>-73.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 OPA333 Low Bandwidth</td>
<td>1M</td>
<td>2.5</td>
<td>4.9</td>
<td>-91mV</td>
<td>54.1</td>
<td>-55.9</td>
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<td></td>
</tr>
<tr>
<td>4 OPA316 Crossover</td>
<td>1M</td>
<td>1.8</td>
<td>3.6</td>
<td>36.7mV</td>
<td>86.1</td>
<td>-85.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 OPA316 Crossover</td>
<td>500k</td>
<td>1.8</td>
<td>3.6</td>
<td>47uV</td>
<td>90.3</td>
<td>-102.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Start & Setup the Plabs-Power Scaling EVM Software

1. Select “Plabs-SAR-EVM” from “start>All Programs”

2. The green “HW Connected” and teal “PSI Controls” indicate good hardware communication.
1: OPA320_Good Filter1

Note RC circuit is from optimization.

Error Target = 38µV
Simulate Error = 28µV
1: OPA320_Good Filter 1

1. Install OPA320_Good filter 1 coupon card in socket.

2. Amplitude = 4.9V
   Offset = 2.5V
   Frequency = 2kHz

3. Press “Capture”
4. Record AC performance
2: OPA320 Bad Filter

Optimal values:
R = 24.9Ω  
C = 1.1nF  

Bad Filter Values:
R = 100Ω  
C = 1.1nF  

Error Target = 38µV  
Simulate Error = -41mV
2: OPA320 Bad Filter

SNR (dB) | THD (dB)
---|---
ADS8860 | 93 | -108
Bad Filter | 82.5 | -73.4

1. Install OPA320_Bad Filter coupon card in socket.
2. Amplitude = 4.9V Offset = 2.5V Frequency = 2kHz
3. Press “Capture”
4. Record AC performance
3: OPA333 Low Bandwidth

Bandwidth Required:
Gain Bandwidth = 17.8MHz

OPA333 Bandwidth:
Gain Bandwidth = 350kHz

Error Target = 38µV
Simulate Error = -88mV
3: OPA333 Low Bandwidth

1. Install OPA333_Low Bandwidth coupon card in socket.

2. Amplitude = 4.9V
   Offset = 2.5V
   Frequency = 2kHz

3. Press “Capture”
4. Record AC performance

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</table>
Bandwidth Required:
Gain Bandwidth = 17.8MHz
OPA316 Bandwidth:
Gain Bandwidth = 10MHz

Error Target = 38μV
Simulate Error = 35mV
1. Install OPA316_Crossover coupon card in socket.

2. Amplitude = 3.6V
Offset = 1.8V
Frequency = 2kHz

3. Note that the sampling rate is 1Msps

4. Press “Capture”

5. Record AC performance

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<th>ADS8860</th>
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SNR: Signal to Noise Ratio
THD: Total Harmonic Distortion
Input signal range to avoid crossover distortion

Crossover happens at 3.8V for OPA316
Changing the Sampling Rate to 500kHz

\[ t_{ACQ} = \frac{1}{f_{sample}} - t_{conv-max} \]

\[ t_{ACQ} = 2\mu s - 710\text{ns} = 1.29\mu s \]

\[ \frac{1}{f_{sample}} = \frac{1}{500\text{kHz}} = 2\mu s \]

\[ t_{conv-max} = 710\text{ns} \]
Changing the Sampling Rate to 500kHz

Acquisition time (t\text{acq}) from last slide.

Bandwidth Required:
Gain Bandwidth= 4MHz
OPA316 Bandwidth:
Gain Bandwidth= 10MHz
5: OPA316 Crossover, fs = 500ksp

**Bandwidth Required:**
- Gain Bandwidth = 4MHz

**OPA316 Bandwidth:**
- Gain Bandwidth = 10MHz

**Error Target** = 38µV

**Simulate Error** = 47µV
OPA316 Crossover, fs = 500ksps

1. No device change needed.
2. Amplitude = 3.6V
   Offset = 1.8V
   Frequency = 2kHz
3. Set sampling rate to 500ksps
4. Press “Capture”
5. Record AC performance

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Settling can be improved

AD8860 Input Model

Not Optimized
Rfilt = 24.9 ohms

Optimized
Rfilt = 59 ohms
# Measured vs Expected Results

Your results should show the same trend as the expected result but the specific values will differ.

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<th>Your Measurements</th>
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Thanks for your time!