ABSTRACT

Many applications, such as motor drives and power inverters, require measurements of both current and voltage to obtain motor information, for example, speed, torque and power, to control, monitor and protect system. Meanwhile, these applications will be operated in harsh, noisy environments and high voltage difference between power stage and control stage. Therefore, this is very important that the device have precise performance and isolation functions simultaneously. In this case, AMC1204 can satisfy these criteria. The AMC1204 is optimized for use in current-sensing applications using low-impedance shunts. However, the device can also be used in isolated voltage sensing. In terms of that, this application note will give you an idea of how large shunt resistor that you could use will not influence device performance and how to optimize the system performance if you want to use large shunt resistors.

Contents

1 Design Consideration of AMC1204 .......................................................... 2
2 Optimize the Performance of AMC1204 with Large Shunt Resistor ...................... 5
3 Conclusion ........................................................................................................ 6

List of Figures

1 Equivalent Analog Input Circuit ................................................................... 2
2 First Rough Solution to Perform Isolated Voltage Monitoring ......................... 2
3 Offset Error vs Different Shunt Resistor (AMC1204) ........................................ 3
4 Gain Error vs Different Shunt Resistor (AMC1204) .......................................... 3
5 INL vs Different Shunt Resistor (AMC1305M25) ............................................. 4
6 Rout Simulation of OPA376 ........................................................................ 5
7 Offset Error vs Different Shunt Resistor With OPA376 (AMC1204) .................. 6
8 Gain Error vs Different Shunt Resistor With OPA376 (AMC1204) ................... 6
1 Design Consideration of AMC1204

The differential analog input of the AMC1204 is implemented with a switched-capacitor circuit. Figure 1 shows the simplified schematic of the ADC input circuitry; the right side of Figure 1 illustrates the input circuitry with the capacitors and switches replaced by an equivalent circuit.

Consider the input impedance of the AMC1204 ($R_{ID}: 12.5 \, \Omega$) in designs with high-impedance shunt resistors that can cause degradation of specifications. However, the bias current of the AMC1204 is very small, so it just will cause gain error and not have a big impact in offset error as occurs in the AMC1305. Therefore, if AMC1204 is designed by such applications, there are important details that need to be remembered when you choose the resistor divider.

First, in order to efficiently use the available linear input range of AMC1204, the voltage across R2 must be within ±250 mV, because the linear input range of AMC1204 is ±250 mV.

The first inclination to carry out the voltage sensing is to implement the circuit shown in Figure 2.

The resistor divider formed by R1 and R2 in Figure 2 can be governed with Equation 1:

$$V_{R2} = \frac{V_{bus} R2}{R1 + R2}$$

Where $V_{R2} = 0.25 \, V$ for AMC1204.
For instance, if the system supply is 30 V and the shunt resistor is 1 kΩ, then R1 can be calculated as 119 kΩ for AMC1204.

Second, as mentioned before, the larger shunt resistor is used, the larger gain error will be obtained. Equation 2 can help you estimate gain error easily.

\[
E_G(\%) = \frac{V_{\text{bus}}}{R_1 + (R_2 // R_{\text{IN}})} \times \frac{(R_2 // R_{\text{IN}}) - V_{\text{IN}}}{V_{\text{IN}}}
\]  

(2)

Where \( V_{\text{IN}} = 0.25 \) V for AMC1204.

Actual influence of offset error and gain error of different shunt resistors for AMC1204 is shown in Figure 3, Figure 4, and Table 1, respectively. When the shunt resistor increases, the offset will be influenced too much, but gain error will grow linearly. For example, if the shunt resistor is equal to 1.004 Ω, the offset error and gain error is 0.32 mV and –0.97%. But when the shunt resistor rises to 2.4924 kΩ, the offset error is still almost the same, 0.40 mV, however gain error will increase to –17.4%. That is because input bias current of the AMC1204 is small enough, but input impedance is not big enough, so it causes load effect that degrades gain error.

Besides, in the calculation, the load effect is considered, while Delta-sigma modulator error is not. Thus, the result of calculation will be slightly different from that of measurement.

![Figure 3. Offset Error vs Different Shunt Resistor (AMC1204)](image3)

![Figure 4. Gain Error vs Different Shunt Resistor (AMC1204)](image4)
### Table 1. Gain Error vs Different Shunt Resistor (AMC1204)

<table>
<thead>
<tr>
<th>Gain Error-Shunt Resistor (Ω)</th>
<th>Voltage divider_cal. (%)</th>
<th>Voltage divider_meas. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.004</td>
<td>-0.008%</td>
<td>-0.97%</td>
</tr>
<tr>
<td>129.57</td>
<td>-1.02%</td>
<td>-2.00%</td>
</tr>
<tr>
<td>486.1</td>
<td>-3.71%</td>
<td>-4.65%</td>
</tr>
<tr>
<td>999</td>
<td>-7.34%</td>
<td>-8.26%</td>
</tr>
<tr>
<td>2492.4</td>
<td>-16.51%</td>
<td>-17.40%</td>
</tr>
</tbody>
</table>

The INL will not be influenced by different shunt resistors. No matter how large shunt resistors will be, INL will always be within specification (max: ±8 LSB). The measurement result for AMC1204 is shown in Figure 5.

![Figure 5. INL vs Different Shunt Resistor (AMC1305M25)](image)

If voltage sensing system is not allowed to add additional compensated circuits, but AMC1204’s performance is desired such as offset, gain error within datasheet specification, then shunt resistor, R2, must be lower than 1 Ω.
2 Optimize the Performance of AMC1204 with Large Shunt Resistor

In order to ignore errors which come from the op amp, you need to consider some specifications. First of all, the offset error of the op amp must be much lower than ±1 mV. Secondly, bandwidth of the op amp must be higher than 1 MHz. Third, the input bias current must be smaller to avoid offset error. Last, closed-loop output impedance must be smaller than 1 Ω. Some op amp datasheets just provide open-loop output impedance, you could use Equation 3 to translate or use TI-TINA to simulate.

\[
R_{out} = \frac{R_O}{1 + A_{ol}|\beta|}
\]

(3)

Based on this criterion, OPA376 is used.

\( V_{os(max)}: 25 \, \mu V, \quad V_{os(typ.)}: 5 \, \mu V \)

\( GBW: 5.5 \, MHz \)

\( I_{ib}(max): 10 \, pA \)

\( Rout \, at \, DC: 163.5 \, \mu \Omega \)

![Rout Simulation of OPA376](image)

Figure 6. Rout Simulation of OPA376

Simulation and measurement results are shown in Figure 7 and Figure 8. The offset error is almost the same when the shunt resistor is equal to 486.1 / 2.492 kΩ, but the gain error will be reduced from –4.65 / –17.4% to –0.93 / –0.90%, respectively.
The designer must be aware that if their system does not have suitable power for the op amp, you might need to design other power paths. Therefore, this is a trade-off between performance and cost.

3 Conclusion

The application report provides straightforward equations to evaluate initial performance when you add large shunt resistor in voltage sensing, and also presents a method to optimize performance of the AMC1204. Hence, as long as you add suitable compensated circuit in these modulators, it can achieve good performance although TI's isolated delta-sigma modulator is optimized by current sensing.
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Automotive and Transportation</td>
</tr>
<tr>
<td>Amplifiers</td>
<td>Communications and Telecom</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Computers and Peripherals</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>DSP</td>
<td>Energy and Lighting</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Industrial</td>
</tr>
<tr>
<td>Interface</td>
<td>Medical</td>
</tr>
<tr>
<td>Logic</td>
<td>Security</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Space, Avionics and Defense</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>OMAP Applications Processors</td>
<td></td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2015, Texas Instruments Incorporated