Application Note

NOVOSENSE

For High Reliability Isolated Amplifier NSI1400x

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ABSTRACT

In high-voltage industrial applications, isolation sensing protects low-voltage circuits from faults of high-voltage power circuits while ensuring communication between different voltage domains, which significantly improves system reliability.

NSI1400 is a high-performance isolated amplifier with output separated from input based on the NOVOSENSE capacitive isolation technology. The products have been widely used in shunt current monitoring, motor drives, uninterruptible power suppliers, solar inverters and other fields. To simplify the customer's design, this application note introduces how to apply NSI1400 according to the customer's demand of current sensing.

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1.Typical Application Circuit

NSI1400 is ideally suited to shunt resistor-based current sensing in high voltage applications such as motor drives. The typical application circuit is shown in Figure 1.

The voltage across the shunt resistor R_{sense} is applied to the differential input of NSI1400 through a RC filter (R_{FLT} and C_{FLT}). The filter capacitance of more than 330pF placing as close as possible to the device must be added for charge buffering of the input switched-capacitor circuit (further details in 2.1 Analog Input with Switched-capacitor Circuit) and better performance in high-noise applications.

The differential output of the isolated amplifier is converted to a single-ended analog output with an operational-amplifier-based circuit. Suggest to add >1kΩ resistor on the OUTP and OUTN pin to prevent output over-current. An analog-to-digital converter usually receives the analog output and converts to digital signal for controller processing.

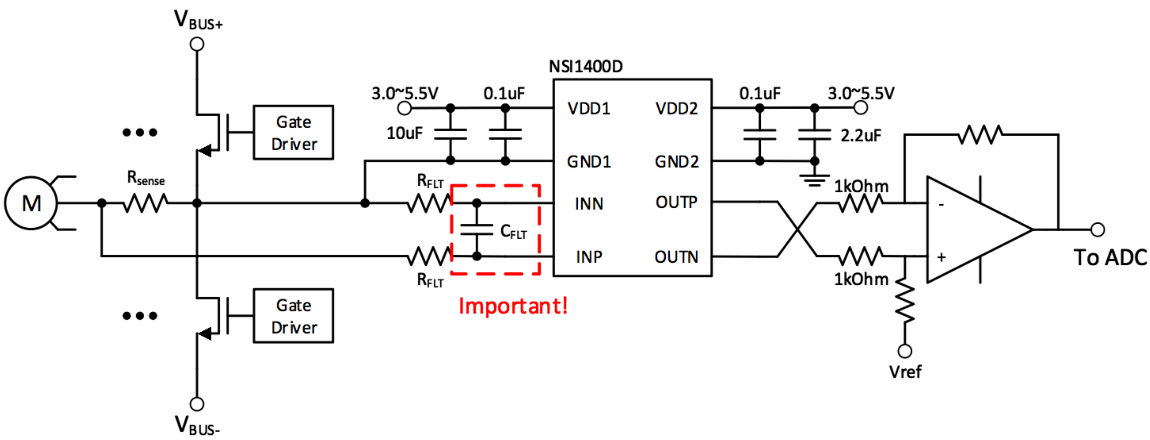

Figure 1. Typical application circuit in phase current sensing

2.Input Conditioning Circuit

In the application of NSI1400, if the output error, such as gain error or input offset voltage, abnormally exceeds the datasheet specification, it may be a problem of incorrect input conditioning circuit design. In this section, the recommended input conditioning circuit of NSI1400 application is introduced based on the switched-capacitor analog input circuit of NSI1400 and the mechanism of anti-aliasing.

2.1.Analog Input with Switched-capacitor Circuit

The NSI1400, as the next generation product of the NSI1200/NSI1300, is optimized in terms of input architecture to reduce the sensing error caused by input bias current. However, the architecture change has new requirements for the selection of input filter capacitance (>330pF recommended). Inappropriate design may increase the sensing error. In order to better help customers understand, the input architecture of NSI1400 is explained below.

The analog input of the NSI1400 is a switched-capacitor circuit based on the second-order Σ-Δ modulator. The equivalent circuit of analog input is shown in Figure 2. The internal capacitance C_{IND} is continuously charged and discharged through periodical switching action with the internal clock frequency f_{CLK} of 12MHz for input signal digitization. In the charging phase, S1 is closed, S2 is open, and C_{IND} is charged to the input differential voltage. In the discharging phase, S1 is open, S2 is closed, C_{IND} discharges to the voltage level of GND1+0.9V. According to the equivalent circuit, the input resistance R_{IND} can be calculated as

$$R_{IND} = 1/(f_{CLK} * C_{IND})$$

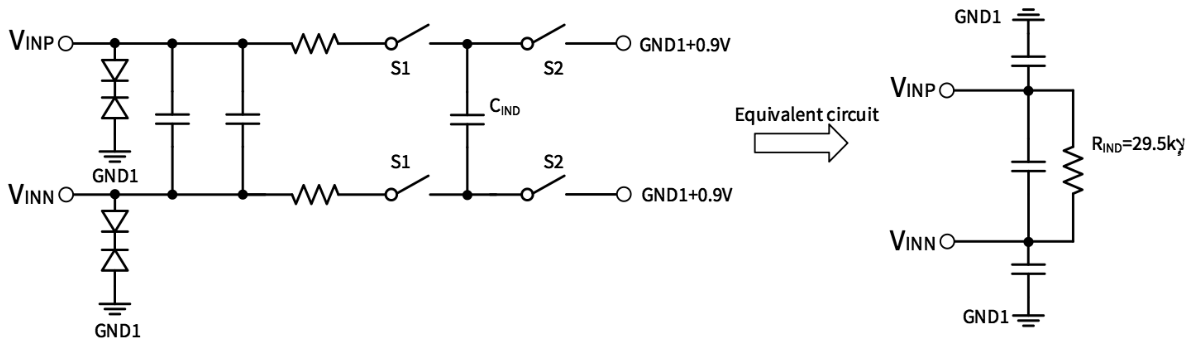

Figure 2. Equivalent Circuit of Analog Input

When a capacitive load is switched onto the input, the amplitude momentarily drops due to charge redistribution. The input source tries to correct the situation and, in this process, excessive ringing can occur due to long input wires which behave like inductance. To remedy this situation, the external capacitor at each input aids in supplying the current spikes created during the sampling process. An external capacitor of more than 330pF (C_{FLT} in Figure 1, also acting as filter capacitance) is one way to improve the capability of transient charge supply. The input capacitor should be placed as close as possible to the device to restrain the oscillation and ensure the sampling accuracy.

2.2.Mechanism of Anti-aliasing

The highest frequency signal that a sampling system can handle with high precision is called its Nyquist limit. The sample rate must be greater than or equal to twice the highest frequency of the input signal. If the input signal frequency exceeds the Nyquist frequency, there will be redundant or harmful signals in the passband, which is called aliasing. Figure 3 shows the mechanism of signal aliasing. For example, the sample rate f_s is 1MHz and the sampling signal band is half of f_s 500kHz (Nyquist frequency). In sampling process, the input signal with a frequency of f_{in} ($f_{in}>f_s/2$) will mirror to the pass band as the wrong alias signal with the frequency of f_s-f_{in}. In practical applications, the sample rate is usually higher to provide a certain margin and reduce filtering requirements.

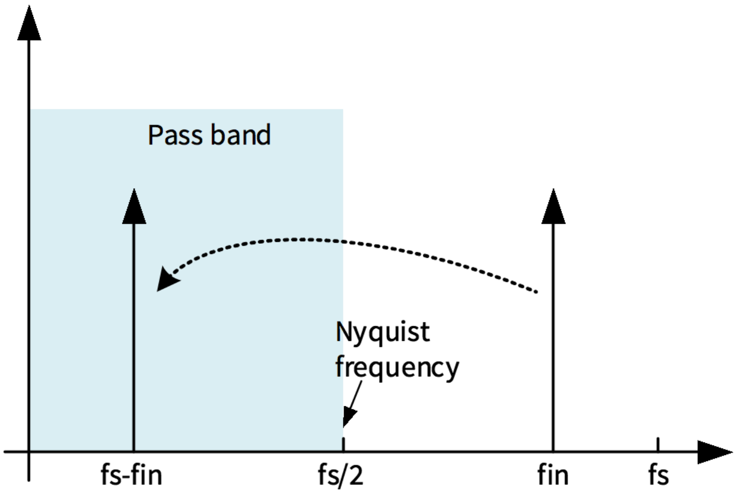

Figure 3. Mechanism of signal aliasing

In addition to meeting the input signal frequency less than the Nyquist limit, the input signal of the sampling system usually contains high-frequency noise with frequencies exceeding the Nyquist frequency. The noise will alias to the passband and become interference signal. Therefore, the anti-aliasing filter placing at the input of the sampling system is necessary to filter out high-frequency noise before sampling and avoid noise aliasing. When selecting a filter, the goal is to provide a cut-off frequency that eliminates high-frequency noise from the sampling input or at least attenuates it so that it does not obviously influence the sampling signal.

NSI1400 is a sampling system with the sample frequency of 12MHz. The cut-off frequency of the anti-aliasing filter is no more than 6MHz to prevent the alias of high-frequency noise that folds into the pass band.

2.3.Design of Input Filter

The input conditioning filter of NSI1400, as is shown in Figure 1, are designed considering charge buffering demand, anti-aliasing, input signal frequency and system bandwidth.

For charge buffering of the input switched-capacitor circuit, the filter capacitor needs a value of more than 330pF. Table 1 shows the measured Gain Error of a NSI1400 with different input filter capacitance. The design specification of Gain Error is within ±0.3%. A filter capacitor of more than 330pF is necessary and more than 1nF is better.

Table 1. Gain Error of a NSI1400 sample with different input filter capacitance

Input filter capacitance	without	330pF	1nF	10nF
Gain error of NSI1400 (%)	× -0.9	√ 0.2	√ <0.1	√ <0.1

For anti-aliasing demand in the application with high-frequency interference, the cut-off frequency of the anti-aliasing filter is no more than 6MHz as is discussed in section 2.2.

A capacitor placed between INN and INP pins that filters out differential noise is called differential capacitor C_{diff}. Capacitors placed between INN/INP pins and GND1 that filter out common-mode noise are called common-mode capacitor C_{cm}. C_{diff} is suggested at least 10 times higher than C_{cm} to reduce the influence of common-mode capacitance error at different input pins, this prevents common-mode noise from being converted into differential noise due to component tolerances. C_{cm} is not necessary if the system common-mode noise is acceptable. Customers can adjust the filter design by demand. The cut-off frequency of common-mode and differential filters are as below:

$$f_{CM} = \frac{1}{2\pi R_{FLT} C_{CM}}$$

$$f_{DIFF} = \frac{1}{2\pi (R_{FLTP} + R_{FLTN}) (C_{DIFF} + \frac{1}{2} C_{CM})}$$

3.Power Supply Circuits

For the applications with bad operating conditions (such as motor control), or power supply circuits that need improvement (such as long wiring of the front power supply), special attention should be paid to the design of the NSI1400 power supply pin. It is recommended that depending on the supply voltage waveform of the customer's system, a voltage stabilizing capacitor of 1~10μF should be connected in parallel with the 0.1uF bypass capacitor placed nearby to reduce the overall ESR and achieve better filtering effect. The 1~10μF capacitor is for low frequency and the 0.1uF capacitor filters out high-frequency noise. Customers can also increase the value of the original capacitor from 0.1uF to more than 1uF to improve the filtering effect without PCB revision.

In applications such as motor control, the power supply of isolated gate driver is usually multiplexed in conjunction with a zener diode to supply power to the NSI1400. A typical power supply circuit is shown in Figure 4, where +15V is the power supply of the gate driver, D1 is the zener diode (typical 5.1V), R1 is the current limiting resistor, and C1 is the decoupling capacitor. When the zener diode power supply circuit is unable to provide the required power supply current IDD1 of NSI1400, it may occur that VDD1 undervoltage leads to output fail-safe and the current limiting resistor consumes too much power. Therefore, attention should be paid to the selection of the current limiting resistor and the zener diode.

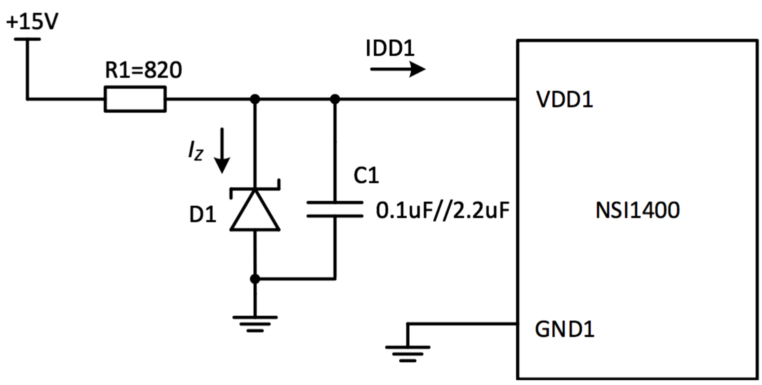

Figure 4. Typical power supply circuit of NSI1400 in motor control application

When selecting the current limiting resistor, the following three aspects should be considered: the maximum power supply current of the NSI1400, the minimum breakdown current of the zener diode and the dissipation power of R1. For NSI1400, the maximum value of IDD1 is 7.2mA under the operation of the maximum supply voltage 5.5V and high temperature +125℃. For the zener diode, the minimum breakdown current IZ of the universal 5.1V zener diode such as 1N4733A is 1mA, that is, the zener diode can generate a stable voltage of 5.1V when the reverse current is greater than 1mA. Therefore, the current flowing through R1 should not be less than $I_{VDD1}+I_Z$=8.2mA.
To sum up, when the working voltage is 5.1V, the current limiting resistor R1 is selected as follows:
$R_1 \le \frac{15-5.1}{0.0082} = 1207\Omega$, and 1206 or 1210 packages are usually recommended for the resistor.
If it is inconvenient to change the current limiting resistor, the zener diode can be changed according to its breakdown characteristic curve. A zener diode with a small breakdown current or with a voltage of more than 3.3V when the breakdown current is insufficient is a good choice, which ensures that the NSI1400 can still work normally.

4.PCB Layout

There are some key guidelines or considerations for optimizing performance in PCB layout:

- Place the input filter capacitors as close as possible to the INP and INN pins for best performance.
- NSI1400 requires a 0.1μF bypass capacitor between VDD1 and GND1, VDD2 and GND2. The capacitor should be placed as close as possible to the VDD pin. If better filtering is required, an additional 1~10μF capacitor may be used.
- Kelvin rules is recommended for the connection between shunt resistor to NSI1400. Because of the Kelvin connection, any voltage drops across the trace and leads should have no impact on the measured voltage.
- Place the shunt resistor close to the INP and INN inputs and keep the layout of both connections symmetrical and run very close to each other to the input of the NSI1400. This minimizes the loop area of the connection and reduces the possibility of stray magnetic fields from interfering with the measured signal.

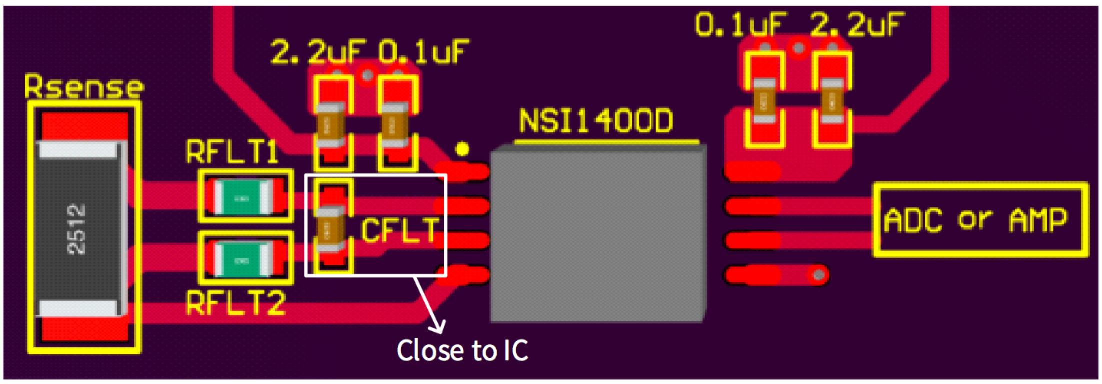

Figure 5. Typical application circuit in phase current sensing

5.Revision History

Revision	Description	Author	Date
1.0	Initial version	Jiahua Xu, Michelle Zhao	22/12/2023

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