Isolation Amplifier
Application Circuits (Voltage Sensing) of the TLP7920

Reference Guide

RD005-RGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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1. Overview

Factory Automation (FA) market has AC servo, General Purpose Inverter, Solar Power Generation and Wind Power Generation areas and those application's key design point is to accurate current sense, voltage sense so that each application can realize high accuracy and stability of motions and controls and isolation performance between input and output signals. In order to realize such kind of high accuracy motions and controls, system has to monitor motor's current and voltage and feedback them to microcontroller (MCU) more properly.

The TLP7920 is an isolation amplifier which has optical coupled isolation feature in order to meet above requirement with 0.02% (typical) linearity accuracy. The TLP7920 also provides a common-mode transient immunity (CMTI) of 20 kV/μs (typical), therefore stable even in noisy motor control environments. In addition, the guaranteed isolation voltage of 5000 Vrms (minimum) makes the TLP7920 suit various industrial applications.

In order to achieve those characteristics, the TLP7920 has a high-precision delta-sigma AD converter at the primary side and DA converter at the secondary side. The primary and secondary sides of the TLP7920 isolation amplifier are optically coupled using an LED and a photodiode to provide electrical isolation and internal signal transfer of optical transfer with digital signal realizes high accuracy signal transfer.

The delta-sigma AD converter at the primary side encodes an input analog signal into digital data, then optically transmitted to the secondary side by an LED. At the secondary side, the optical signal is received by a photodiode, decoded by a decoder circuit, converted back to an analog signal by a DA converter, filtered internal conversion noise by a lowpass filter (LPF), then output analog signal properly.

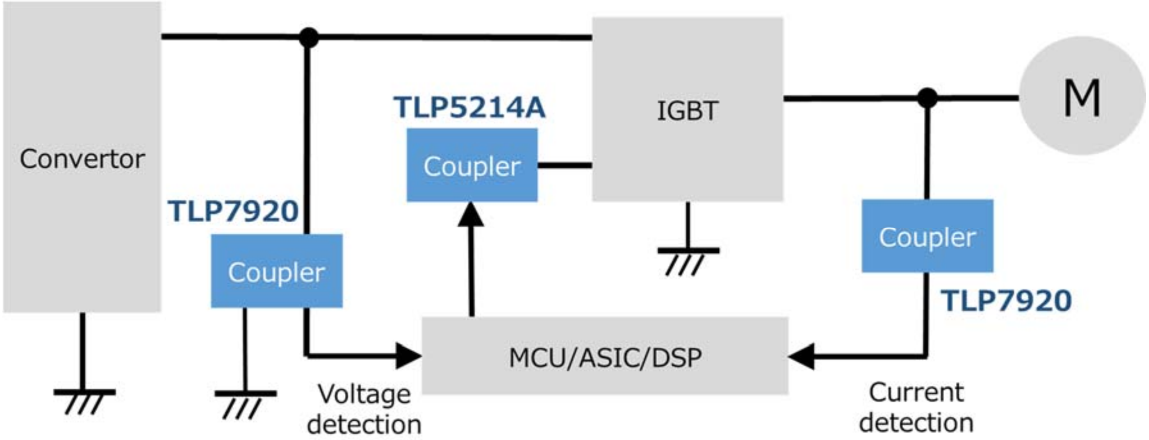
This reference guide provides the unique features and characteristics of the TLP7920, focusing on common-mode transient immunity, nonlinearity characteristic, and power consumption, as well as design guidelines for typical voltage-sensing applications. For details of other features and functions of the TLP7920, see its datasheet.

To download the datasheet for the TLP7920 → Click Here

1.1 Target applications

- Voltage sensing for industrial motor applications, including inverters, servo amplifiers, robots, machine tools, and high-capacity power supplies
- Voltage sensing for wind power and PV inverters, and industrial storage battery systems
- Voltage sensing for office and housing equipment, including uninterruptible power supplies (UPS), server power supplies, home storage battery systems, and air conditioners

Example of an application to an inverter



*　Toshiba offers the TLP5214A photocoupler suitable for use as an IGBT gate driver.

For details of the TLP5214A → Click Here

2. Major features of the TLP7920

- **Common-mode transient immunity (CMTI)**

  Common-mode noise is a type of electrical noise that overlaps on both signal and GND lines in the same direction. A photocoupler is used to optically transmit a signal between two isolated circuits with independent power supplies, however even in this case, a common-mode noise is generated by changes in the voltage of either one of the power supplies (for example, input a noise from outside). A common-mode noise generates a displacement current to flow through the internal coupling capacitance between the primary (input) and secondary (output) sides of a photocoupler and if a displacement current excees a given level into coupling capacitor, the photocoupler has malfunction, then resulting in faulty system operation.

  A displacement current generated by transient common-mode noise could cause bit errors in an isolation amplifier, in the worst-case, it leads to a short-circuit failure of an IGBT. There fore it is important for stable system operations to tolerate common-mode noise. CMTI indicates the ability of an isolation amplifier to tolerate high-slew-rate transient voltage induced across GND lines. An isolation amplifier with a high CMTI provides high immunity to common-mode noise and is suit applications requiring electrical isolation.

Figure 2.1 shows an example of a test circuit for measuring the output waveform with a common-mode voltage (V_{CM}) applied.

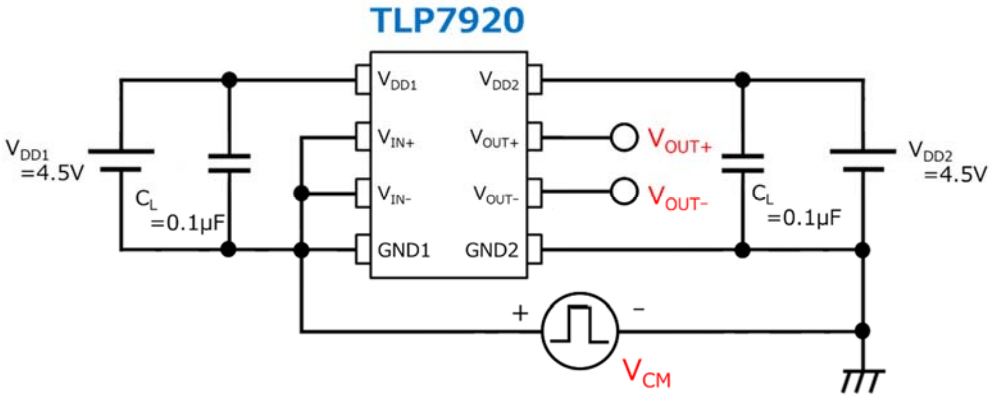
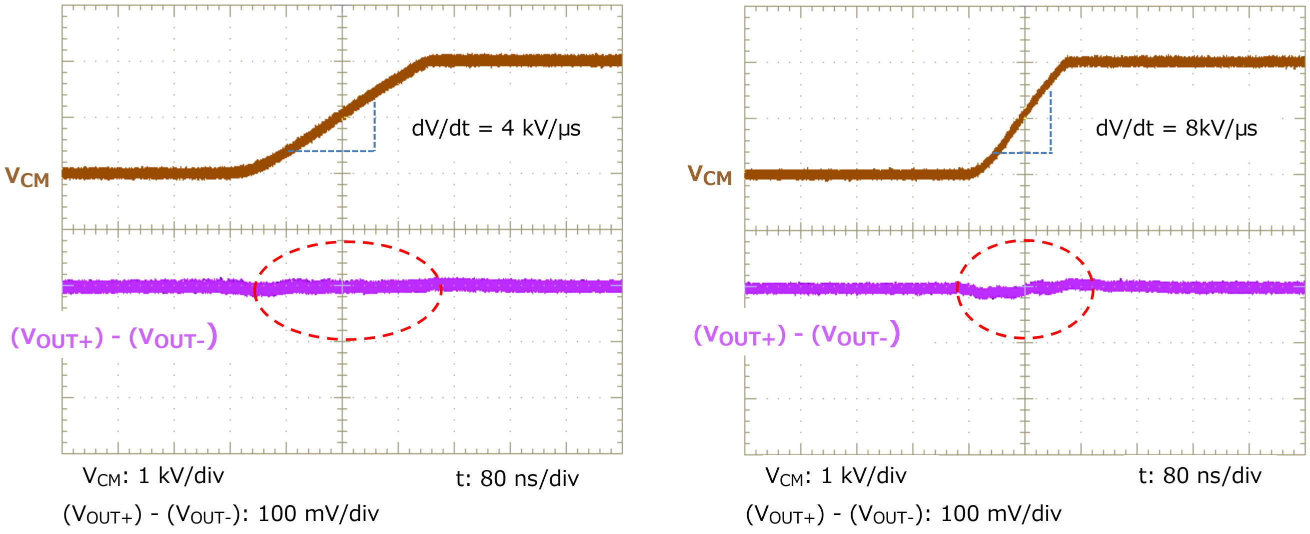


Figure 2.1 Example of a test circuit for measuring the output waveform with a common-mode voltage (V_{CM}) applied

An inverter contains discrete IGBT (or IGBT module) with a collector-emitter voltage (V_{CE}) of 600 to 650V or 1200V. The 600V to 650V IGBTs are generally used at a supply voltage of 400V, and 1200V IGBTs are commonly used at 800V. Typically, IGBTs have rise and fall times (t_r and t_f) of roughly 100ns when switching. Under these conditions, the slew rate (dV/dt) of V_{CM} is calculated to be 4kV/μs at a supply voltage of 400V and 8kV/μs at 800V. Figure 2.2 shows examples of output waveforms of the TLP7920 when common-mode voltages (V_{CM}) with 4-kV/μs and 8-kV/μs slew rates are applied. As shown in Figure 2.2, V_{OUT} does not have much noise, which proves that the TLP7920 has enough CMTI performance to apply actual applications.



A) When dV/dt = 4 kV/μs **B) When dV/dt = 8 kV/μs**

Figure 2.2 Example of output waveforms of the TLP7920 with common-mode voltages (V_{CM}) applied

Just for reference, Figure 2.3 shows an example of an output waveform when the common-mode voltage V_{CM} has a very large dV/dt rate with 60kV/µs. The V_{OUT} waveform has a noise spike caused by V_{CM} sudden change. This noise spike could cause a total system malfunction if it becomes larger.

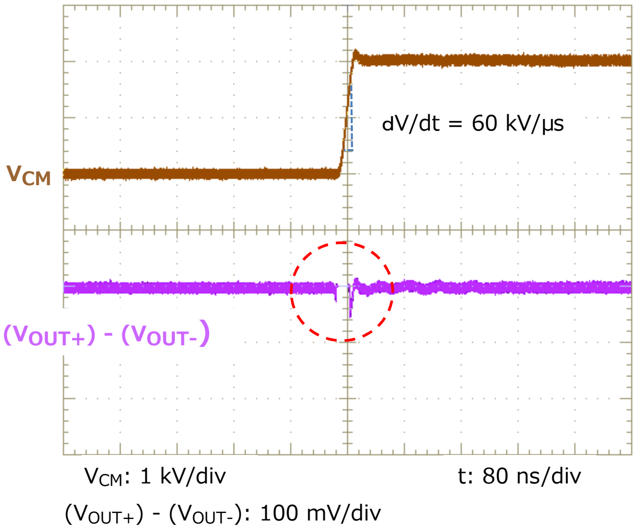


Figure 2.3 Example of an output waveform of the TLP7920 when a common-mode voltage (V_{CM}) with a very large slew rate is applied

- **About output linearity characteristics**

When system feedback needs using isolation amplifier detecting current fluctuations, it is important for input-output linearity characteristics to control system properly. The output of an isolation amplifier with bad linearity characteristics does not respond accurately with specific input so there are lacking of the stability and accuracy of a system. In the trend of increasing speed, accurate control is required for inverters and it is important for isolation amplifier to minimize the output errors. Although an electronic circuit or software can be used to correct output errors, both methods are impractically complicated and difficult, considering variations in device characteristics. Using an isolation amplifier with high precision linearity characteristics is more practical. Figure 2.4 shows a test circuit for measuring the linearity characteristics of an isolation amplifier.

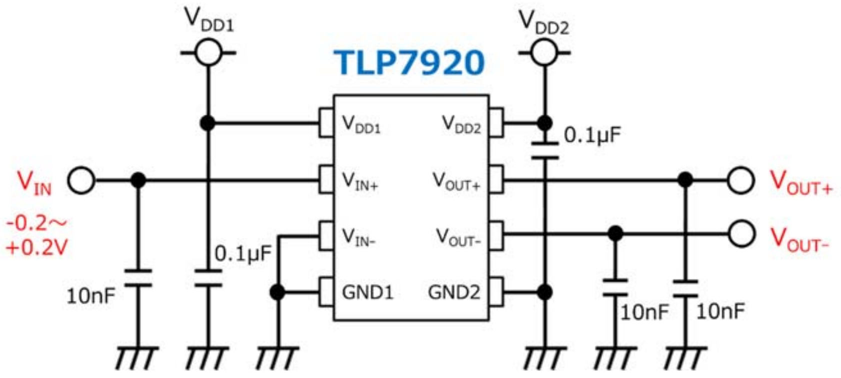


Figure 2.4 Example of a nonlinearity test circuit

The NL_{200} or NL_{100} parameter represents the linearity of an isolation amplifier. NL_{200} is calculated as follows:

1. The least-squares method is used to find a line of the best fit that represents the relationship between the input voltage differential (V_{IN+}-V_{IN-}) and the output voltage differential (V_{OUT+}-V_{OUT-}).
2. The deviations of the output voltage differential (V_{OUT+}-V_{OUT-}) from the line of the best fit are calculated.
3. The sum of the absolute values of the maximum and minimum deviations (|dev_max|+|dev_min|) is calculated.
4. The ratio of this sum to the full-scale differential output voltage (V_{OH}-V_{OL}) is calculated.

Figure 2.5 shows the relationship between the input voltage and the output voltage deviation from the line of the best fit.

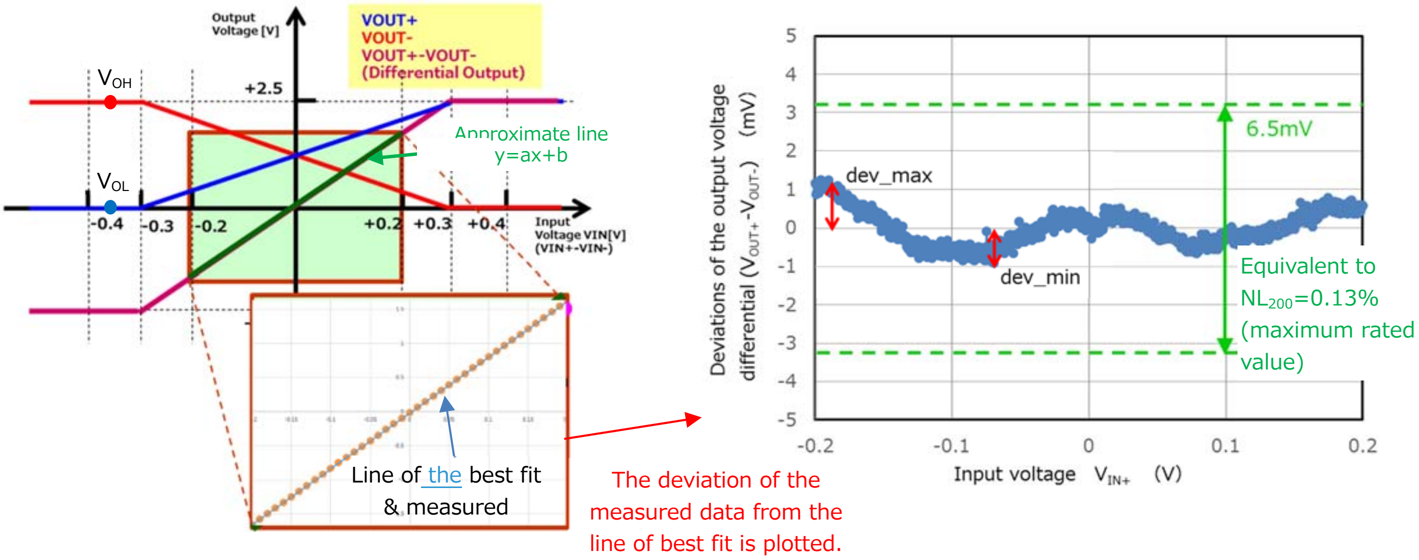


Figure 2.5 Input voltage vs. output voltage deviation from the line of best fit

NL_{200} is calculated as follows:

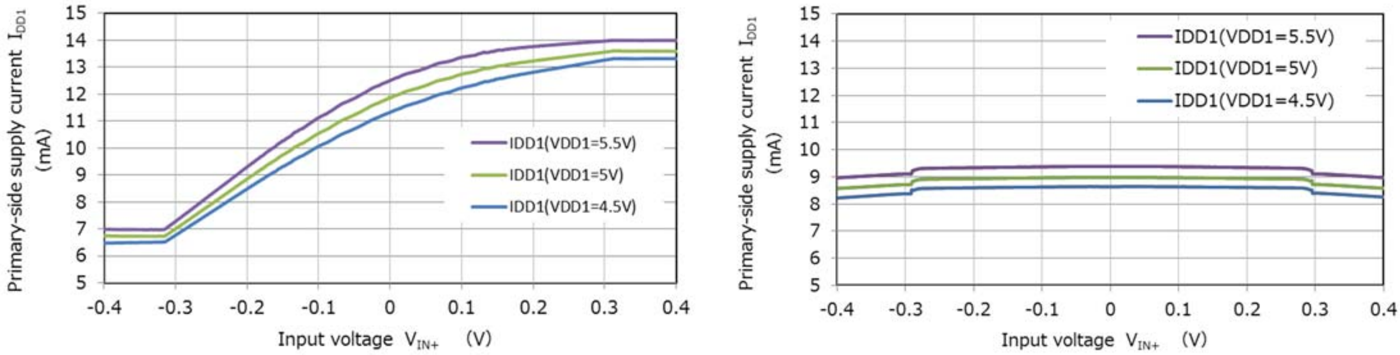
$$\boldsymbol{NL_{200}}(\%) = \frac{\dfrac{(|\boldsymbol{dev\_max}| + |\boldsymbol{dev\_min}|)}{\mathbf{2}}}{\boldsymbol{V_{OH}} - \boldsymbol{V_{OL}}} \times \mathbf{100}$$

From Figure 2.5, dev_max = 1.3 mV, dev_min = -1 mV, and V_{OH}-V_{OL} = 2.5 V, then:

$$NL_{200} = \frac{\dfrac{0.0013 + 0.001}{2}}{2.5} \times 100 = 0.046\%$$

- **Primary-side supply current**

Figure 2. 6 shows the relationships between the input voltage and the primary-side supply current of the TLP7920 (B) side) and a competitor's isolation amplifier (A) side). The primary-side supply current of the competitor's isolation amplifier increases with input voltage while the TLP7920 has a unique digital encoder/decoder technology to maintain the primary-side supply current at almost a constant level around 9 mA (typical) over a range of input voltage (recommend operating range: -0.2 to +0.2 V). This contributes reduction of the maximum circuit current, simplifying the design of a primary-side power supply.

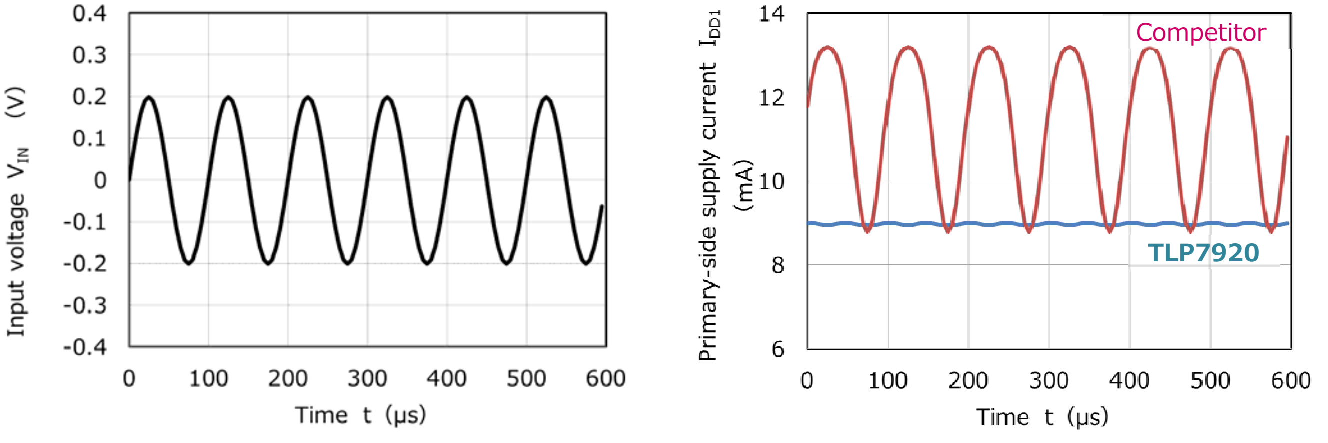


A) Competitor A

B) TLP7920

Figure 2.6 Relationships between the input voltage and the primary-side supply current of isolation amplifiers

Figure 2.7 (B) shows the changes in the primary-side supply current in response to input voltage changes at a given frequency in Figure 2.7 (A).



A) Input voltage changes

B) Primary-side supply current waveforms

Figure 2.7 Primary-side supply current waveforms in response to input voltage changes

The primary-side supply current of the competitor's isolation amplifier changes between 9 mA and 13 mA in response to changes in input voltage while the primary-side supply current of the TLP7920 remains around 9 mA regardless of input voltage change. For example, a floating power supply such as a bootstrap is used as a primary-side power supply for an isolation amplifier since the floating power supply allows the use of small-value capacitors to reduce the circuit size. Obviously, the constant supply current of the TLP7920 contributes power supply consumption reduction and the circuit size reduction. In the trend of increasing system speed, this also contributes suppress electromagnetic interference (EMI) caused by large supply voltage fluctuations.

3. Application circuit example and its bill of materials

3.1 Example of an application circuit for voltage sensing

Figure 3.1 shows an example of a voltage-sensing circuit using the TLP7920.

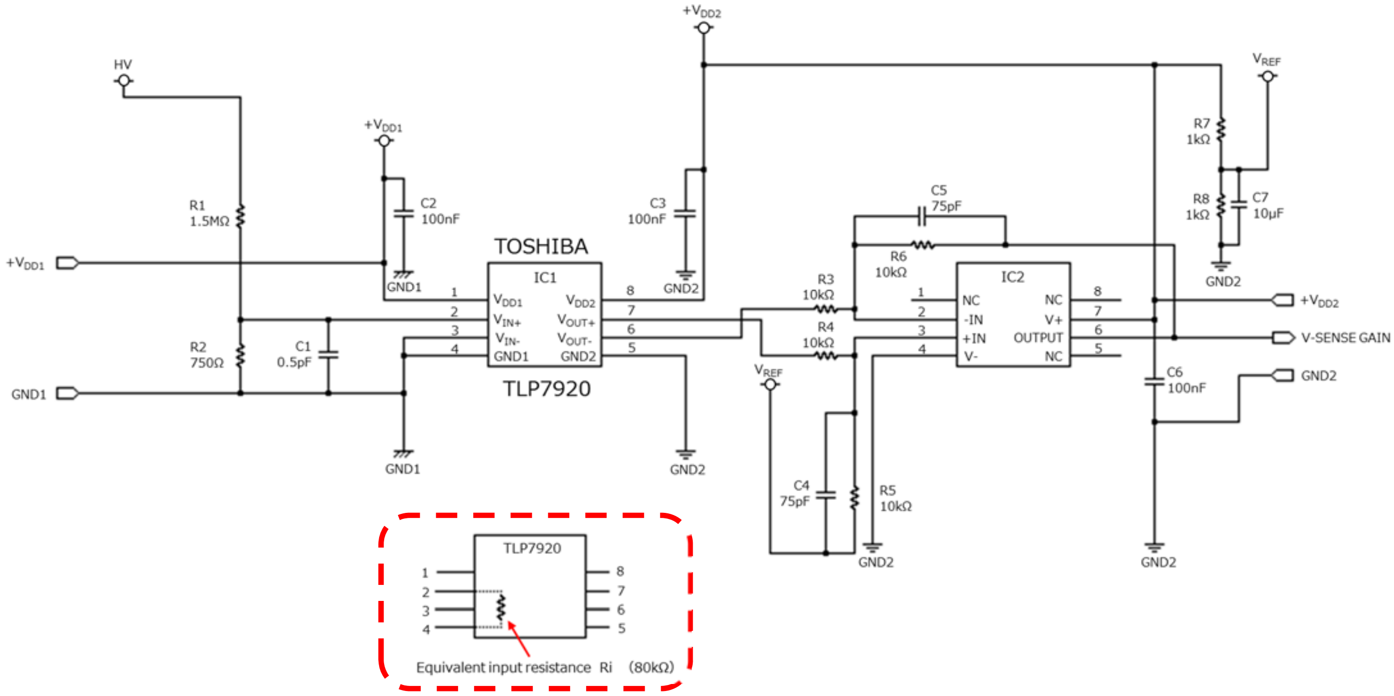


Figure 3.1 Example of a voltage-sensing circuit using the TLP7920

3.2 Bill of materials

Table 3.1 shows a bill of materials for the voltage-sensing circuit using the TLP7920

Table 3.1 Bill of materials for the voltage-sensing circuit using the TLP7920

No.	Ref.	Qty	Value	Part Number	Manufacturer	Description	Packaging	Typical Dimensions in mm (inches)
1	IC1	1	—	TLP7920	TOSHIBA		DIP8	9.66 x 7.62
2	IC2	1	—	OPA237UA	TI		SOIC	6.0 x 4.9
3	R1	1	750Ω			0.25 W, ±5%	3216	3.2 x 1.6 (1206)
4	R2	1	750 kΩ			800 V, 0.25 W, ±0.5%	6331	6.3 x 3.1 (2512)
5	R3	1	750 kΩ			800 V, 0.25 W, ±0.5%	6331	6.3 x 3.1 (2512)
6	R4, R5, R6, R7	4	10 kΩ			0.25 W, ±0.5%	2012	2.0 x 1.25 (0805)
7	R8, R9	2	1 kΩ			0.25 W, ±0.5%	2012	2.0 x 1.25 (0805)
8	C1	1	0.5 pF			Ceramic, 50 V, ±10%	1005	1.0 x 0.5 (0402)
9	C2, C3, C6	3	100 nF			Ceramic, 25V, ±10%	2012	2.0 x 1.25 (0805)
10	C4, C5	2	75 pF			Ceramic, 100V, ±5%	1608	1.6 x 0.8 (0603)
11	C7	1	10 µF			Ceramic, 16V, ±10%	2012	2.0 x 1.25 (0805)

4. Guidelines for designing a voltage-sensing circuit

4.1 Voltage-sensing resistors in a voltage-sensing circuit

For the voltage-sensing purpose, the voltage applied across R1+R2+R3 in Figure 3.1 is detected. Even if HV is much higher than the input voltage range of an isolation amplifier, it is possible for TLP7920 to detect divided voltage with a divider. The voltage-sensing error is determined considering the tolerances of R1, R2, and R3 and the error of the equivalent input resistance R_i (80 kΩ) across Pin 2 and GND of TLP7920. The followings are calculation examples of voltage-sensing resistors.

Eexample 1:

Sensing error : below 0.5%

Equivalent input resistor of TLP7820 (R_i) : 80 kΩ

$R1:R1 \,//\, R_i = R1:(R1\times 80k\Omega) / (R1+80k\Omega) = 1:0.995$

$0.995 = 80k\Omega/(R1+80k\Omega)$

$0.995 \times R1 + 0.995 \times 80k\Omega = 80\ k\Omega \quad \therefore R1 \approx 402\ \Omega$

When R1 is selected from E24 series, R1 = 390 Ω.

Applied voltage : 400 V

Detecting voltage : 200 mV

$400\text{V}:200\text{mV} = (R2+R3) + 390\Omega:39\ \Omega$

$200\text{mV} \times (R2+R3) + 200\text{mV} \times 390\Omega = 400\text{V} \times 390\Omega$

$\therefore R2+R3 \approx 780\ \text{k}\Omega$

When R2 and R3 are selected from E24 series, R2 = 390 Ω and R3 = 390 Ω.

* R2 and R3 are connected in series to ensure creepage distance of resistors.

Eexample 2:

Sensing error : below 1%

Equivalent input resistor of TLP7820 (R_i) : 80 kΩ

$R1:R1 // R_i = R1:(R1\times 80\text{k}\Omega) / (R1+80\text{k}\Omega) = 1:0.99$

$0.99 = 80\text{k}\Omega/(R1+80\text{k}\Omega)$

$0.99 \times R1 + 0.99 \times 80\text{k}\Omega = 80\ \text{k}\Omega \quad \therefore R1 \approx 808\ \Omega$

When R1 is selected from E24 series, R1 = 750 Ω.

Applied voltage : 400 V

Detecting voltage : 200 mV

$400\text{V}:200\text{mV} = (R2+R3) + 750\Omega:750\Omega$

$200\text{mV} \times (R2+R3) + 200\text{mV} \times 750\Omega = 400\text{V} \times 750\Omega$

$\therefore R2+R3 \approx 1.5\ \text{M}\Omega$

When R2 and R3 are selected from E24 series, R2 = 750 Ω and R3 = 750 Ω.

* R2 and R3 are connected in series to ensure creepage distance of resistors.

The tolerances of R1, R2, and R3 should be considered to calculate actual voltage-sensing error.

4.2 Test mode considerations

The TLP7920 enters test mode when either the V_{IN+} or V_{IN-} pin exceeds (V_{DD1}-2) volts (e.g., 5V - 2V = 3V when V_{DD1} = 5V). Don't use the TLP7820 in such a condition.

5. Simulation

5.1 Basic operation

This section shows the simulation results for verifying the basic operation of the TLP7920. Figure 5.1 shows the simulation circuit under the following conditions:

▮ Simulation conditions

- V_{DD1} of IC1: 5V
- V_{DD2} of IC1 and V+ of IC2: 3.3V
- Vin
  Input voltage (10-kHz sine wave with 0.2Vp-p)

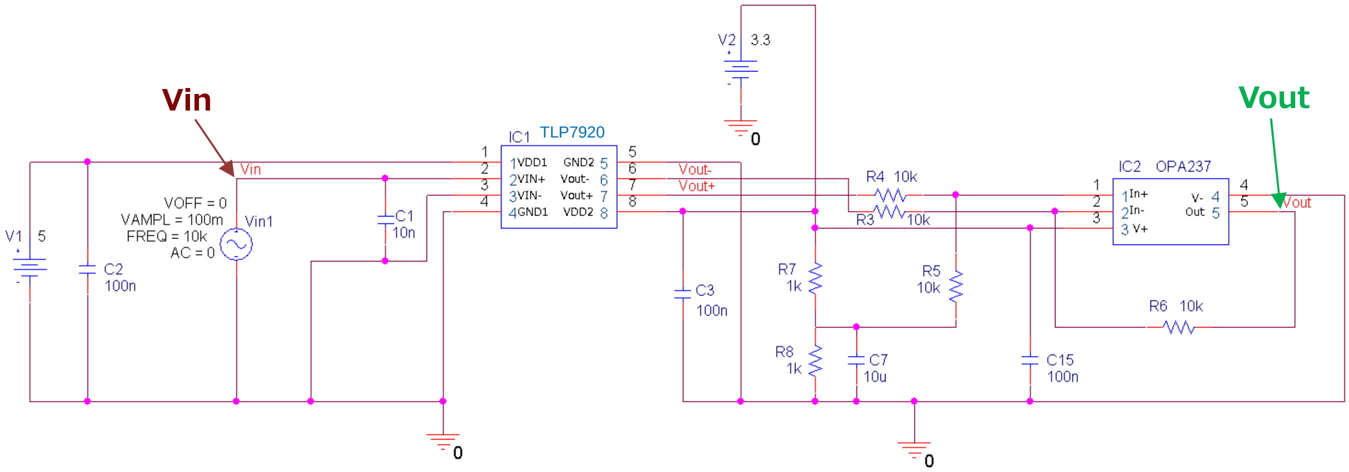


Figure 5.1 Simulation circuit to verify basic operation

Figure 5.2 shows the simulation results. The output is a 10kHz sine wave with 1.64Vp-p, which has x8.2 as large an amplitude as the input signal (10kHz sine wave) with 0.2Vp-p. This is equal to the specified typical gain of x8.2 of the TLP7920, indicating that simulation ran properly.

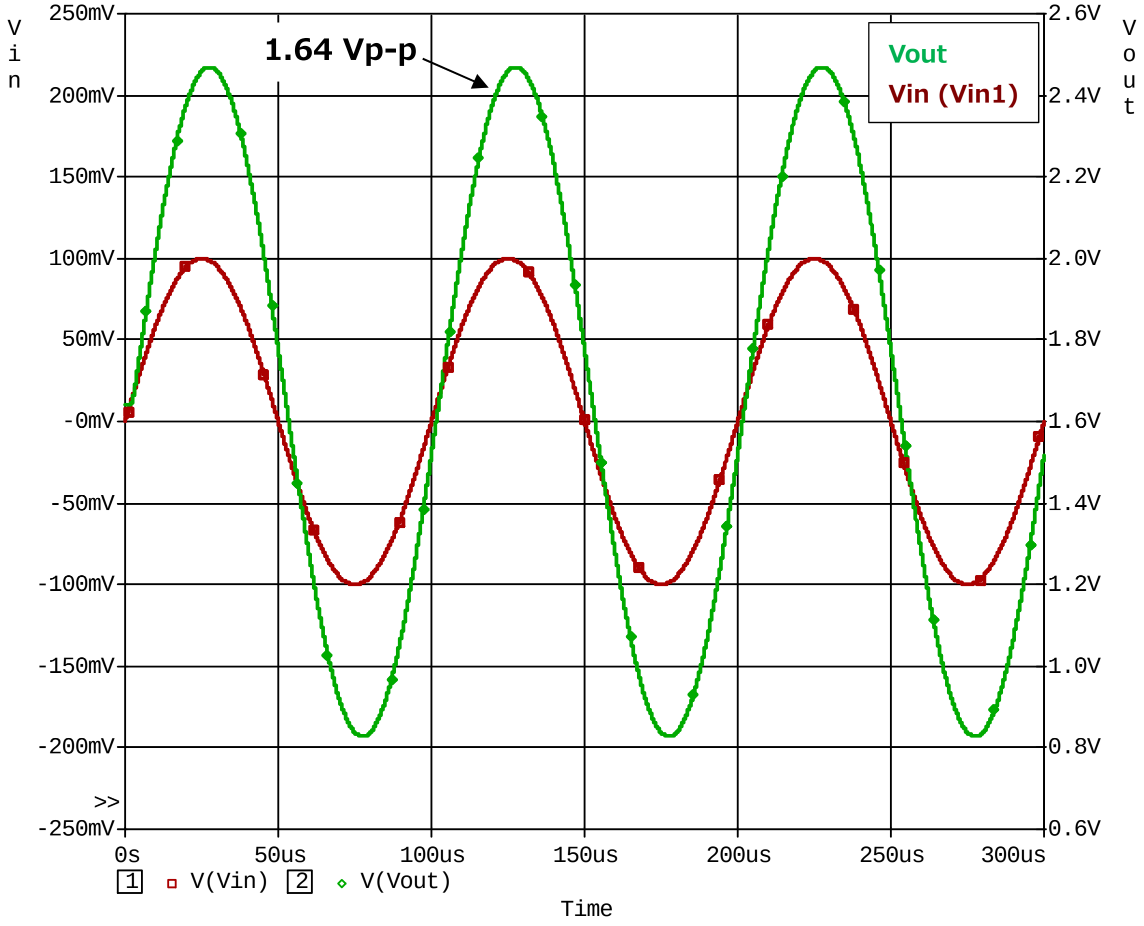


Figure 5.2 Simulation results

5.2 Noise superimposed on the input voltage

Running a simulation superimposing a noise signal (a 500-kHz sine wave with 100 mVp-p) on the input voltage, Vin1. The other conditions are the same as for the previous simulation. Figure 5.3 shows the circuit simulated.

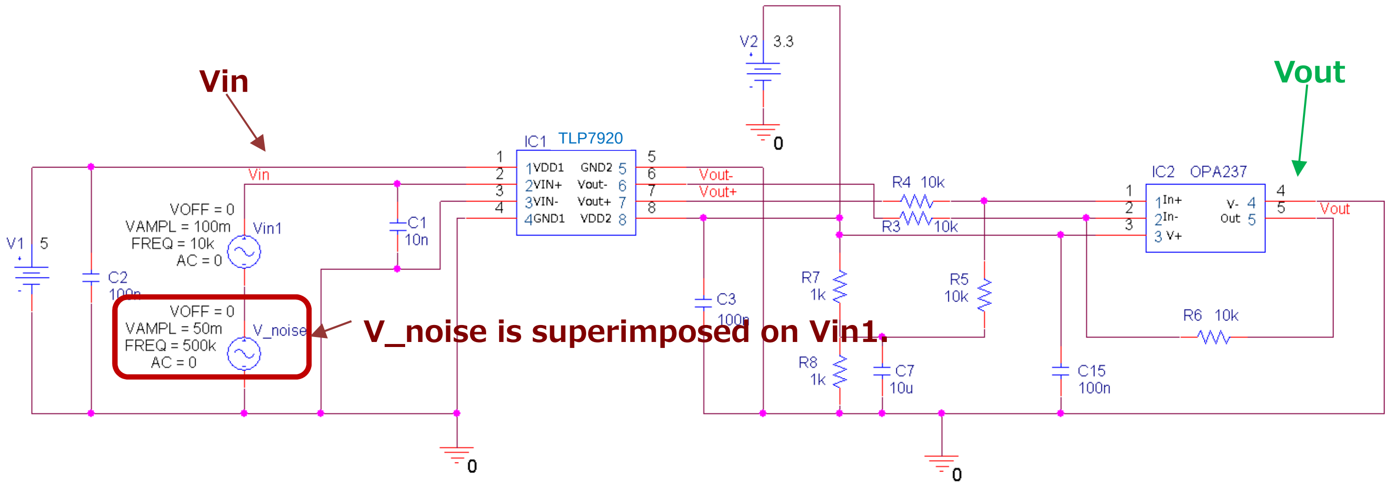


Figure 5.3 Simulation circuit superimposing a noise

Figure 5.4 shows the simulation results, which indicate that the output waveform was not measured properly due to the influence of the noise.

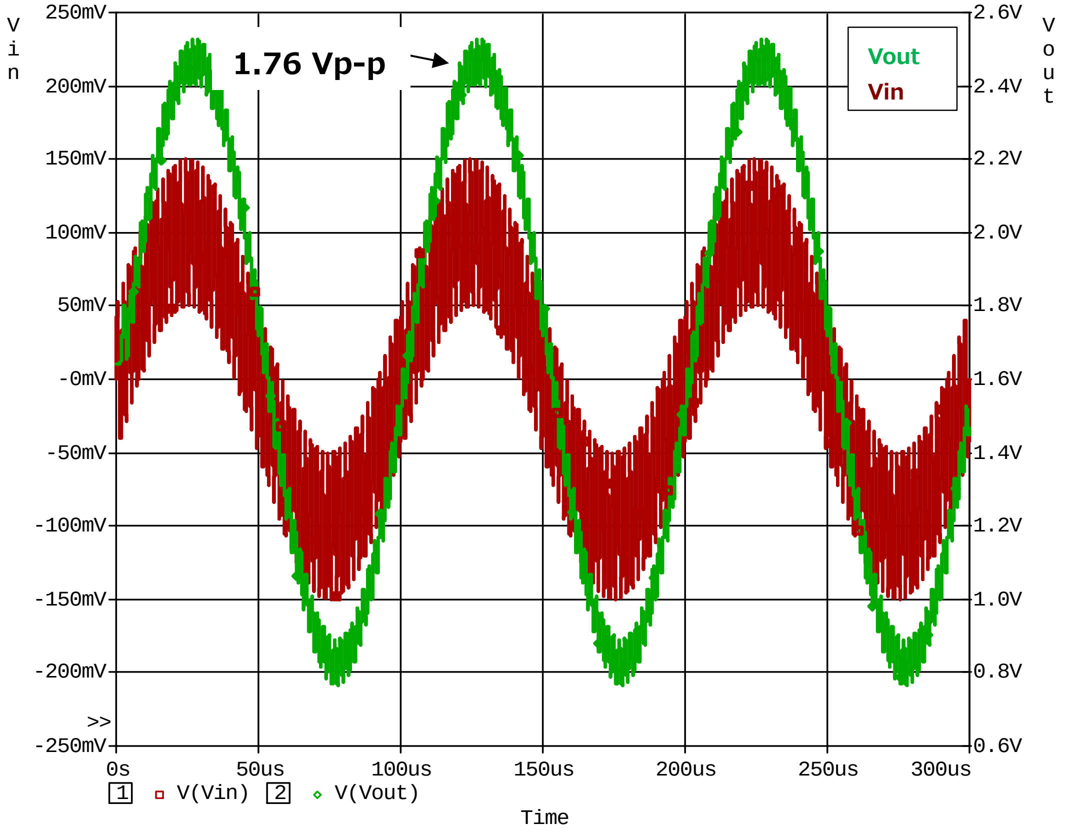


Figure 5.4 Simulation waveforms with noise

5.3 Circuit with filters

Running a simulation with input filters. A 100mVp-p noise signal (1MHz sine wave) was superimposed onto Vin1. The added filters were as follows:

Primary-side input line:

Anti-aliasing LPF frequency: 230kHz
LPF resistor: R1＝R2=68Ω
Input bypass capacitor C1 = 0.01μF

Secondary-side output line:

Noise filter frequency: 230kHz
Amplitude adjustment gain: 0 dB
Input series resistors: 10 kΩ
Input bypass capacitors: C4 = C5 =68 pF

Figure 5.5 shows the simulation circuit.

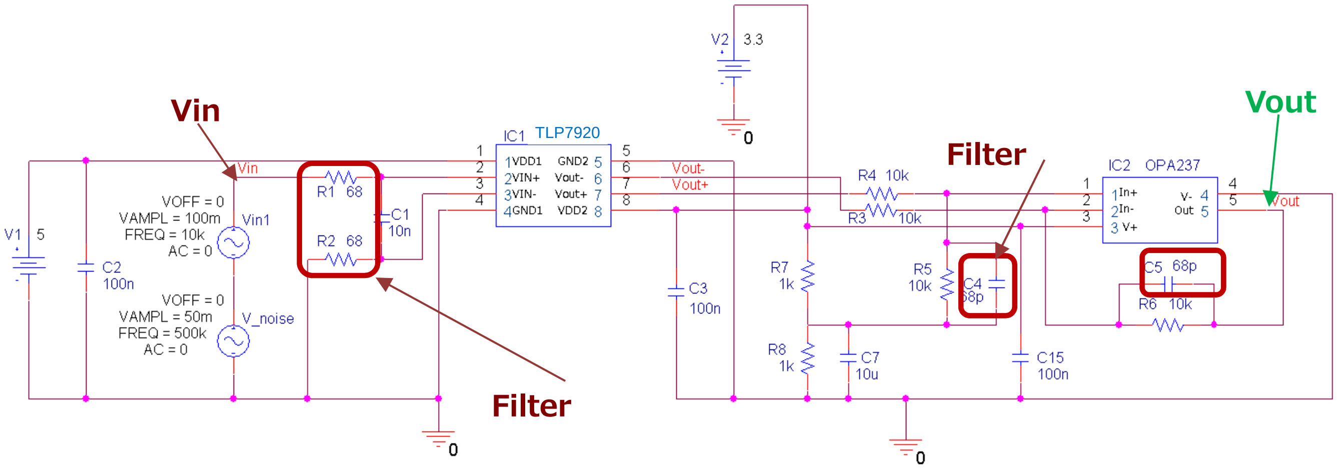


Figure 5.5 Circuit with filters simulated

Figure 5.6 provides the simulation results, which show that the filters removed a noise from the output waveform. The output is a 10kHz sine wave with 1.64Vp-p, which has x8.2 as large an amplitude as the input signal (10kHz sine wave) with 0.2Vp-p. This is equal to the specified typical gain of x8.2 of the TLP7920, indicating that simulation ran properly.

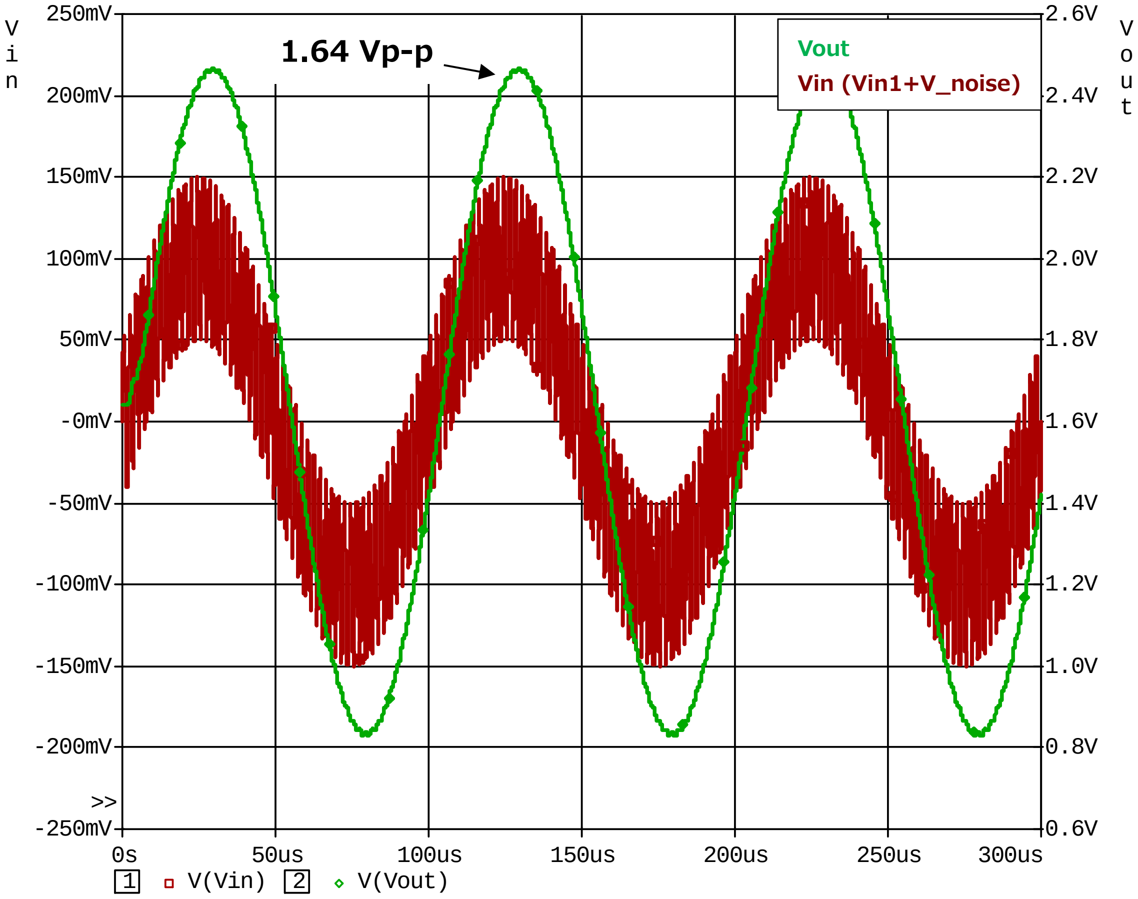


Figure 5.6 Results of simulation of a circuit with filters

6. Product overview

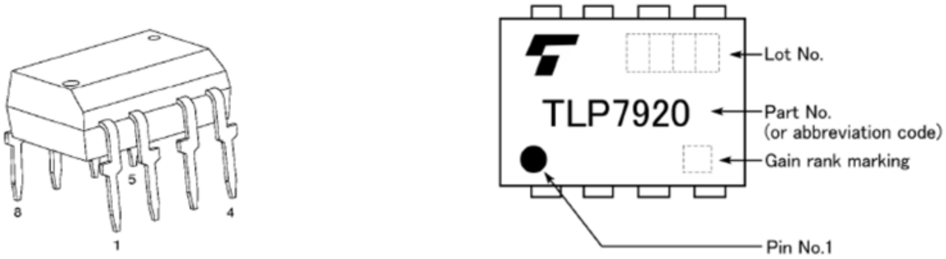
6.1. Overview

The TLP7920 is an optically coupled isolation amplifier that has a high-precision delta-sigma AD converter at the primary side and a DA converter at the secondary side.

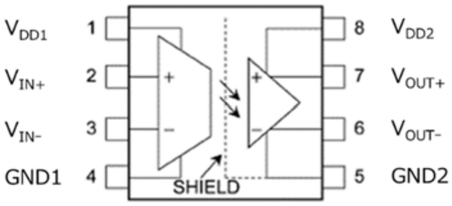
- Recommended supply voltage ranges:
  Primary side = 4.5 to 5.5 V, Secondary side = 3.0 to 5.5 V
- Operating temperature range: -40 to +105°C
- Common-mode transient immunity (CMTI): 15kV/μs (minimum)
- Low power consumption:
  Primary supply current = 8.6 mA (typical), Secondary supply current = 6.2 mA (typical)
- Excellent output nonlinearity characteristics:
  NL_{200}=0.02% (typical) at Vin+ = -200mV to +200mV
  NL_{100}=0.015% (typical) at Vin+ = -100mV to +100mV
- Excellent temperature stability
  Input offset drift: 2μV/°C (typical)
  Gain drift: 0.00012V/V/°C (typical)
  V_{OUT} nonlinearity drift: 0.00007%/°C (typical)
- Safety standards
  UL-approved: UL1577, File No. E67349
  cUL-approved: CSA Component Acceptance Service No. 5A File No. E67349
  VDE-approved: EN60747-5-5, EN60065, EN60950-1, EN 62368-1 (Note 1)
  Note 1: When VDE-approved parts are needed, please designate the Option (D4).

6.2. External view and pin assignment

External view and marking



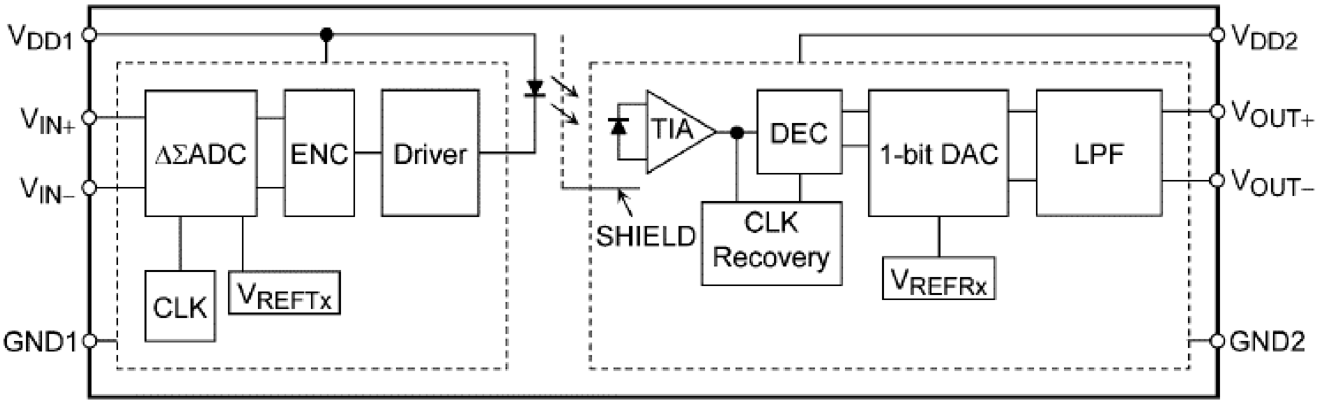
Pin assignment



Pin No.	Symbol	Description
1	V_{DD1}	Input side supply voltage
2	V_{IN+}	Positive input
3	V_{IN-}	Negative input
4	GND1	Input side ground
5	GND2	Output side ground
6	V_{OUT-}	Negative output
7	V_{OUT+}	Positive output
8	V_{DD2}	Output side supply voltage

Figure 6.1 External view, marking, and pin assignment of the TLP7920

6.3. Internal block diagram



Note: Add 0.1µF bypass capacitors between Pin 1 and Pin 4 and between Pin 5 and Pin 8.

Figure 6.2 Internal block diagram of the TLP7920

6.4 Output voltages for different primary- and secondary-side power supply combinations

Table 6.1 shows the output voltages obtained from different primary- and secondary-side power supply combinations.

Table 6.1 Output voltages for different power supply combinations

■ V_{OUT+} output ■ V_{OUT-} output

		Primary-Side Power Supply, V_{DD1}	
		ON	OFF
Secondary-Side Power Supply V_{DD2}	ON	V_{IN} x Gain/2 +1.25 (V)	GND
	OFF	GND	GND

		Primary-Side Power Supply, V_{DD1}	
		ON	OFF
Secondary-Side Power Supply V_{DD2}	ON	V_{IN} x Gain/2 +1.25 (V)	+2.5 V
	OFF	GND	GND

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