AN14682

OPAMP Usage on MCX A3xx

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Document information

Information	Content
Keywords	AN14682, operational amplifier, MCX A3xx
Abstract	This application note describes fundamental of OPAMP and how to use the MCX A3xx OPAMP.

1 Introduction

The operational amplifier (OPAMP) is an analog peripheral. As suggested by its name, an OPAMP is commonly used for signal amplification and it can be configured in various modes. An ideal operational amplifier has infinite input impedance and nearly zero output impedance. This characteristic allows the OPAMP to be used as a voltage follower, connecting the OPAMP output directly to the input of an analog-to-digital converter (ADC). This configuration helps minimize the impact of the ADC's input impedance on signal sampling. Also, the OPAMP can perform inverting, non-inverting, and differential amplification functions. Figure 1 illustrates the block diagram of an OPAMP.

In MCX A3xx series MCU, it integrated four OPAMPs without internal gain. The GBW of MCX A3xx OPAMP is 4 MHz.

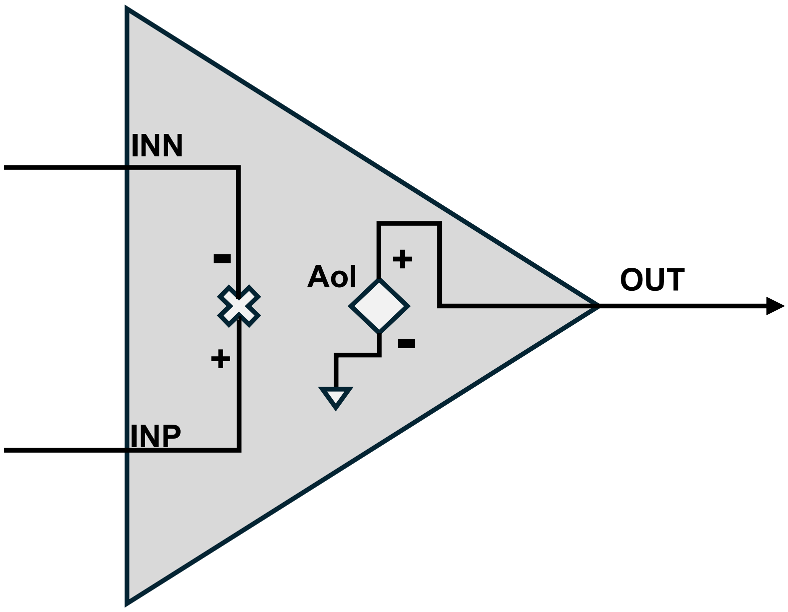

Figure 1. Block diagram of OPAMP

1.1 Difference between ideal and real OPAMP

While it is assumed that an OPAMP is ideal, however, in reality, no OPAMP is truly ideal. The A_{ol} shown in Figure 1 is the DC open-loop voltage gain of OPAMP. In an ideal state, the A_{ol} must be infinite.

Figure 2 illustrates an inverting amplifier circuit. Based on the OPAMP principle, the resulting equation is shown as Equation (1):

$$V_{inn} = V_{inp} \tag{1}$$

Equation (2) is derived as follows:

$$V_{inn} = V_{out} \times \frac{R_1}{R_1 + R_2} + V_{INN} \times \frac{R_2}{R_1 + R_2} \tag{2}$$

If V_{INN} is connected to GND, the V_{inn} is shown in Equation (3):

$$V_{inn} = V_{out} \times \frac{R_1}{R_1 + R_2} \tag{3}$$

From Equation (1) and Equation (2), derive Equation (4) and Equation (5) as follows:

$$V_{inp} = V_{out} \times \frac{R_1}{R_1 + R_2} \tag{4}$$

$$\frac{V_{out}}{V_{inp}} = \frac{1}{\frac{R_1}{R_1 + R_2}} \tag{5}$$

Equation (5) is based on an ideal OPAMP, however, in reality, no OPAMP is truly ideal. Therefore, consider the A_{vol} in Equation (6):

$$\frac{V_{out}}{V_{inp}} = \frac{1}{\frac{R_1}{R_1 + R_2} + \frac{1}{A_{ol}}} \tag{6}$$

Equation (6) shows that the A_{vol} affects the precision of OPAMP gain. This value is 95 dB in the MCX A3xx OPAMP data sheet. Change the unit dB to V/V and use Equation (7) when A_{dol} is equal to 95 dB:

$$A_{dol} = 20 \times \log(A_{ol}) \tag{7}$$

The A_{ol} must be equal to 56234 V/V.

In Equation (6), if R_1 and R_2 are set to 10 kΩ, the ideal gain is 2. When A_{vol} is considered, the actual gain is 1.999929. Most OPAMP data sheet provides this parameter.

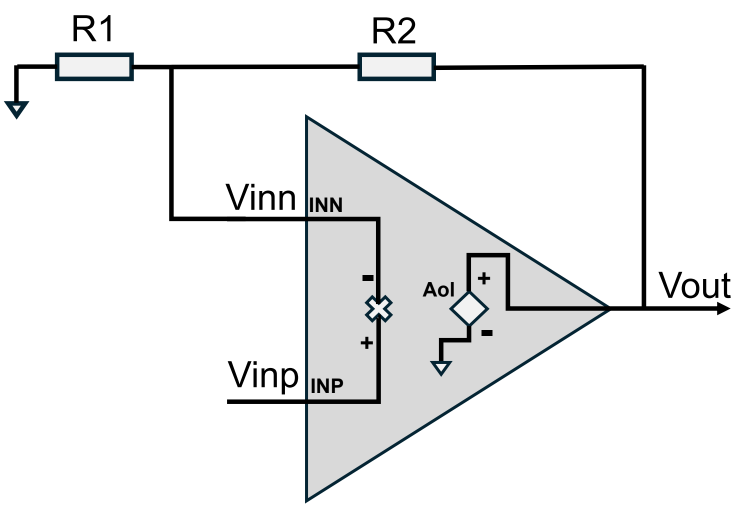

Figure 2. Non-inverting amplify circuit of OPAMP

2 OPAMP use case

As mentioned before, the OPAMP can be used in many different functions. This chapter introduces some use cases for OPAMP.

2.1 Voltage follower

Figure 3 shows the voltage follower circuit for OPAMP. In this OPAMP use case, the input signal is connected to V_{inp}, and the relationship between V_{inp} and V_{out} is shown in Equation (8):

$$V_{out} = V_{inp} \tag{8}$$

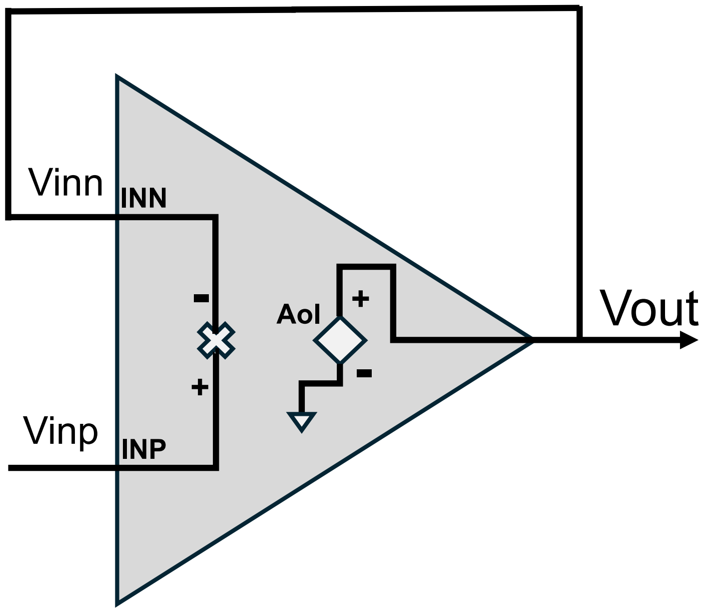

Figure 3. Voltage follower circuit of OPAMP

The voltage follower circuit is commonly used in ADC sample circuit to decrease the ADC input impedance influence.

CAUTION: *The MCX A3xx OPAMP IP is not rail to rail input. The voltage range in INN and INP, which is called input common mode voltage range, is 0 ~ VDDANA - 1 V. The output voltage is nearly rail to rail and its range is 0.15 V ~ VDDANA - 0.15 V.*

2.2 Inverting amplify

Figure 4 shows the inverting amplify circuit for OPAMP. Based on the principle of OPAMP, Equation (9) is derived as follows:

$$V_{inn} = V_{inp} \tag{9}$$

Equation (10) is derived as follows:

$$V_{inp} = V_{out} \times \frac{R_1}{R_1 + R_2} + V_{INN} \times \frac{R_2}{R_1 + R_2} \tag{10}$$

If we connect V_{inp} to GND, the V_{inp} is shown in Equation (11):

$$0 = V_{out} \times \frac{R_1}{R_1 + R_2} + V_{INN} \times \frac{R_2}{R_1 + R_2} \tag{11}$$

From Equation (11), derive Equation (12) and Equation (13) as follows:

$$V_{out} \times \frac{R_1}{R_1 + R_2} = -V_{INN} \times \frac{R_2}{R_1 + R_2} \tag{12}$$

$$\frac{V_{out}}{V_{inn}} = -\frac{R_2}{R_1} \tag{13}$$

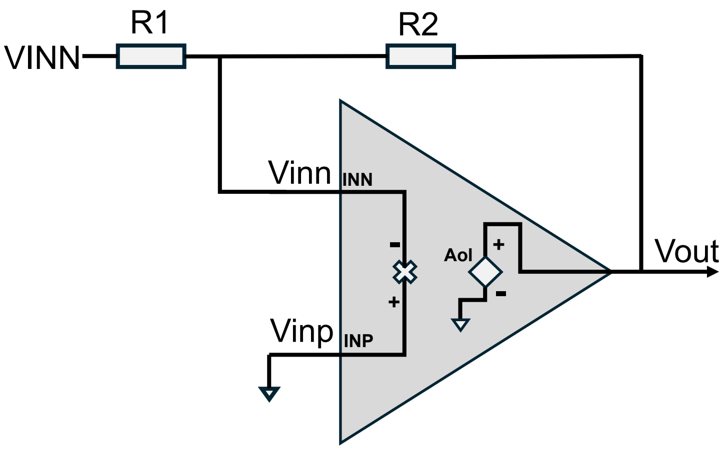

Figure 4. Inverting amplify circuit of OPAMP

2.3 Non-inverting amplify

For non-inverting amplifier circuit of the OPAMP, Section 1.1 "Difference between ideal and real OPAMP" provides the calculation process.

2.4 Differential amplify

Figure 2 shows Differential amplify circuit for OPAMP. Based on the principle of OPAMP, the resulting equation is shown as Equation (14):

$$V_{inn} = V_{inp} \tag{14}$$

Also, derive Equation (15) and Equation (16) as follows:

$$V_{inn} = V_{out} \times \frac{R_1}{R_1 + R_2} + V_{INN} \times \frac{R_2}{R_1 + R_2} \tag{15}$$

$$V_{inp} = V_{offset} \times \frac{R_3}{R_3 + R_4} + V_{INP} \times \frac{R_4}{R_3 + R_4} \tag{16}$$

From Equation (14), Equation (15), and Equation (16), derive Equation (17), and Equation (18) as follows:

$$V_{out} \times \frac{R_1}{R_1 + R_2} + V_{INN} \times \frac{R_2}{R_1 + R_2} = V_{offset} \times \frac{R_3}{R_3 + R_4} + V_{INP} \times \frac{R_4}{R_3 + R_4} \tag{17}$$

$$V_{out} = \frac{R_1 + R_2}{R_1} \times \left(V_{offset} \times \frac{R_3}{R_3 + R_4} + V_{INP} \times \frac{R_4}{R_3 + R_4} - V_{INN} \times \frac{R_2}{R_1 + R_2}\right) \tag{18}$$

Now, Equation (19) shows the differential amplifier algorithm:

$$V_{out} = V_{offset} \times \frac{R_3 \times (R_1 + R_2)}{R_1 \times (R_3 + R_4)} + V_{INP} \times \frac{R_4 \times (R_1 + R_2)}{R_1 \times (R_3 + R_4)} - V_{INN} \times \frac{R_2}{R_1} \tag{19}$$

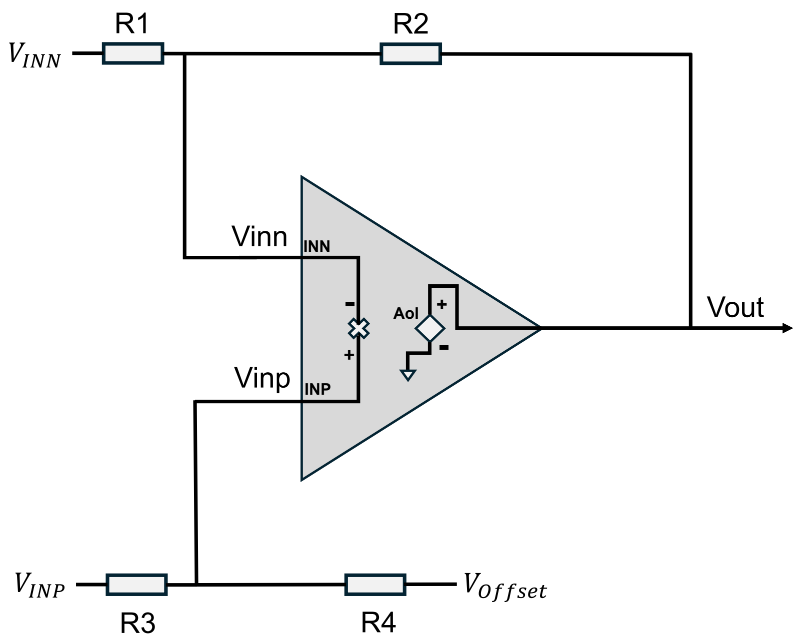

Figure 5. Differential amplify circuit of OPAMP

2.5 Voltage add circuit

Figure 6 shows the voltage add circuit of OPAMP. Based on the principle of OPAMP, Equation (20) is derived as follows:

$$V_{inn} = V_{inp} \tag{20}$$

Also, derive Equation (21) as follows:

$$V_{out} = -R_2 \times \left(\frac{1}{R_1} \times V_{IN1} + \frac{1}{R_3} \times V_{IN2}\right) \tag{21}$$

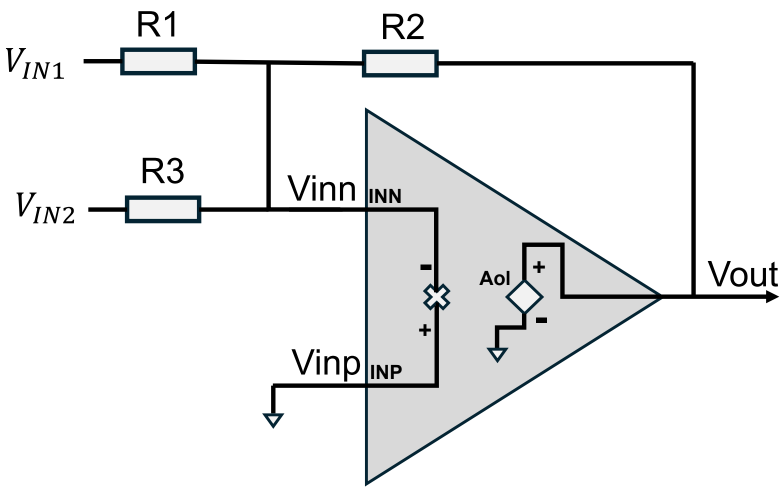

Figure 6. Voltage add circuit of OPAMP

2.6 Integral circuit

Figure 7 shows the integral circuit of OPAMP. Based on the principle of OPAMP, derive Equation (22) as follows:

$$V_{inn} = V_{inp} \quad (22)$$

Equation (23) is derived as follows:

$$V_{out} = -\frac{1}{C} \times \int \frac{V_{INN}}{R} dt \quad (23)$$

From Equation (23), derive Equation (24) as follows:

$$V_{out} = -\frac{1}{RC} \times \int_{t_0}^{t_1} \frac{V_{INN}}{R} dt + V_{out}\left(t_0\right) \quad (24)$$

To avoid the potential imbalance of OPAMP, when using OPAMP as an integral function, use the circuit shown in Figure 8.

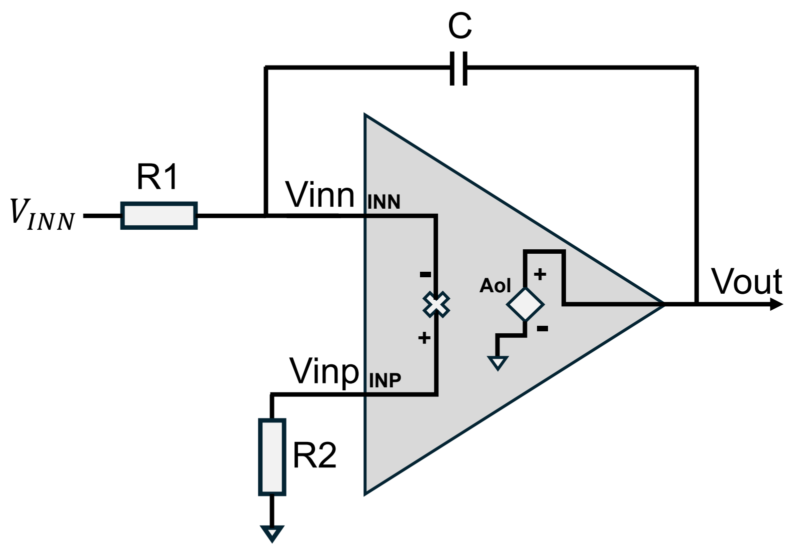

Figure 7. Integral circuit of OPAMP

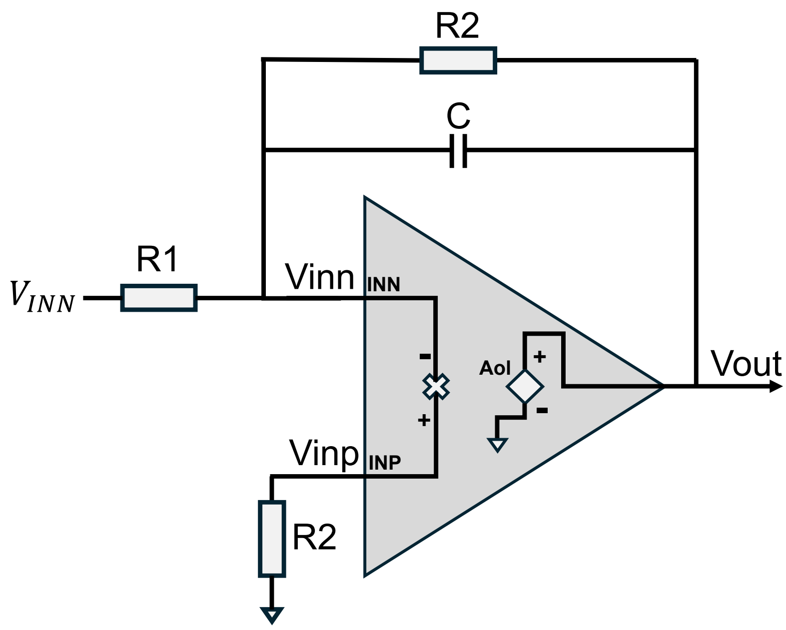

Figure 8. Stable integral circuit of OPAMP

2.7 Single to different OPAMP circuit

Figure 9 shows a circuit, which uses two OPAMPs to achieve single end input to differential output. Based on the principle of OPAMP, derive Equation (25) and Equation (26) as follows:

$$V_{inn1} = V_{inp1} \tag{25}$$

$$V_p = V_{in} \tag{26}$$

Also, derive Equation (27) and Equation (28) as follows:

$$V_{inn1} = V_n \times \frac{R_1}{R_1 + R_2} + V_{in} \times \frac{R_2}{R_1 + R_2} \tag{27}$$

$$V_{inp1} = V_{cm} \tag{28}$$

From Equation (27) and Equation (28), derive Equation (29) and Equation (30) as follows:

$$V_{cm} = V_n \times \frac{R_1}{R_1 + R_2} + V_{in} \times \frac{R_2}{R_1 + R_2} \tag{29}$$

$$V_n = V_{cm} \times \frac{R_1 + R_2}{R_1} - V_{in} \times \frac{R_2}{R_1} \tag{30}$$

If $R_1 = R_2$ and V_{cm} is connected to GND, Equation (31) and Equation (32) are derived as follows:

$$V_n = -V_{in} \tag{31}$$

$$V_p = -V_n \tag{32}$$

Therefore, from the circuit shown in Figure 9, the single signal V_{in} can be transferred to differential signals V_p and V_n. The V_p and V_n can be used as the differential ADC inputs.

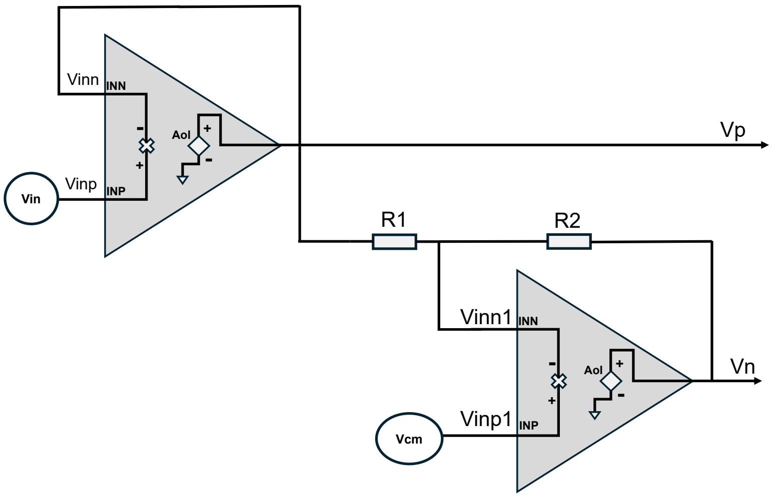

Figure 9. Single end to differential circuit

3 MCX A3xx OPAMP usage

Figure 10 shows the block diagram of MCX A3xx OPAMP typical use case.

MCX A3xx OPAMP integrates compensation capacitors to accommodate different gain values. The OPAMP_CTRL[OPA_CC_SEL] register is used to configure these different gains. Also, the configuration of the compensation capacitors ensures that the GBW of the OPAMP is maintained at 4 MHz.

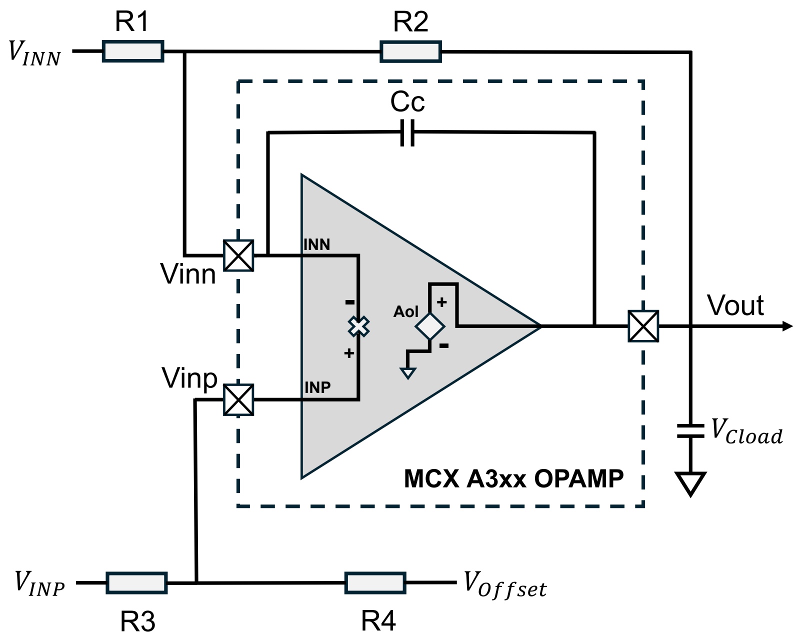

Figure 10. MCX A3xx OPAMP block diagram

Table 1 lists some key parameters of the MCX A3xx OPAMP.

Table 1. MCX A3xx OPAMP parameter

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{cm}	Input common mode voltage range		0		V_{vdda} - 1	V
V_{out}	Output voltage range		0.15		V_{vdda} - 0.15	V
V_{os}	Input offset voltage		-7	0	7	mV
CMRR	Input common mode rejection ratio			80		dB
PSRR	Power supply rejection ratio			80		dB
UGB	Unity gain bandwidth	cc config = 2'b00, gain = 2		8		MHz
		cc config = 2'b01, gain = 4		16		MHz
		cc config = 2'b10, gain = 8		32		MHz
		cc config = 2'b11, gain = 16		64		MHz
A_v	DC open-loop voltage gain			95		dB
PM	Phase margin			60		deg
T_{settle}	Settling time			450		ns
SR	Slew rate	C_{load} = 20 pF		10		V/us
V_n	Voltage noise density @ 1 kHz	Gain = 1		150		nv/sqrtHz
Z_{out}	Closed-loop output impedance	cc config = 2'b00, f = 200 kHz		1.703		Ω
		cc config = 2'b01, f = 200 kHz		14.72		Ω
		cc config = 2'b00, f = 1 MHz		8.514		Ω
		cc config = 2'b01, f = 1 MHz		73.47		Ω

CAUTION: *Due to the limitations of the MCX A3xx OPAMP instructor, the parasitic capacitance at the OPAMP_OUT pin must be under 2 pF in voltage follower mode.*

If the parasitic capacitance value exceeds 2 pF, add a 3 kΩ resistor between the OPAMP_OUT pin and GND. For detailed connection, refer to Figure 10. When using the circuit shown in Figure 11, the parasitic capacitance value can be up to 10 pF. Also, set the OPAMP_CTRL[OPA_CC_SEL] register to 01 to enhance the stability of the OPAMP.

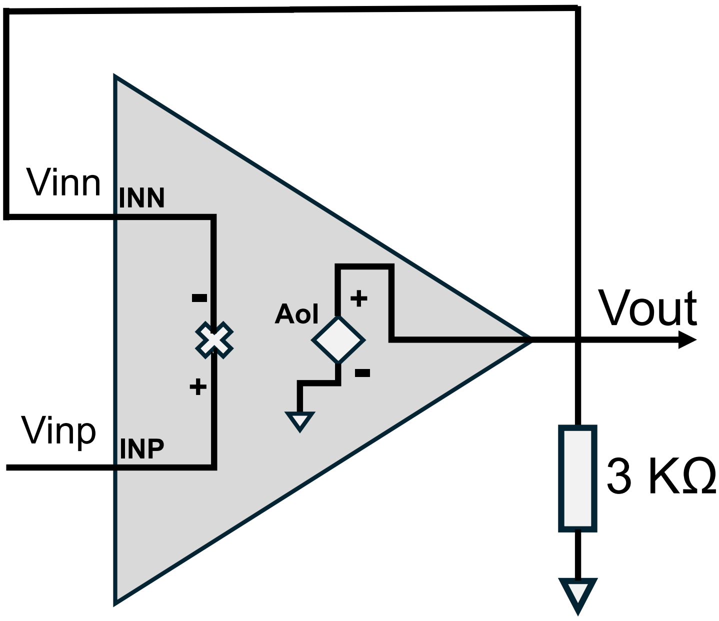

Figure 11. MCX A3xx OPAMP voltage follower circuit

4 Revision history

Table 2 summarizes revisions to this document.

Table 2. Revision history

Document ID	Release date	Description
AN14682 v.1.0	16 July 2025	Initial public release

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