AN14190

OPAMP usage on MCXN947

Rev. 1.0 — 20 January 2024 **Application note**

Document information

Information	Content
Keywords	AN14190, OPAMP, motor control, power management, amplify
Abstract	This application note describes the functions of OPAMP module and how to use OPAMP features on MCXN947.

1 Introduction to MCX OPAMP

OPAMP is widely used in motor control, power management applications, which can be used for current and voltage detection, small signal amplifiers, and so on. The MCXN947 microcontroller integrates three individual OPAMP modules. The OPAMP module in MCXN947 can be configured to Low Noise mode or High-Speed mode. Both positive and negative gains are programmable. In addition, both positive and negative gains can be configured to the Buffer mode so that the user can connect external resistors to configure the gains and functions. The MCXN947 OPAMP module provides two positive input pins. The trigger controller can switch these two pins. In addition, the OPAMP positive reference voltage, negative gain resistor, ladder voltage output, and OPAMP output can be connected to ADC. The positive reference voltage can be connected to VDDA2/2, DAC, VERF0, and VERF1V internally. Figure 1 shows the MCX N947 OPAMP module block diagram.

This application note describes the functions of OPAMP module and how to use OPAMP features on MCXN947.

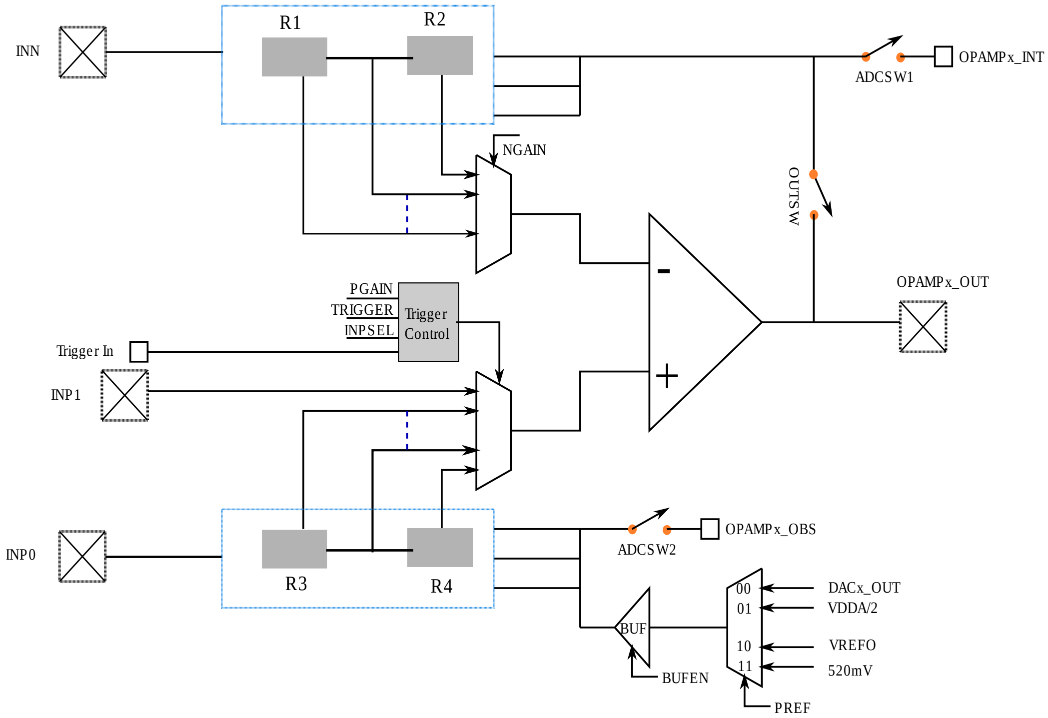

Figure 1. MCXN947 OPAMP module block diagram

2 Typical kinds of OPAMP

OPAMP is an electronic integrated circuit, which contains a multistage amplifier circuit. Its input stage is a differential amplifier circuit. It has high input resistance and the ability to suppress zero drift.

An ideal OPAMP contains the following characteristics:

- Input bias current $I_B = 0$
- Input offset voltage $V_E = 0$
- Input impedance $Z_{IN} = \infty$
- Output impedance $Z_{OUT} = 0$
- Gain $a = \infty$

To simplify the analysis, see Figure 2 for an ideal OPAMP.

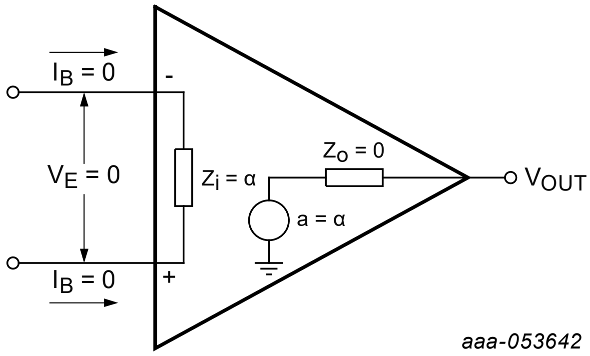

Figure 2. Ideal OPAMP

2.1 Voltage follower OPAMP

Figure 3 shows the connection of the voltage follower OPAMP.

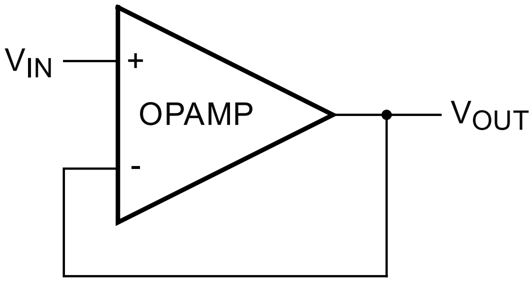

Figure 3. Voltage follower OPAMP

In the non-inverting OPAMP, if let the R2 = 0 and remove R1, we can get the equation (1) as below:

$$V_{OUT} = V_{IN} \tag{1}$$

To perform impedance adaptation on input signals, the circuit uses OPAMP as a follower buffer.

2.2 Non-inverting OPAMP

Figure 4 shows the non-inverting OPAMP connection.

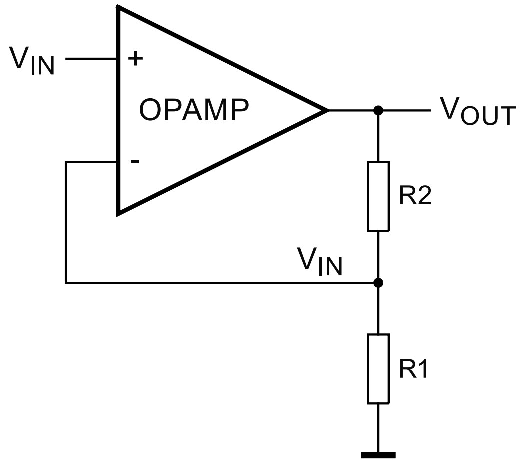

Figure 4. Non-inverting OPAMP

Non-inverting OPAMP has the input signal connected to its positive input. According to the ideal OPAMP assumptions, when input current I_B = 0 and input offset voltage V_E = 0, we get the equation as below:

$$V_{IN} = V_{OUT} \frac{R_1}{R_1+R_2} \quad (2)$$

Then:

$$V_{OUT} = V_{IN} \left(1+ \frac{R_2}{R_1}\right) \quad (3)$$

The output signal is the amplified signal and non-inverted from the input signal. The circuit input impedance is an infinite impedance.

2.3 Inverting OPAMP

Figure 5 shows the inverting OPAMP connection.

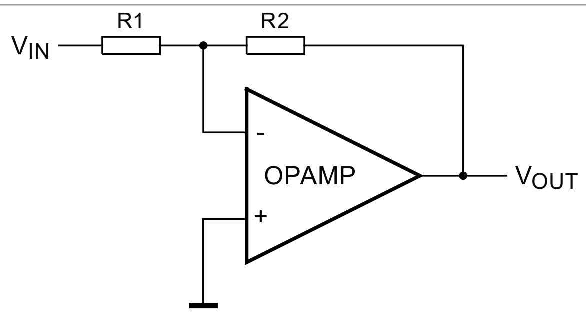

Figure 5. Inverting OPAMP

Inverting OPAMP has the input signal connected to its negative input. According to the ideal OPAMP assumptions, if input current I_B = 0 and input offset voltage V_E = 0, we get the equation as below:

$$\frac{V_{IN}}{R_1} = -\frac{V_{OUT}}{R_2} \quad (4)$$

Then:

$$V_{OUT} = \left(-\frac{R_2}{R_1}\right) V_{IN} \quad (5)$$

The output signal is the amplified signal and inverted from the input signal.

2.4 Differential OPAMP

Figure 6 shows the differential OPAMP connection.

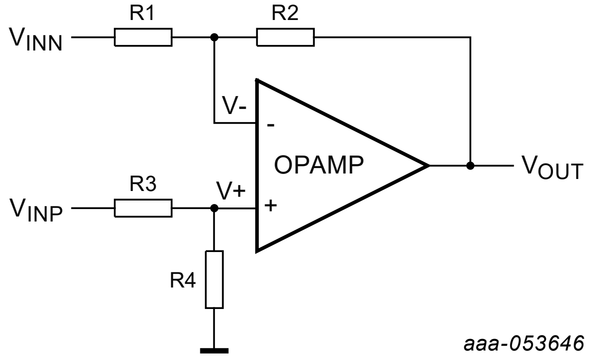

Figure 6. Differential OPAMP

Differential OPAMP amplifies the voltage difference between input signals. According to the ideal OPAMP assumptions, if input current I_B = 0 and input offset voltage V_E = 0, we get the equation as below:

From:

$$\frac{V_{INP} - V_+}{R_3} = \frac{V_+}{R_4} \quad (6)$$

We can get:

$$V_+ = \frac{R_4}{R_3 + R_4} V_{INP} \quad (7)$$

From:

$$\frac{V_- - V_{INN}}{R_1} = \frac{V_{OUT} - V_-}{R_2} \quad (8)$$

We can get:

$$V_{OUT} = \frac{R_1 + R_2}{R_1} V_- - \frac{R_2}{R_1} V_{INN} \quad (9)$$

According to V+ = V-, from Equation 7 and Equation 9, we can get:

$$V_{OUT} = \frac{R_1 + R_2}{R_1} * \frac{R_4}{R_3 + R_4} V_{INP} - \frac{R_2}{R_1} V_{INN} \quad (10)$$

If R1 = R3, R2 = R4, then:

$$V_{OUT} = \frac{R_2}{R_1}\left(V_{INP} - V_{INN}\right) \quad (11)$$

In the circuit, the differential signal, (V_{INP} – V_{INN}), is multiplied by the stage gain. The circuit is a differential amplifier. It amplifies only the differential portion of the input signal and rejects the common mode portion of the input signal.

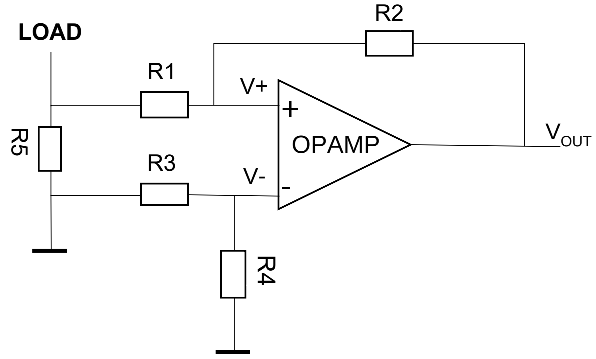

Figure 7. Current sense circuit

Figure 7 shows the differential OPAMP use case. It can be used to detect and calculate the load current.

2.5 OPAMP integral circuit

Figure 8 shows the OPAMP to be used in an integral circuit.

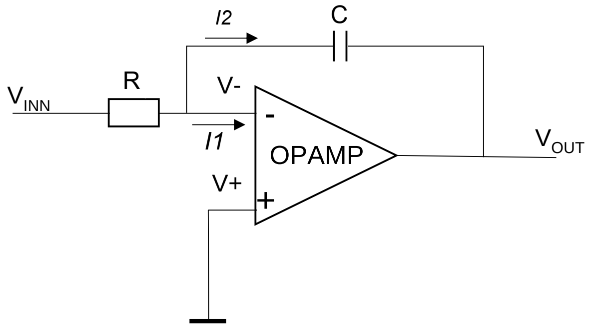

Figure 8. OPAMP integral circuit

Based on the virtual short circuit and virtual open circuit princple as shown in equation (12) and (13):

$$V_{+} = V_{-} \tag{12}$$

$$I_1 = 0 \tag{13}$$

We get equation (14), as below:

$$I_2 = I_1 = \frac{V_{INN}}{R} \tag{14}$$

Assume that the initial voltage of the capacitor is zero, we get equation (15):

$$V_{-} - V_{OUT} = \frac{1}{C} \int I_2 d_t = \frac{1}{C} \int \frac{V_{INN}}{R} d_t \tag{15}$$

The equation (16) shows the V_{OUT} value in an OPAMP out pin:

$$V_{OUT} = -\frac{1}{RC} \int V_{INN} d_t \tag{16}$$

2.6 OPAMP differentiating circuit

Figure 9 shows the OPAMP to be used in a differential circuit.

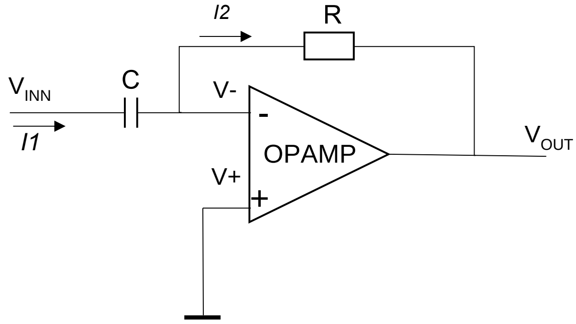

Figure 9. OPAMP differentiating circuit

Based on the virtual short circuit and virtual open circuit principle, we get equation:

$$V_{OUT} = -I_2 * R = -I_1 * R = -RC\frac{dV_{INN}}{d_t} \quad (17)$$

The equation (18) shows the V_{OUT} value in OPAMP out pin:

$$V_{OUT} = -RC\frac{dV_{INN}}{d_t} \quad (18)$$

3 Demo for OPAMP on MCXN947

In this section, we use FRDM-MCXN947 board to do OPAMP function test and the test demo based on SDK_2_14_0_FRDM-MCXN947.

3.1 Demo platform

This section describes the hardware and software requirements.

3.1.1 Hardware

The demo is developed on the FRDM-MCXN947 board. Figure 10 shows the MCXN947 FRDM board.

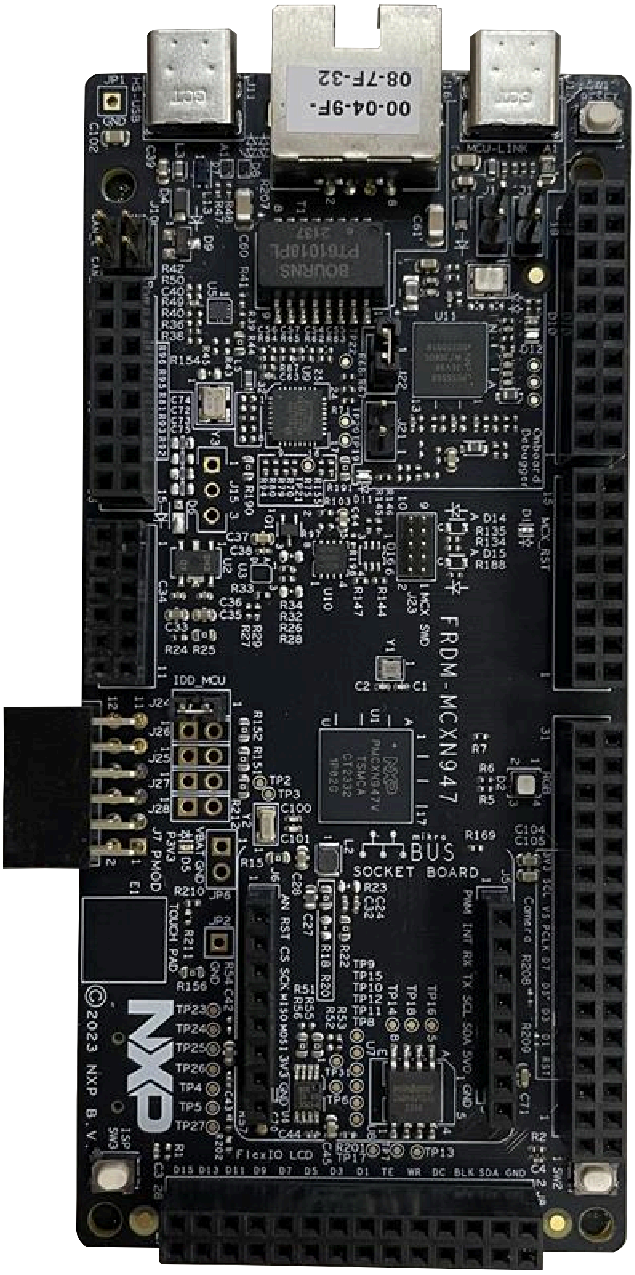

Figure 10. FRDM-MCXN947 board

3.1.2 Software

- Software: SDK_2_14_0_FRDM-MCXN947
- IDE: MDK5.37

4 OPAMP module test

The OPAMP module has several functions, such as voltage follower, non-inverting, inverting, differential, and so on. This section introduces how to set up OPAMP functions.

4.1 Follower test

Figure 11 shows the follower test hardware settings. To test this function, connect J1-4 with J4-1 on MCXN947-FRDM board. To connect DAC0_OUT with OPAMP0_INP0, measure the J8-20 voltage from OPAMP0_OUT pin.

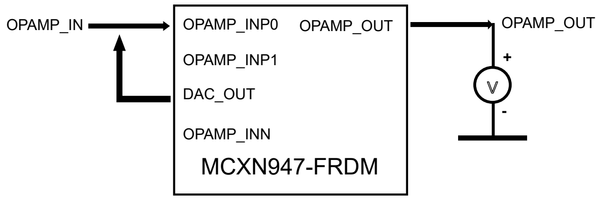

Figure 11. MCXN947-FRDM hardware settings

The following code shows the voltage follower OPAMP test code.

```
void OPAMP_Configuration(void)
{
    opamp_config_t config;
    OPAMP_GetDefaultConfig(&config);
    config.PosInputChannelSelection = kOPAMP_PosInputChannel0;
    config.posGain = kOPAMP_PosGainNonInvert2X;
    config.negGain = kOPAMP_NegGainBufferMode;
    config.enable = true;
    config.enableRefBuffer = false;
    OPAMP_Init(DEMO_OPAMP_BASEADDR, &config);
}
```

4.2 Non-inverting test

The hardware settings is same as shown in Figure 11. Connect J1-4 with J4-1 on FRDM-MCXN947 board. To connect DAC0_OUT with OPAMP0_INP0, measure the J8-20 voltage from OPAMP0_OUT pin.

The following code shows the non-inverting OPAMP test code.

```
void OPAMP_Configuration(void)
{
    opamp_config_t config;
    OPAMP_GetDefaultConfig(&config);
    config.PosInputChannelSelection = kOPAMP_PosInputChannel0;
    config.posGain = kOPAMP_PosGainNonInvertDisableBuffer2X;
    config.negGain = kOPAMP_NegGainInvert1X;
    config.enable = true;
    config.enableRefBuffer = false;
    OPAMP_Init(DEMO_OPAMP_BASEADDR, &config);
}
```

4.3 Differential test

The hardware settings is same as shown in Figure 11. Connect J1-4 with J4-1 on MCXN947-FRDM board. To connect DAC0_OUT with OPAMP0_INP0, measure the J8-20 voltage from OPAMP0_OUT pin.

The following code shows the differential OPAMP test code.

```
void OPAMP_Configuration(void)
{
    opamp_config_t config;
```

```
    OPAMP_GetDefaultConfig(&config);
    config.PosInputChannelSelection = kOPAMP_PosInputChannel0;
    config.posGain = kOPAMP_PosGainNonInvert1X;
    config.negGain = kOPAMP_NegGainInvert1X;
    config.posRefVoltage = kOPAMP_PosRefVoltVrefh3;
    config.enable = true;
    config.enableRefBuffer = true;
    OPAMP_Init(DEMO_OPAMP_BASEADDR, &config);
}
```

5 Note about the source code in the document

Example code shown in this document has the following copyright and BSD-3-Clause license:

6 Revision history

Table 1 summarizes the revisions done to this document.

Table 1. Revision history

Document ID	Release date	Description
AN14190 v.1.0	20 January 2024	Initial public release

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