# Setting ECO parameters in XMC7000 MCU family

## About this document

### Scope and purpose

XMC7000 MCU family supports a highly accurate clock system using the external crystal oscillator (ECO). ECOs are available with a crystal unit and ceramic resonator. See the datasheet for the frequency ranges supported by the ECO.

This guide describes how to connect a crystal unit and ceramic resonator to the XMC7000 device, and how to calculate and set the XMC7000 parameters using the ECO Trim Calculator.

### Intended audience

This document is intended for anyone using the XMC7000 MCU family to determine ECO trim parameters.

## Table of contents

# 1 Overview

**Figure 1** shows the configuration circuit of the XMC7000 device. This circuit supports both crystal unit and ceramic resonator.

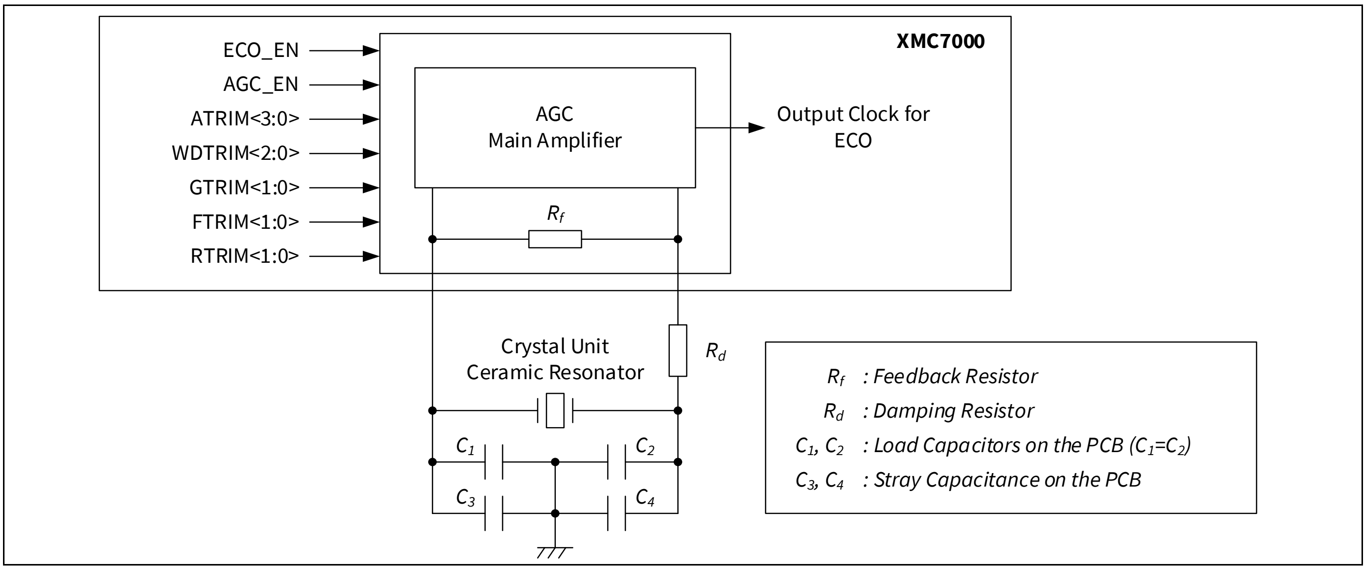


**Figure 1 Block diagram of the ECO circuit**

The feedback resistor $(R_f)$ is already implemented in the XMC7000 device. A damping resistance $(R_d)$ is normally used to limit the XTAL drive level when a CMOS inverter is used as the main amplifier. However, in XMC7000, a CMOS inverter is not used as the main amplifier. So, you do not need to use a damping resistor.

Determine the load capacitances $(C_1, C_2)$ using a crystal unit/ceramic resonator and XMC7000 matching test. See **Matching test**. $C_3$ and $C_4$ are the stray capacitances. Stray capacitance $(C_s)$ is the capacitance caused by the physical structure of electronic circuits. See **Stray capacitance** for the stray capacitance. Here, it is assumed that the MCU internal wiring capacitance and the MCU pin capacitance are also included in the stray capacitance.

The load capacitance on the PCB can be calculated from $C_1, C_2, C_3$ and $C_4$ as shown in **Equation 1**.

$$Load\ Capacitance = \frac{C_1 \times C_2}{C_1 + C_2} + \frac{C_3 \times C_4}{C_3 + C_4} = \frac{C_1 \times C_2}{C_1 + C_2} + C_s \qquad \text{Equation 1}$$

In general, the frequency deviation is the smallest when the load capacitance on the PCB and the parallel load capacitance described in the crystal unit or ceramic resonator datasheets are the same.

XMC7000 device supports a wide frequency range for ECO. So, the XMC7000 device can set the trimming parameters that control the oscillator according to the crystal unit and ceramic resonator.

The method to determine the parameters differs between the crystal unit and ceramic resonator. For more details on how to determine and set the parameters, see **Setting the GTRIM**.

**Table 1** lists the related ECO parameters of the XMC7000 device.

**Table 1 ECO parameters of XMC7000**

| Parameters | Name | Description | Related register |
|---|---|---|---|
| ATRIM | Amplitude TRIM | Controls the crystal drive level when automatic gain control (AGC) is enabled | CLK_ECO_CONFIG2 |
| WDTRIM | WatchDog TRIM | Controls the threshold of Crystal Unit Magnitude where the ECO block releases the clock to the system | CLK_ECO_CONFIG2 |
| GTRIM | Amplifier Gain TRIM | Controls for amplifier gain | CLK_ECO_CONFIG2 |
| FTRIM | LPF Frequency TRIM | Tunes the low-pass filter between the ECO_IN pin and the amplifier to prevent the amplification of harmonics of the intended crystal frequency | CLK_ECO_CONFIG2 |
| RTRIM | Feedback Resistor TRIM | Selects the feedback resistor according to the frequency of the crystal unit | CLK_ECO_CONFIG2 |
| AGC_EN | AGC ENable | Enables/disables the AGC circuit | CLK_ECO_CONFIG |
| ECO_EN | ECO ENable | Enables/disables the ECO clock source | CLK_ECO_CONFIG |

*Note: These parameters are set by software.*

By setting these parameters, as shown in **Figure 2**, XMC7000 device gets the internal ECO clock output.

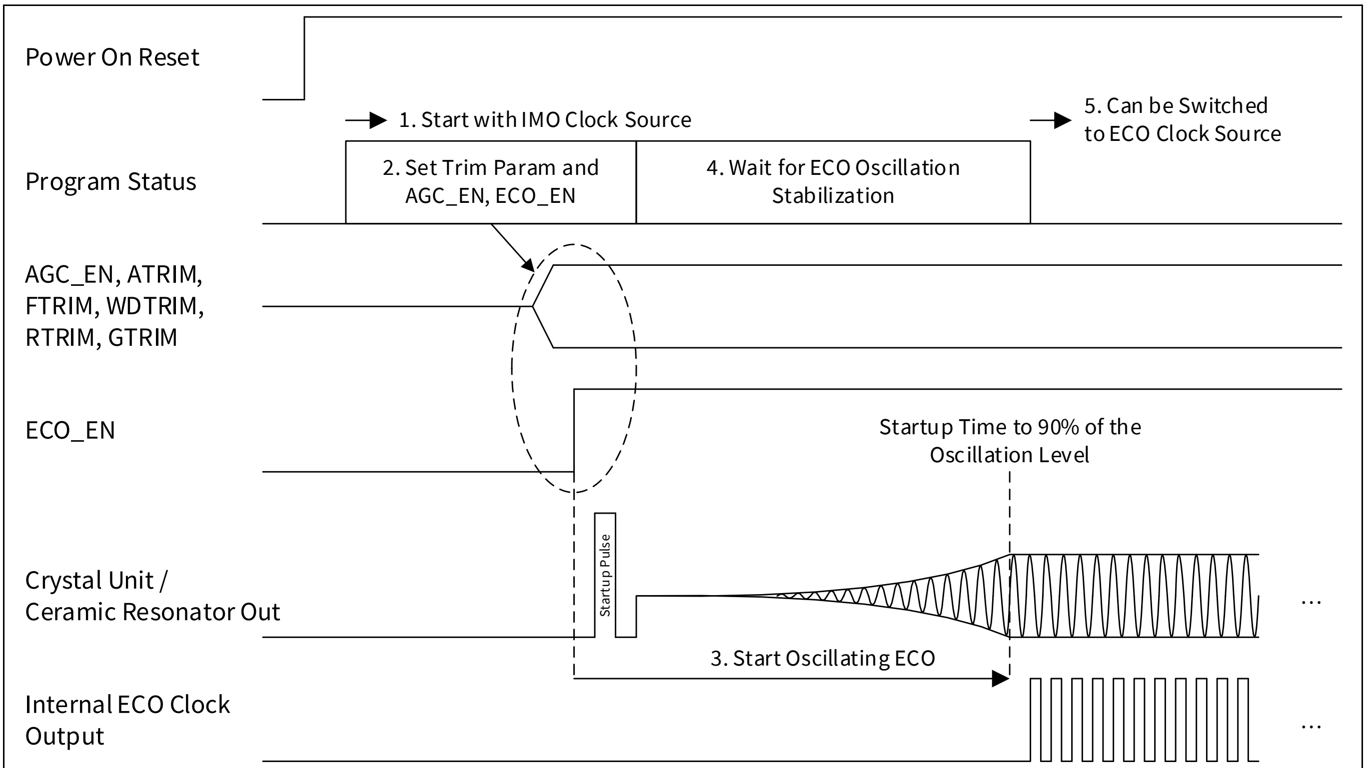


**Figure 2 ECO operation and setting flow in a XMC7000 device**

The following is the operation outline:

1. After powering on, the program starts with the IMO clock source.
2. The program sets the trim parameters (ATRIM, WDTRIM, FTRIM, RTRIM, and GTRIM) and AGC_EN, and then activates ECO_EN.
3. After the start-up pulse is output, the XMC7000 device starts oscillating the ECO according to the set parameters.
4. When the oscillation is stable (defined as the time to reach 90% of the oscillation level under steady state conditions), the XMC7000 device outputs the clock based on the ECO clock source. You can check the ECO_READY bit in the CLK_ECO_STATUS register to see whether the oscillation has stabilized.
5. After the oscillation stabilizes, the clock source can be switched to the ECO.

## 2 Parameters related to ECO

The parameters related to ECO are calculated from the specifications of the crystal unit and ceramic resonator.

The following are the required specifications:

- $f$ : Fundamental frequency
- $D_L$ : Maximum drive level
- $ESR(R_{1\_xtal})$: Equivalent series resistance (ESR)
- $C_{0\_xtal}$ : Shunt capacitance
- $C_L$ : Parallel load capacitance
- $|-R|$: The crystal unit vendor's recommended value of negative resistance.

*Note: These values are decided in consultation with the crystal unit vendor.*

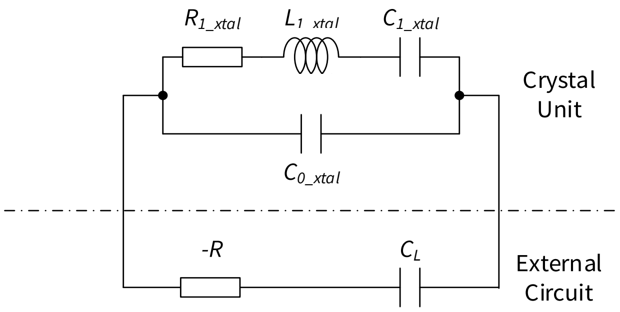


**Figure 3 Equivalent circuit of crystal unit/ceramic resonator and external circuit**

For details on the specifications, see the datasheets of the crystal unit and ceramic resonator. Check with the vendor for the specifications that are not in the datasheet.

In the ceramic resonator, $D_L$ and $|-R|$ are not specified. This is because increasing or decreasing $D_L$ and $|-R|$ has little effect on the characteristics of the ceramic resonator.

**Figure 4** shows the parameters related to the ECO calculation flow for the crystal unit and ceramic resonator.

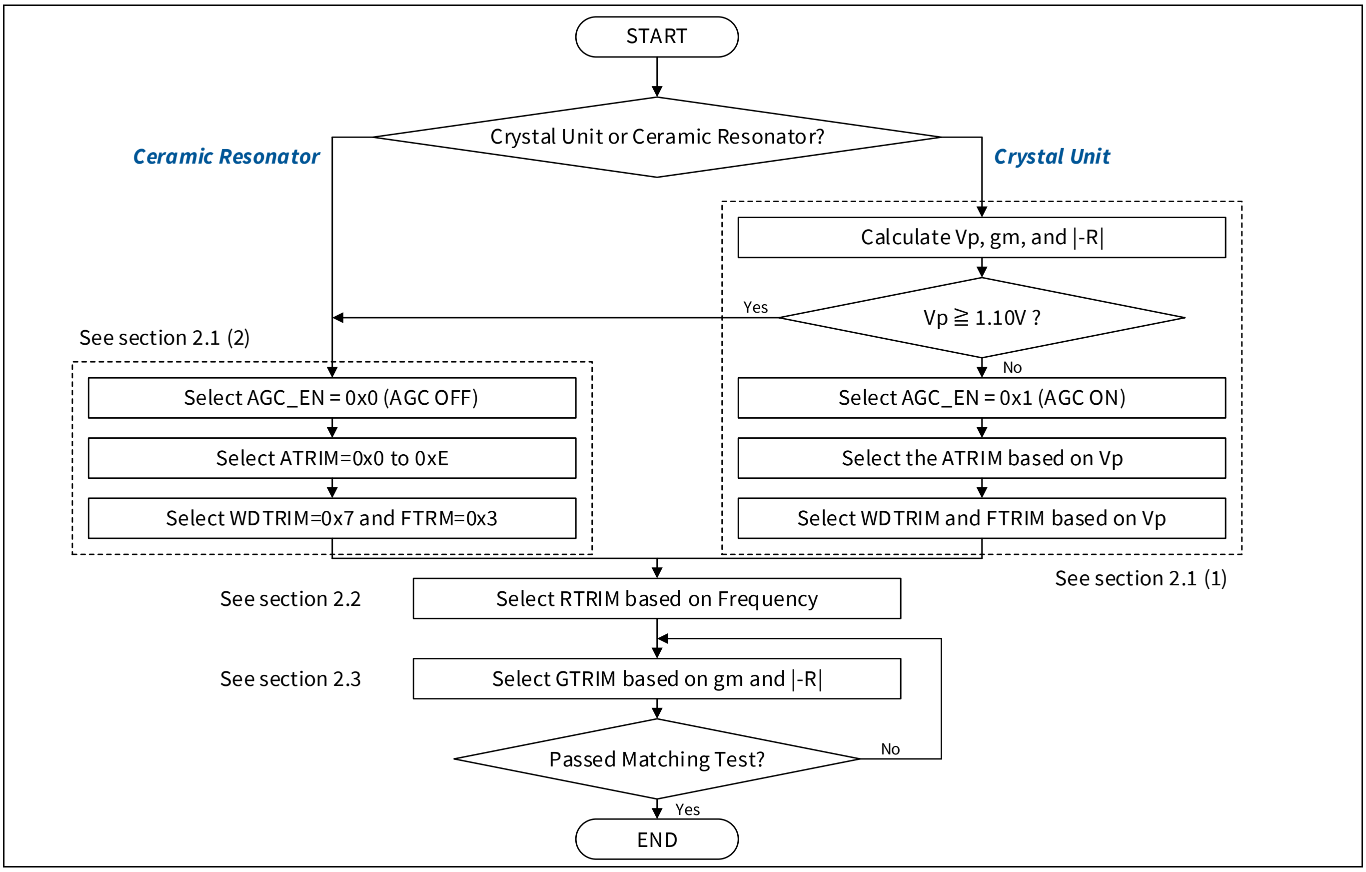


**Figure 4** Determining basic flow for ECO parameters

## 2.1 Setting AGC_EN, ATRIM, WDTRIM, and FTRIM

### 1. AGC_EN, ATRIM, WDTRIM, and FTRIM settings for the crystal unit

The value of AGC_EN, ATRIM, WDTRIM, FTRIM is determined from the Max Peak Value $(V_p)$. $V_p$ can be calculated using **Equation 2**.

$$Max\ Peak\ Value(V_p) = \frac{\sqrt{\frac{D_L}{2ESR}}}{\pi f (C_0 + C_L)} \qquad \text{Equation 2}$$

**Table 2** AGC_EN, ATRIM, WDTRIM, and FTRIM settings for the crystal unit

<table>
<tr><th>$V_p$ (V)</th><th>AGC_EN</th><th>ATRIM</th><th>WDTRIM</th><th>FTRIM</th></tr>
<tr><td>$0.50 \le V_p < 0.55$</td><td>0x1</td><td>0x4</td><td rowspan="2">0x2</td><td rowspan="7">0x3</td></tr>
<tr><td>$0.55 \le V_p < 0.60$</td><td>0x1</td><td>0x5</td></tr>
<tr><td>$0.60 \le V_p < 0.65$</td><td>0x1</td><td>0x6</td><td rowspan="2">0x3</td></tr>
<tr><td>$0.65 \le V_p < 0.70$</td><td>0x1</td><td>0x7</td></tr>
<tr><td>$0.70 \le V_p < 0.75$</td><td>0x1</td><td>0x8</td><td rowspan="2">0x4</td></tr>
<tr><td>$0.75 \le V_p < 0.80$</td><td>0x1</td><td>0x9</td></tr>
<tr><td>$0.80 \le V_p < 0.85$</td><td>0x1</td><td>0xA</td><td>0x5</td></tr>
</table>

<table>
<tr><th>$V_p$ (V)</th><th>AGC_EN</th><th>ATRIM</th><th>WDTRIM</th><th>FTRIM</th></tr>
<tr><td>$0.85 \le V_p < 0.90$</td><td>0x1</td><td>0xB</td><td></td><td rowspan="6"></td></tr>
<tr><td>$0.90 \le V_p < 0.95$</td><td>0x1</td><td>0xC</td><td rowspan="2">0x6</td></tr>
<tr><td>$0.95 \le V_p < 1.00$</td><td>0x1</td><td>0xD</td></tr>
<tr><td>$1.00 \le V_p < 1.05$</td><td>0x1</td><td>0xE</td><td rowspan="2">0x7</td></tr>
<tr><td>$1.05 \le V_p < 1.10$</td><td>0x1</td><td>0xF</td></tr>
<tr><td>$1.10 \le V_p$</td><td>0x0</td><td>0x0-0xE [1]</td><td>0x7</td></tr>
</table>

The calculated $V_p$ is a reference value for not exceeding the drive level.

When AGC_EN='0 (OFF)', XMC7000 does not restrict the oscillation magnitude; therefore, the calculated $V_p$ does not have any effect.

Finally, the values of AGC_EN, ATRIM, WDTRIM, and FTRIM are confirmed by the matching test.

**2. AGC_EN, ATRIM, WDTRIM, and FTRIM settings for the ceramic resonator**

The values of AGC_EN, ATRIM, WDTRIM, and FTRIM are fixed. Use the value for $1.10 \le V_p$.

**Table 3 AGC_EN, ATRIM, WDTRIM, and FTRIM settings for the crystal unit and ceramic resonator**

| $V_p$ (V) | AGC_EN | ATRIM | WDTRIM | FTRIM |
|---|---|---|---|---|
| $1.10 \le V_p$ | 0x0 | 0x0-0xE [1] | 0x7 | 0x3 |

## 2.2 Setting RTRIM

The RTRIM value is determined by $f$ as shown in **Table 4**. Determine the crystal unit and ceramic resonator in the same way.

**Table 4 RTRIM settings for the crystal unit and ceramic resonator**

| Fundamental frequency (MHz) | RTRIM |
|---|---|
| $28.6 < f$ | 0x0 |
| $23.33 < f \le 28.6$ | 0x1 |
| $16.5 < f \le 23.33$ | 0x2 |
| $f \le 16.5$ | 0x3 |

[1] Select any value from 0x0 to 0xE.

## 2.3 Setting the GTRIM value

The value of GTRIM is determined by $g_m$. $g_m$ can be calculated using **Equation 3**.

$$Transconductance(g_m) > 20 \times ESR \times (2\pi \times f)^2 \times (C_0 + C_L)^2 \quad \text{Equation 3}$$

**Table 5 GTRIM settings for the crystal unit and ceramic resonator**

| $g_m$ (mA/V) | GTRIM |
|---|---|
| $0.0 \leq g_m < 2.2$ | 0x0 |
| $2.2 \leq g_m < 4.4$ | 0x1 |
| $4.4 \leq g_m < 6.6$ | 0x2 |
| $6.6 \leq g_m < 8.8$ | 0x3 |
| $8.8 \leq g_m < 11$ | 0x4 |
| $11.0 \leq g_m < 13.2$ | 0x5 |
| $13.2 \leq g_m < 15.4$ | 0x6 |
| $15.4 \leq g_m \leq 17.6$ | 0x7 |

*Note:*

1. *The $g_m$ calculated by **Equation 3** is based on ESR*5. If $-R$ requires more than ESR*10, double gm.*
2. *If the calculated $g_m$ is 17.6 or higher, you will not get the TRIM value. This means that the ceramic resonator oscillation cannot be guaranteed. Consider using a different crystal unit and ceramic resonator.*

# 3 Determining the ECO parameters with the ECO trim calculator

## 3.1 ECO trim calculator example for the crystal unit

This section describes the parameter calculation method for the crystal unit with the following specifications:

- $f$: 16 $[MHz]$
- $D_L$: 300 $[\mu W]$
- $ESR$: 50 $[ohm]$
- $C_{0\_xtal}$: 1 $[pF]$
- $C_L$: 8 $[pF]$
- $|-R|$: $Over$ 500 $[ohm]$ (10 times the ESR, $ESR \times 10 = 50 \times 10 = 500$)

Enter the above specifications in the cells, highlighted in yellow, of the ECO trim calculator.

| Parameter | Value | | Max Peak Value ($V_p$) [V] | Transconductance ($g_m$) [mA/V] |
|---|---|---|---|---|
| f (Fundamental Frequency) | 16.000 | [MHz] | 3.829 | 3.837 |
| $D_L$ (Maximum Drive Level) | 300.0 | [uW] | | |
| ESR (Equivalent Series Resistance, R1_max) | 50.0 | [ohm] | | |
| $C_{0\_xtal}$ (Shunt Capacitance) | 1.000 | [pF] | | |
| $C_L$ (Parallel Load Capacitance) | 8.000 | [pF] | | |
| Vendor recommended value of \|- R\| | 500 | [ohm] | | |

The ECO trim calculator calculates the XMC7000 parameters based on the entered specifications and automatically displays the values in cells highlighted in orange.

**[ATRIM, WDTRIM and FTRIM Settings]**

| $V_P$ [V] | ATRIM | WDTRIM | FTRIM |
|---|---|---|---|
| 0.50 ≤ $V_P$ < 0.55 | 0x4 | 0X2 | 0x3 |
| 0.55 ≤ $V_P$ < 0.60 | 0x5 | | |
| 0.60 ≤ $V_P$ < 0.65 | 0x6 | 0x3 | |
| 0.65 ≤ $V_P$ < 0.70 | 0x7 | | |
| 0.70 ≤ $V_P$ < 0.75 | 0x8 | 0x4 | 0x3 |
| 0.75 ≤ $V_P$ < 0.80 | 0x9 | | |
| 0.80 ≤ $V_P$ < 0.85 | 0xA | 0x5 | |
| 0.85 ≤ $V_P$ < 0.90 | 0xB | | |
| 0.90 ≤ $V_P$ < 0.95 | 0xC | 0x6 | 0x3 |
| 0.95 ≤ $V_P$ < 1.00 | 0xD | | |
| 1.00 ≤ $V_P$ < 1.05 | 0xE | 0x7 | |
| 1.05 ≤ $V_P$ < 1.10 | 0xF | | |
| 1.10 ≤ $V_P$ | 0x0 - 0xE | 0x7 | 0x3 |

(Note) Reconsider to use another Crystal Unit if ATRIM, WDTRIM, FTRIM cells are not highlighted.

**[AGC Enable]**

| $V_P$ [V] | AGC_EN |
|---|---|
| $V_P$ < 1.10 | 0x1 (ON) |
| 1.10 ≤ $V_P$ | 0x0 (OFF) |

**[GTRIM Settings]**

| $g_m$ [mA/V] | GTRIM | Calculated Negative Resistance \|-R\| for TRM [kohm] |
|---|---|---|
| 0.0 ≤ $g_m$ < 2.2 | 0x0 | 0.000 to 0.672 |
| 2.2 ≤ $g_m$ < 4.4 | 0x1 | 0.672 to 1.344 |
| 4.4 ≤ $g_m$ < 6.6 | 0x2 | 1.344 to 2.016 |
| 6.6 ≤ $g_m$ < 8.8 | 0x3 | 2.016 to 2.687 |
| 8.8 ≤ $g_m$ < 11.0 | 0x4 | 2.687 to 3.359 |
| 11.0 ≤ $g_m$ < 13.2 | 0x5 | 3.359 to 4.031 |
| 13.2 ≤ $g_m$ < 15.4 | 0x6 | 4.031 to 4.703 |
| 15.4 ≤ $g_m$ < 17.6 | 0x7 | 4.703 to 5.375 |

(Note) Reconsider to use another Crystal Unit if any GTRIM cells are not highlighted.

**[RTRIM Settings]**

| Fundamental Frequency f (MHz) | RTRIM |
|---|---|
| 28.6 < f | 0x0 |
| 23.33 < f ≤ 28.6 | 0x1 |
| 16.5 < f ≤ 23.33 | 0x2 |
| f ≤ 16.5 | 0x3 |

*Note:*

1. *The negative resistance value changes with temperature.*
2. *These trim values must be evaluated and determined in a matching test. If the measured negative resistance value is small, increase GTRIM and measure the negative resistance value again.*
3. *When the calculated $V_p$ is less than 0.5, ATRIM, WDTRIM, and FTRIM cells will not be highlighted. Reconsider using a different Crystal Unit.*
4. *When the calculated $g_m$ is 17.6 or higher, none of the GTRIM cells is highlighted. Reconsider using a different crystal unit.*
5. *The specified crystal Maximum Drive Level ($D_L$): 300 µW does not mean that the crystal actually consumes 300 µW. The XMC7000 ECO amplifier is not rail-to-rail driven. Limit the maximum peak value to approximately 1.6–1.8 V even when AGC_EN = 0. This corresponds to $D_L$ from 55 µW to 65 µW. (You can see that the Max Peak Value is 1.782 V by entering $D_L$ = 65 µW in the ECO trim calculator.) Note that if you add $R_d$, the amplitude and power consumption will change and the XMC7000 MCU may not work.*

The following are the calculated parameters:

- AGC_EN = 0x0
- ATRIM = 0x0 (It is okay to select any value from 0x0 to 0xE)
- WDTRIM = 0x7
- FTRIM = 0x3
- GTRIM = 0x1
- RTRIM = 0x3

## 3.2 ECO trim calculator example for the ceramic resonator

This section describes the parameter calculation method for the ceramic resonator with the following specifications:

- $f$: 20 $[MHz]$
- $ESR$: 40 $[ohm]$
- $C_{0\_xtal}$: 7.55 $[pF]$
- $C_L$: 7.5 $[pF]$

*Note: $D_L$ and $-R$ are not required by the ceramic resonator, so there is no need to enter them into the ECO trim calculator.*

Enter the above specifications in the cells, highlighted in green, of the ECO trim calculator.

| Parameter | Value | | Max Peak Value ($V_p$) [V] | Transconductance ($g_m$) [mA/V] |
|---|---|---|---|---|
| f (Fundamental Frequency) | 20.000 | [MHz] | - | 2.861 |
| $D_L$ (Maximum Drive Level) | - | [uW] | | |
| ESR (Equivalent Series Resistance) | 40.0 | [ohm] | | |
| $C_{0\_xtal}$ (Shunt Capacitance) | 7.550 | [pF] | | |
| $C_L$ (Parallel Load Capacitance) | 7.500 | [pF] | | |

The ECO trim calculator calculates the XMC7000 parameters based on the entered specifications and automatically displays the values in cells highlighted in blue.

**[ATRIM, WDTRIM and FTRIM Settings]**

| $V_P$ [V] | ATRIM | WDTRIM | FTRIM |
|---|---|---|---|
| 0.50 ≤ $V_P$ < 0.55 | 0x4 | 0x2 | 0x3 |
| 0.55 ≤ $V_P$ < 0.60 | 0x5 | | |
| 0.60 ≤ $V_P$ < 0.65 | 0x6 | 0x3 | |
| 0.65 ≤ $V_P$ < 0.70 | 0x7 | | |
| 0.70 ≤ $V_P$ < 0.75 | 0x8 | 0x4 | 0x3 |
| 0.75 ≤ $V_P$ < 0.80 | 0x9 | | |
| 0.80 ≤ $V_P$ < 0.85 | 0xA | 0x5 | |
| 0.85 ≤ $V_P$ < 0.90 | 0xB | | |
| 0.90 ≤ $V_P$ < 0.95 | 0xC | 0x6 | 0x3 |
| 0.95 ≤ $V_P$ < 1.00 | 0xD | | |
| 1.00 ≤ $V_P$ < 1.05 | 0xE | 0x7 | |
| 1.05 ≤ $V_P$ < 1.10 | 0xF | | |
| 1.10 ≤ $V_P$ | 0x0 - 0xE | 0x7 | 0x3 |

**[AGC Enable]**

| $V_P$ [V] | AGC_EN |
|---|---|
| $V_P$ < 1.10 | 0x1 (ON) |
| 1.10 ≤ $V_P$ | 0x0 (OFF) |

**[GTRIM Settings]**

| $g_m$ [mA/V] | GTRIM | Calculated Negative Resistance \|-R\| for TRM [kohm] |
|---|---|---|
| 0.0 ≤ $g_m$ < 2.2 | 0x0 | 0.000 to 0.154 |
| 2.2 ≤ $g_m$ < 4.4 | 0x1 | 0.154 to 0.308 |
| 4.4 ≤ $g_m$ < 6.6 | 0x2 | 0.308 to 0.461 |
| 6.6 ≤ $g_m$ < 8.8 | 0x3 | 0.461 to 0.615 |
| 8.8 ≤ $g_m$ < 11.0 | 0x4 | 0.615 to 0.769 |
| 11.0 ≤ $g_m$ < 13.2 | 0x5 | 0.769 to 0.923 |
| 13.2 ≤ $g_m$ < 15.4 | 0x6 | 0.923 to 1.076 |
| 15.4 ≤ $g_m$ < 17.6 | 0x7 | 1.076 to 1.230 |

(Note) Reconsider to use another Crystal Unit if any GTRIM cells are not highlighted.

**[RTRIM Settings]**

| Fundamental Frequency f (MHz) | RTRIM |
|---|---|
| 28.6 < f | 0x0 |
| 23.33 < f ≤ 28.6 | 0x1 |
| 16.5 < f ≤ 23.33 | 0x2 |
| f ≤ 16.5 | 0x3 |

*Note:*

1. *The negative resistance value changes with temperature.*
2. *These trim values must be evaluated and determined in a matching test.*
3. *When the calculated $g_m$ is 17.6 or higher, none of the GTRIM cells is highlighted. Reconsider using a different crystal unit.*

The following are the calculated parameters:

- AGC_EN = 0x0
- ATRIM = 0x0 (It is okay to select any value from 0x0 to 0xE)
- WDTRIM = 0x7
- FTRIM = 0x3
- GTRIM = 0x1
- RTRIM = 0x2

# 4 Exception handling

If the matching test fails, try the following:

- When the measured negative resistance value ($|-R|$) is insufficient.

  XMC7000 has a built-in amplifier to control the ECO. The gain of the amplifier can be increased with GTRIM, and the negative resistance value ($|-R|$) will increase.

  However, these have limitations. If the negative resistance value ($|-R|$) is insufficient even with the maximum GTRIM value, use another crystal unit.

# 5 Additional information

## 5.1 Matching test

In the matching test, the drive level, frequency accuracy, negative resistance, and startup time are generally tested (see **Table 6**). The results of the matching test are valid for the reported test board only.

**Table 6 Test items for the matching test**

| Test items | Description |
| --- | --- |
| Drive level | Measures the power consumed by the crystal unit. Generally, if the power consumption is greater than the maximum driving capability of the crystal unit, a $R_d$ is required. However, in XMC7000, the power consumption is adjusted by the AGC enable and trim value without $R_d$. |
| Frequency accuracy | Changes the values of $C_1$, $C_2$ and measures the frequency accuracy. $C_1$, $C_2$ are determined to achieve the desired frequency accuracy. In general, the crystal vendor mounts $C_1$ and $C_2$ on the PCB that contain $C_S$ (stray capacitance) in matching tests. Then, select $C_1$ and $C_2$ that have the smallest frequency deviation. |
| Negative resistance | Measures the negative resistance of the oscillation circuit and calculates the oscillation margin |
| Startup time | To confirm that the crystal unit and ceramic resonator oscillate normally, measures the time until the oscillation amplitude shifts to the steady state region (the time until it reaches 90% of the steady state oscillation level) |

Check with the crystal unit vendor for more information on the matching test.

## 5.2 Stray capacitance

Stray capacitance is the capacitance caused by the physical structure of electronic circuits. It is generated by the close wiring or via of the board.

- Stray capacitance affects the operation of electronic circuits at higher frequencies. To minimize stray capacitance, make the circuit wiring as short as possible.
- Do not mount vias on the test board as much as possible.

Consult your crystal unit vendor when designing your board.

Contact the board vendor for the stray capacitance value.

## Revision history

| Document version | Date of release | Description of changes |
|---|---|---|
| ** | 2022-03-28 | Initial release |

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