



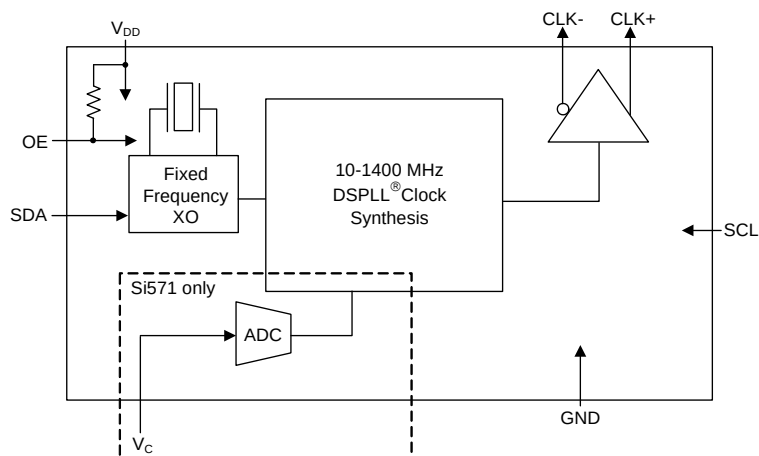
## Features

- ## Applications

- ### Description

The Si570 XO/Si571 VCXO utilizes Silicon Laboratories' advanced DSPLL<sup>®</sup> circuitry to provide a low-jitter clock at any frequency. The Si570/Si571 are user-programmable to any output frequency from 10 to 945 MHz and select frequencies to 1400 MHz with <1 ppb resolution. The device is programmed via an I<sup>2</sup>C serial interface. Unlike traditional XO/VCXOs where a different crystal is required for each output frequency, the Si57x uses one fixed-frequency crystal and a DSPLL clock synthesis IC to provide any-frequency operation. This IC-based approach allows the crystal resonator to provide exceptional frequency stability and reliability. In addition, DSPLL clock synthesis provides superior supply noise rejection, simplifying the task of generating low-jitter clocks in noisy environments typically found in communication systems.

## Functional Block Diagram

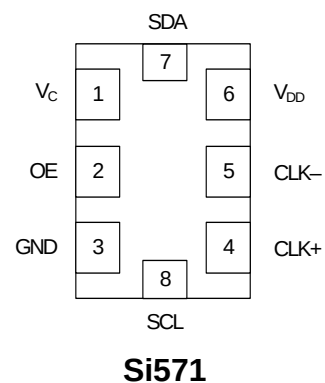
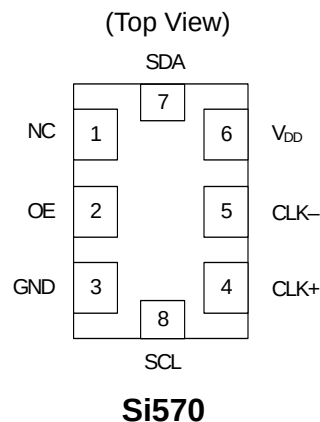


### Ordering Information:

See page 32.

### Pin Assignments:

See page 31.





# TABLE OF CONTENTS

| <b><u>Section</u></b>                              | <b><u>Page</u></b> |
|----------------------------------------------------|--------------------|
| <b>1. Detailed Block Diagrams</b>                  | <b>4</b>           |
| <b>2. Electrical Specifications</b>                | <b>5</b>           |
| <b>3. Functional Description</b>                   | <b>15</b>          |
| 3.1. Programming a New Output Frequency            | 15                 |
| 3.2. Si570 Programming Procedure                   | 19                 |
| 3.3. Si570 Troubleshooting FAQ                     | 21                 |
| 3.4. I2C Interface                                 | 22                 |
| <b>4. Serial Port Registers</b>                    | <b>23</b>          |
| <b>5. Si570 (XO) Pin Descriptions</b>              | <b>30</b>          |
| <b>6. Si571 (VCXO) Pin Descriptions</b>            | <b>31</b>          |
| <b>7. Ordering Information</b>                     | <b>32</b>          |
| <b>8. Si57x Mark Specification</b>                 | <b>33</b>          |
| <b>9. Outline Diagram and Suggested Pad Layout</b> | <b>34</b>          |
| <b>10. 8-Pin PCB Land Pattern</b>                  | <b>35</b>          |
| <b>Document Change List</b>                        | <b>36</b>          |
| <b>Contact Information</b>                         | <b>37</b>          |

## 1. Detailed Block Diagrams

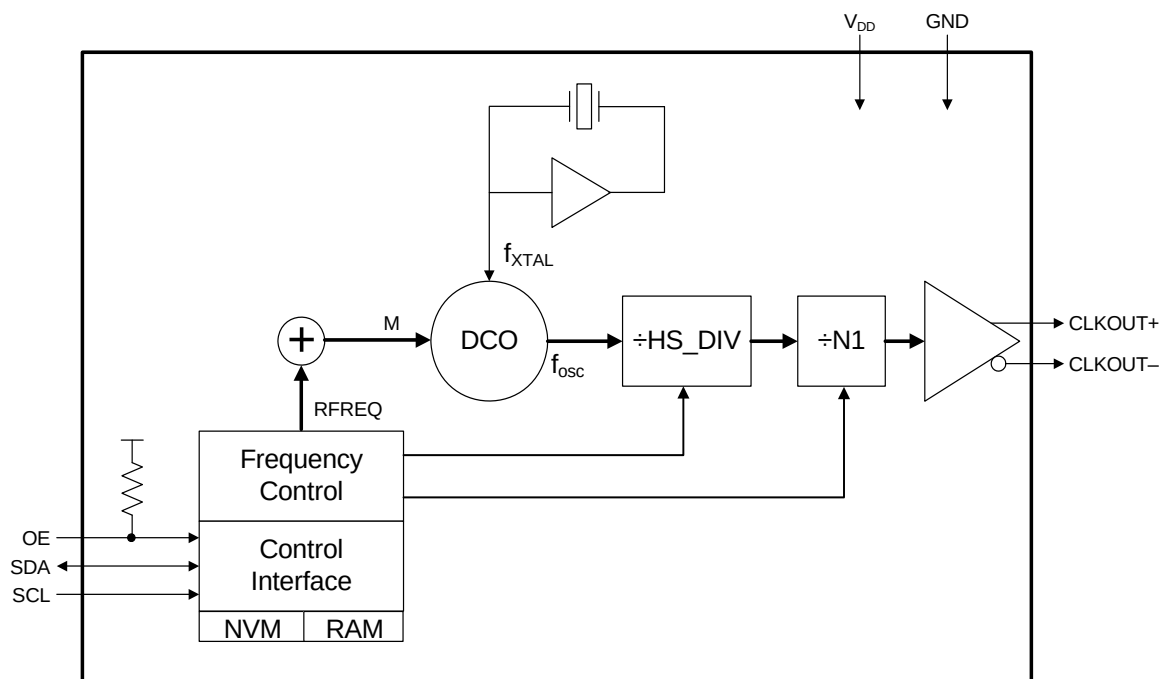


Figure 1. Si570 Detailed Block Diagram

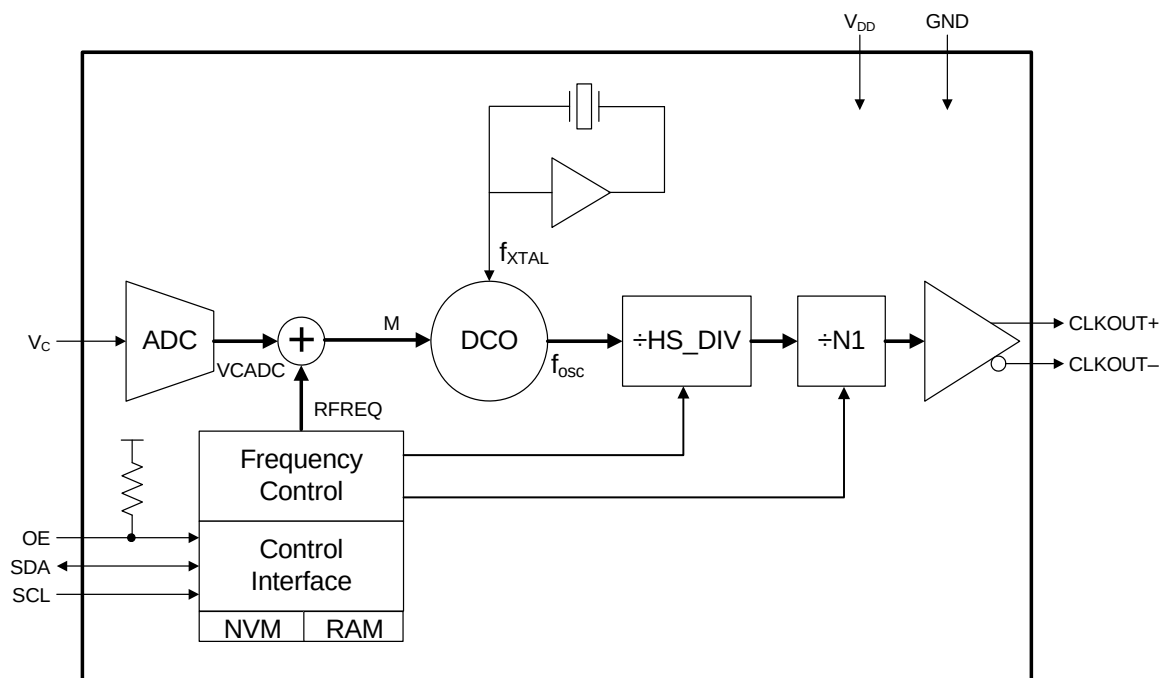


Figure 2. Si571 Detailed Block Diagram

## 2. Electrical Specifications

**Table 1. Recommended Operating Conditions**

| Parameter                                                                                                                                                                                                                                                                                                      | Symbol   | Test Condition           | Min                  | Typ | Max  | Unit |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------|----------------------|-----|------|------|
| Supply Voltage <sup>1</sup>                                                                                                                                                                                                                                                                                    | $V_{DD}$ | 3.3 V option             | 2.97                 | 3.3 | 3.63 | V    |
|                                                                                                                                                                                                                                                                                                                |          | 2.5 V option             | 2.25                 | 2.5 | 2.75 |      |
|                                                                                                                                                                                                                                                                                                                |          | 1.8 V option             | 1.71                 | 1.8 | 1.89 |      |
| Supply Current                                                                                                                                                                                                                                                                                                 | $I_{DD}$ | Output enabled<br>LVPECL | —                    | 120 | 130  | mA   |
|                                                                                                                                                                                                                                                                                                                |          | CML                      | —                    | 108 | 117  |      |
|                                                                                                                                                                                                                                                                                                                |          | LVDS                     | —                    | 99  | 108  |      |
|                                                                                                                                                                                                                                                                                                                |          | CMOS                     | —                    | 90  | 98   |      |
|                                                                                                                                                                                                                                                                                                                |          | TriState mode            | —                    | 60  | 75   |      |
| Output Enable (OE) <sup>2</sup> ,<br>Serial Data (SDA),<br>Serial Clock (SCL)                                                                                                                                                                                                                                  |          | $V_{IH}$                 | $0.75 \times V_{DD}$ | —   | —    | V    |
|                                                                                                                                                                                                                                                                                                                |          | $V_{IL}$                 | —                    | —   | 0.5  |      |
| Operating Temperature Range                                                                                                                                                                                                                                                                                    | $T_A$    |                          | –40                  | —   | 85   | °C   |
| <b>Notes:</b> <ol style="list-style-type: none"> <li>Selectable parameter specified by part number. See Section "7. Ordering Information" on page 32 for further details.</li> <li>OE pin includes a 17 k<math>\Omega</math> pullup resistor to <math>V_{DD}</math>. See "7. Ordering Information".</li> </ol> |          |                          |                      |     |      |      |

**Table 2.  $V_C$  Control Voltage Input (Si571)**

| Parameter                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Symbol     | Test Condition              | Min | Typ                                 | Max      | Unit       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|-----------------------------|-----|-------------------------------------|----------|------------|
| Control Voltage Tuning Slope <sup>1,2,3</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | $K_V$      | $V_C$ 10 to 90% of $V_{DD}$ | —   | 33<br>45<br>90<br>135<br>180<br>356 | —        | ppm/V      |
| Control Voltage Linearity <sup>4</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $L_{VC}$   | BSL                         | –5  | $\pm 1$                             | +5       | %          |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |            | Incremental                 | –10 | $\pm 5$                             | +10      |            |
| Modulation Bandwidth                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | BW         |                             | 9.3 | 10.0                                | 10.7     | kHz        |
| $V_C$ Input Impedance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | $Z_{VC}$   |                             | 500 | —                                   | —        | k $\Omega$ |
| Nominal Control Voltage <sup>5</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | $V_{CNOM}$ | @ $f_O$                     | —   | $V_{DD}/2$                          | —        | V          |
| Control Voltage Tuning Range                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | $V_C$      |                             | 0   |                                     | $V_{DD}$ | V          |
| <b>Notes:</b> <ol style="list-style-type: none"> <li>Positive slope; selectable option by part number. See "7. Ordering Information" on page 32.</li> <li>For best jitter and phase noise performance, always choose the smallest <math>K_V</math> that meets the application's minimum APR requirements. See "AN266: VCXO Tuning Slope (<math>K_V</math>), Stability, and Absolute Pull Range (APR)" for more information.</li> <li><math>K_V</math> variation is <math>\pm 10\%</math> of typical values.</li> <li>BSL determined from deviation from best straight line fit with <math>V_C</math> ranging from 10 to 90% of <math>V_{DD}</math>. Incremental slope is determined with <math>V_C</math> ranging from 10 to 90% of <math>V_{DD}</math>.</li> <li>Nominal output frequency set by <math>V_{CNOM} = 1/2 \times V_{DD}</math>.</li> </ol> |            |                             |     |                                     |          |            |

**Table 3. CLK± Output Frequency Characteristics**

| Parameter                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Symbol    | Test Condition                    | Min                      | Typ              | Max                     | Unit |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------------------------------|--------------------------|------------------|-------------------------|------|
| Programmable Frequency Range <sup>1,2</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $f_O$     | LVPECL/LVDS/CML                   | 10                       | —                | 1417.5                  | MHz  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           | CMOS                              | 10                       | —                | 160                     |      |
| Temperature Stability <sup>1,3</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |           | $T_A = -40$ to $+85$ °C           | -7<br>-20<br>-50<br>-100 | —<br>—<br>—<br>— | 7<br>+20<br>+50<br>+100 | ppm  |
| Initial Accuracy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |           |                                   | —                        | 1.5              | —                       | ppm  |
| Aging                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | $f_a$     | Frequency drift over first year   | —                        | —                | ±3                      | ppm  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           | Frequency drift over 20-year life | —                        | —                | ±10                     | ppm  |
| Total Stability                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           | Temp stability = ±7 ppm           | —                        | —                | ±20                     | ppm  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           | Temp stability = ±20 ppm          | —                        | —                | ±31.5                   | ppm  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           | Temp stability = ±50 ppm          | —                        | —                | ±61.5                   | ppm  |
| Absolute Pull Range <sup>1,3</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | APR       |                                   | ±12                      | —                | ±375                    | ppm  |
| Power up Time <sup>4</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | $t_{OSC}$ |                                   | —                        | —                | 10                      | ms   |
| <b>Notes:</b> <ol style="list-style-type: none"> <li>1. See Section "7. Ordering Information" on page 32 for further details.</li> <li>2. Specified at time of order by part number. Three speed grades available:<br/>Grade A covers 10 to 945 MHz, 970 to 1134 MHz, and 1213 to 1417.5 MHz.<br/>Grade B covers 10 to 810 MHz.<br/>Grade C covers 10 to 280 MHz.</li> <li>3. Selectable parameter specified by part number.</li> <li>4. Time from power up or tristate mode to <math>f_O</math>.</li> </ol> |           |                                   |                          |                  |                         |      |

Table 4. CLK± Output Levels and Symmetry

| Parameter                                                                                                                                          | Symbol     | Test Condition                                                                     | Min                 | Typ             | Max             | Unit     |
|----------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------------------------------------------------------------------------------|---------------------|-----------------|-----------------|----------|
| LVPECL Output Option <sup>1</sup>                                                                                                                  | $V_O$      | mid-level                                                                          | $V_{DD} - 1.42$     | —               | $V_{DD} - 1.25$ | V        |
|                                                                                                                                                    | $V_{OD}$   | swing (diff)                                                                       | 1.1                 | —               | 1.9             | $V_{PP}$ |
|                                                                                                                                                    | $V_{SE}$   | swing (single-ended)                                                               | 0.55                | —               | 0.95            | $V_{PP}$ |
| LVDS Output Option <sup>2</sup>                                                                                                                    | $V_O$      | mid-level                                                                          | 1.125               | 1.20            | 1.275           | V        |
|                                                                                                                                                    | $V_{OD}$   | swing (diff)                                                                       | 0.5                 | 0.7             | 0.9             | $V_{PP}$ |
| CML Output Option <sup>2</sup>                                                                                                                     | $V_O$      | 2.5/3.3 V option mid-level                                                         | —                   | $V_{DD} - 1.30$ | —               | V        |
|                                                                                                                                                    |            | 1.8 V option mid-level                                                             | —                   | $V_{DD} - 0.36$ | —               | V        |
|                                                                                                                                                    | $V_{OD}$   | 2.5/3.3 V option swing (diff)                                                      | 1.10                | 1.50            | 1.90            | $V_{PP}$ |
|                                                                                                                                                    |            | 1.8 V option swing (diff)                                                          | 0.35                | 0.425           | 0.50            | $V_{PP}$ |
| CMOS Output Option <sup>3</sup>                                                                                                                    | $V_{OH}$   | $I_{OH} = 32 \text{ mA}$                                                           | $0.8 \times V_{DD}$ | —               | $V_{DD}$        | V        |
|                                                                                                                                                    | $V_{OL}$   | $I_{OL} = 32 \text{ mA}$                                                           | —                   | —               | 0.4             | V        |
| Rise/Fall time (20/80%)                                                                                                                            | $t_R, t_F$ | LVPECL/LVDS/CML                                                                    | —                   | —               | 350             | ps       |
|                                                                                                                                                    |            | CMOS with $C_L = 15 \text{ pF}$                                                    | —                   | 1               | —               | ns       |
| Symmetry (duty cycle)                                                                                                                              | SYM        | LVPECL: $V_{DD} - 1.3 \text{ V}$ (diff)<br>LVDS: 1.25 V (diff)<br>CMOS: $V_{DD}/2$ | 45                  | —               | 55              | %        |
| <b>Notes:</b><br>1. $R_{term} = 50 \Omega$ to $V_{DD} - 2.0 \text{ V}$ .<br>2. $R_{term} = 100 \Omega$ (differential).<br>3. $C_L = 15 \text{ pF}$ |            |                                                                                    |                     |                 |                 |          |

**Table 5. CLK± Output Phase Jitter (Si570)**

| Parameter                                                                                                                                                                                                                           | Symbol         | Test Condition                         | Min | Typ  | Max  | Unit |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|----------------------------------------|-----|------|------|------|
| Phase Jitter (RMS) <sup>1</sup><br>for F <sub>OUT</sub> ≥ 500 MHz                                                                                                                                                                   | ϕ <sub>J</sub> | 12 kHz to 20 MHz (OC-48)               | —   | 0.25 | 0.40 | ps   |
|                                                                                                                                                                                                                                     |                | 50 kHz to 80 MHz (OC-192)              | —   | 0.26 | 0.37 |      |
| Phase Jitter (RMS) <sup>1</sup><br>for F <sub>OUT</sub> of 125 to 500 MHz                                                                                                                                                           | ϕ <sub>J</sub> | 12 kHz to 20 MHz (OC-48)               | —   | 0.36 | 0.50 | ps   |
|                                                                                                                                                                                                                                     |                | 50 kHz to 80 MHz (OC-192) <sup>2</sup> | —   | 0.34 | 0.42 |      |
| Phase Jitter (RMS)<br>for F <sub>OUT</sub> of 10 to 160 MHz<br>CMOS Output Only                                                                                                                                                     | ϕ <sub>J</sub> | 12 kHz to 20 MHz (OC-48) <sup>2</sup>  | —   | 0.62 | —    | ps   |
|                                                                                                                                                                                                                                     |                | 50 kHz to 20 MHz <sup>2</sup>          | —   | 0.61 | —    |      |
| <b>Notes:</b><br>1. Refer to AN256 for further information.<br>2. Max offset frequencies:<br>80 MHz for F <sub>OUT</sub> ≥ 250 MHz<br>20 MHz for 50 MHz ≤ F <sub>OUT</sub> <250 MHz<br>2 MHz for 10 MHz ≤ F <sub>OUT</sub> <50 MHz. |                |                                        |     |      |      |      |

Table 6. CLK± Output Phase Jitter (Si571)

| Parameter                                                                                                                                                                                                                                                                    | Symbol         | Test Condition                                                          | Min    | Typ          | Max    | Unit |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------------------------------------------------------------------------|--------|--------------|--------|------|--|
| Phase Jitter (RMS) <sup>1,2,3</sup><br>for F <sub>OUT</sub> ≥ 500 MHz                                                                                                                                                                                                        | ϕ <sub>J</sub> | Kv = 33 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.26<br>0.26 | —<br>— | ps   |  |
|                                                                                                                                                                                                                                                                              |                | Kv = 45 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.27<br>0.26 | —<br>— |      |  |
|                                                                                                                                                                                                                                                                              |                | Kv = 90 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.32<br>0.26 | —<br>— |      |  |
|                                                                                                                                                                                                                                                                              |                | Kv = 135 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 0.40<br>0.27 | —<br>— |      |  |
|                                                                                                                                                                                                                                                                              |                | Kv = 180 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 0.49<br>0.28 | —<br>— |      |  |
|                                                                                                                                                                                                                                                                              |                | Kv = 356 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 0.87<br>0.33 | —<br>— |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
|                                                                                                                                                                                                                                                                              |                |                                                                         |        |              |        |      |  |
| <b>Notes:</b>                                                                                                                                                                                                                                                                |                |                                                                         |        |              |        |      |  |
| 1. Differential Modes: LVPECL/LVDS/CML. Refer to AN255, AN256, and AN266 for further information.                                                                                                                                                                            |                |                                                                         |        |              |        |      |  |
| 2. For best jitter and phase noise performance, always choose the smallest K <sub>V</sub> that meets the application's minimum APR requirements. See "AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)" for more information.                         |                |                                                                         |        |              |        |      |  |
| 3. See "AN255: Replacing 622 MHz VCXO devices with the Si550 VCXO" for comparison highlighting power supply rejection (PSR) advantage of Si55x versus SAW-based solutions.                                                                                                   |                |                                                                         |        |              |        |      |  |
| 4. Single ended mode: CMOS. Refer to the following application notes for further information:<br>"AN255: Replacing 622 MHz VCXO Devices with the Si55x VCXO"<br>"AN256: Integrated Phase Noise"<br>"AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)" |                |                                                                         |        |              |        |      |  |
| 5. Max offset frequencies:<br>80 MHz for F <sub>OUT</sub> ≥ 250 MHz<br>20 MHz for 50 MHz ≤ F <sub>OUT</sub> <250 MHz<br>2 MHz for 10 MHz ≤ F <sub>OUT</sub> <50 MHz.                                                                                                         |                |                                                                         |        |              |        |      |  |

**Table 6. CLK± Output Phase Jitter (Si571) (Continued)**

| Parameter                                                                                     | Symbol   | Test Condition                                                 | Min    | Typ          | Max    | Unit |
|-----------------------------------------------------------------------------------------------|----------|----------------------------------------------------------------|--------|--------------|--------|------|
| Phase Jitter (RMS) <sup>2,4,5</sup><br>for F <sub>OUT</sub> 10 to 160 MHz<br>CMOS Output Only | $\phi_J$ | Kv = 33 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz  | —<br>— | 0.63<br>0.62 | —<br>— | ps   |
|                                                                                               |          | Kv = 45 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz  | —<br>— | 0.63<br>0.62 | —<br>— |      |
|                                                                                               |          | Kv = 90 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz  | —<br>— | 0.67<br>0.66 | —<br>— |      |
|                                                                                               |          | Kv = 135 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz | —<br>— | 0.74<br>0.72 | —<br>— |      |
|                                                                                               |          | Kv = 180 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz | —<br>— | 0.83<br>0.8  | —<br>— |      |
|                                                                                               |          | Kv = 356 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 20 MHz | —<br>— | 1.26<br>1.2  | —<br>— |      |

**Notes:**

1. Differential Modes: LVPECL/LVDS/CML. Refer to AN255, AN256, and AN266 for further information.
2. For best jitter and phase noise performance, always choose the smallest K<sub>V</sub> that meets the application's minimum APR requirements. See "AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)" for more information.
3. See "AN255: Replacing 622 MHz VCSO devices with the Si550 VCXO" for comparison highlighting power supply rejection (PSR) advantage of Si55x versus SAW-based solutions.
4. Single ended mode: CMOS. Refer to the following application notes for further information:  
 "AN255: Replacing 622 MHz VCSO Devices with the Si55x VCXO"  
 "AN256: Integrated Phase Noise"  
 "AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)"
5. Max offset frequencies:  
 80 MHz for F<sub>OUT</sub> ≥ 250 MHz  
 20 MHz for 50 MHz ≤ F<sub>OUT</sub> < 250 MHz  
 2 MHz for 10 MHz ≤ F<sub>OUT</sub> < 50 MHz.

Table 6. CLK± Output Phase Jitter (Si571) (Continued)

| Parameter                                                                          | Symbol   | Test Condition                                                          | Min    | Typ          | Max    | Unit |
|------------------------------------------------------------------------------------|----------|-------------------------------------------------------------------------|--------|--------------|--------|------|
| Phase Jitter (RMS) <sup>1,2,3,5</sup><br>for F <sub>OUT</sub> of 125 to<br>500 MHz | $\phi_J$ | Kv = 33 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.37<br>0.33 | —<br>— | ps   |
|                                                                                    |          | Kv = 45 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.37<br>0.33 | —<br>— |      |
|                                                                                    |          | Kv = 90 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192)  | —<br>— | 0.43<br>0.34 | —<br>— |      |
|                                                                                    |          | Kv = 135 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 0.50<br>0.34 | —<br>— |      |
|                                                                                    |          | Kv = 180 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 0.59<br>0.35 | —<br>— |      |
|                                                                                    |          | Kv = 356 ppm/V<br>12 kHz to 20 MHz (OC-48)<br>50 kHz to 80 MHz (OC-192) | —<br>— | 1.00<br>0.39 | —<br>— |      |

**Notes:**

1. Differential Modes: LVPECL/LVDS/CML. Refer to AN255, AN256, and AN266 for further information.
2. For best jitter and phase noise performance, always choose the smallest K<sub>V</sub> that meets the application's minimum APR requirements. See "AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)" for more information.
3. See "AN255: Replacing 622 MHz VCXO devices with the Si550 VCXO" for comparison highlighting power supply rejection (PSR) advantage of Si55x versus SAW-based solutions.
4. Single ended mode: CMOS. Refer to the following application notes for further information:  
 "AN255: Replacing 622 MHz VCXO Devices with the Si55x VCXO"  
 "AN256: Integrated Phase Noise"  
 "AN266: VCXO Tuning Slope (kV), Stability, and Absolute Pull Range (APR)"
5. Max offset frequencies:  
 80 MHz for F<sub>OUT</sub> ≥ 250 MHz  
 20 MHz for 50 MHz ≤ F<sub>OUT</sub> < 250 MHz  
 2 MHz for 10 MHz ≤ F<sub>OUT</sub> < 50 MHz.

Table 7. CLK± Output Period Jitter

| Parameter      | Symbol           | Test Condition | Min | Typ | Max | Unit |
|----------------|------------------|----------------|-----|-----|-----|------|
| Period Jitter* | J <sub>PER</sub> | RMS            | —   | 2   | —   | ps   |
|                |                  | Peak-to-Peak   | —   | 14  | —   |      |

**\*Note:** Any output mode, including CMOS, LVPECL, LVDS, CML. N = 1000 cycles. Refer to "AN279: Estimating Period Jitter from Phase Noise" for further information.

# Si570/Si571

**Table 8. Typical CLK± Output Phase Noise (Si570)**

| Offset Frequency (f) | 120.00 MHz<br>LVDS | 156.25 MHz<br>LVPECL | 622.08 MHz<br>LVPECL | Unit   |
|----------------------|--------------------|----------------------|----------------------|--------|
| 100 Hz               | -112               | -105                 | -97                  | dBc/Hz |
| 1 kHz                | -122               | -122                 | -107                 |        |
| 10 kHz               | -132               | -128                 | -116                 |        |
| 100 kHz              | -137               | -135                 | -121                 |        |
| 1 MHz                | -144               | -144                 | -134                 |        |
| 10 MHz               | -150               | -147                 | -146                 |        |
| 100 MHz              | n/a                | n/a                  | -148                 |        |

**Table 9. Typical CLK± Output Phase Noise (Si571)**

| Offset Frequency (f) | 74.25 MHz<br>90 ppm/V<br>LVPECL | 491.52 MHz<br>45 ppm/V<br>LVPECL | 622.08 MHz<br>135 ppm/V<br>LVPECL | Unit   |
|----------------------|---------------------------------|----------------------------------|-----------------------------------|--------|
| 100 Hz               | -87                             | -75                              | -65                               | dBc/Hz |
| 1 kHz                | -114                            | -100                             | -90                               |        |
| 10 kHz               | -132                            | -116                             | -109                              |        |
| 100 kHz              | -142                            | -124                             | -121                              |        |
| 1 MHz                | -148                            | -135                             | -134                              |        |
| 10 MHz               | -150                            | -146                             | -146                              |        |
| 100 MHz              | n/a                             | -147                             | -147                              |        |

**Table 10. Environmental Compliance**

(The Si570/571 meets the following qualification test requirements.)

| Parameter                  | Conditions/Test Method   |
|----------------------------|--------------------------|
| Mechanical Shock           | MIL-STD-883, Method 2002 |
| Mechanical Vibration       | MIL-STD-883, Method 2007 |
| Solderability              | MIL-STD-883, Method 2003 |
| Gross and Fine Leak        | MIL-STD-883, Method 1014 |
| Resistance to Solder Heat  | MIL-STD-883, Method 2036 |
| Moisture Sensitivity Level | J-STD-020, MSL1          |
| Contact Pads               | Gold over Nickel         |

**Table 11. Programming Constraints and Timing**(V<sub>DD</sub> = 3.3 V ±10%, T<sub>A</sub> = -40 to 85 °C)

| Parameter                                | Symbol            | Test Condition                                             | Min    | Typ     | Max    | Unit |
|------------------------------------------|-------------------|------------------------------------------------------------|--------|---------|--------|------|
| Output Frequency Range                   | CKO <sub>F</sub>  | HS_DIV x N1 > = 6                                          | 10     | —       | 945    | MHz  |
|                                          |                   | HS_DIV = 5<br>N1 = 1                                       | 970    | —       | 1134   | MHz  |
|                                          |                   | HS_DIV = 4<br>N1 = 1                                       | 1.2125 | —       | 1.4175 | GHz  |
| Frequency Reprogramming Resolution       | M <sub>RES</sub>  | f <sub>x<sub>tal</sub></sub> = 114.285 MHz                 | —      | 0.09    | —      | ppb  |
| Internal Oscillator Frequency            | f <sub>OSC</sub>  |                                                            | 4850   | —       | 5670   | MHz  |
| Internal Crystal Frequency Accuracy      | f <sub>XTAL</sub> | Maximum variation is ±2000 ppm                             | —      | 114.285 | —      | MHz  |
| Delta Frequency for Continuous Output    |                   | From center frequency                                      | -3500  | —       | +3500  | ppm  |
| Unfreeze to NewFreq Timeout              |                   |                                                            | —      | —       | 10     | ms   |
| Settling Time for Small Frequency Change |                   | <±3500 ppm from center frequency                           | —      | —       | 100    | μs   |
| Settling Time for Large Frequency Change |                   | >±3500 ppm from center frequency after setting NewFreq bit | —      | —       | 10     | ms   |

**Table 12. Thermal Characteristics**(Typical values T<sub>A</sub> = 25 °C, V<sub>DD</sub> = 3.3 V)

| Parameter                              | Symbol          | Test Condition | Min | Typ  | Max | Unit |
|----------------------------------------|-----------------|----------------|-----|------|-----|------|
| Thermal Resistance Junction to Ambient | θ <sub>JA</sub> | Still Air      | —   | 84.6 | —   | °C/W |
| Thermal Resistance Junction to Case    | θ <sub>JC</sub> | Still Air      | —   | 38.8 | —   | °C/W |
| Ambient Temperature                    | T <sub>A</sub>  |                | -40 | —    | 85  | °C   |
| Junction Temperature                   | T <sub>J</sub>  |                | —   | —    | 125 | °C   |

**Table 13. Absolute Maximum Ratings<sup>1,2</sup>**

| Parameter                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Symbol            | Rating                        | Unit    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------|---------|
| Supply Voltage, 1.8 V Option                                                                                                                                                                                                                                                                                                                                                                                                                                                         | V <sub>DD</sub>   | –0.5 to +1.9                  | V       |
| Supply Voltage, 2.5/3.3 V Option                                                                                                                                                                                                                                                                                                                                                                                                                                                     | V <sub>DD</sub>   | –0.5 to +3.8                  | V       |
| Input Voltage                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | V <sub>I</sub>    | –0.5 to V <sub>DD</sub> + 0.3 | V       |
| Storage Temperature                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | T <sub>S</sub>    | –55 to +125                   | °C      |
| ESD Sensitivity (HBM, per JESD22-A114)                                                                                                                                                                                                                                                                                                                                                                                                                                               | ESD               | >2000                         | V       |
| Soldering Temperature (Lead-free Profile)                                                                                                                                                                                                                                                                                                                                                                                                                                            | T <sub>PEAK</sub> | 260                           | °C      |
| Soldering Temperature Time @ T <sub>PEAK</sub> (Lead-free Profile)                                                                                                                                                                                                                                                                                                                                                                                                                   | t <sub>p</sub>    | 20–40                         | seconds |
| <b>Notes:</b> <ol style="list-style-type: none"><li>1. Stresses beyond the absolute maximum ratings may cause permanent damage to the device. Functional operation or specification compliance is not implied at these conditions.</li><li>2. The device is compliant with JEDEC J-STD-020. Refer to packaging FAQ available for download at <a href="http://www.siliconlabs.com/VCXO">www.siliconlabs.com/VCXO</a> for further information, including soldering profiles.</li></ol> |                   |                               |         |

### 3. Functional Description

The Si570 XO and the Si571 VCXO are low-jitter oscillators ideally suited for applications requiring programmable frequencies. The Si57x can be programmed to generate virtually any output clock in the range of 10 MHz to 1.4 GHz. Output jitter performance complies with and exceeds the strict requirements of high-speed communication systems including OC-192/STM-64 and 10 Gigabit Ethernet (10 GbE).

The Si57x consists of a digitally-controlled oscillator (DCO) based on Silicon Laboratories' third-generation DSPLL technology, which is driven by an internal fixed-frequency crystal reference.

The device's default output frequency is set at the factory and can be reprogrammed through the two-wire I<sup>2</sup>C serial port. Once the device is powered down, it will return to its factory-set default output frequency.

While the Si570 outputs a fixed frequency, the Si571 has a pullable output frequency using the voltage control input pin. This makes the Si571 an ideal choice for high-performance, low-jitter, phase-locked loops.

#### 3.1. Programming a New Output Frequency

The output frequency ( $f_{out}$ ) is determined by programming the DCO frequency ( $f_{DCO}$ ) and the device's output dividers (HS\_DIV, N1). The output frequency is calculated using the following equation:

$$f_{out} = \frac{f_{DCO}}{\text{Output Dividers}} = \frac{f_{XTAL} \times \text{RFREQ}}{\text{HSDIV} \times \text{N1}}$$

The DCO frequency is adjustable in the range of 4.85 to 5.67 GHz by setting the high-resolution 38-bit fractional multiplier (RFREQ). The DCO frequency is the product of the internal fixed-frequency crystal ( $f_{XTAL}$ ) and RFREQ.

The 38-bit resolution of RFREQ allows the DCO frequency to have a programmable frequency resolution of 0.09 ppb.

As shown in Figure 3, the device allows reprogramming of the DCO frequency up to  $\pm 3500$  ppm from the center frequency configuration without interruption to the output clock. Changes greater than the  $\pm 3500$  ppm window will cause the device to recalibrate its internal tuning circuitry, forcing the output clock to momentarily stop and start at any arbitrary point during a clock cycle. This re-calibration process establishes a new center frequency and can take up to 10 ms. Circuitry receiving a clock from the Si57x device that is sensitive to glitches or runt pulses may have to be reset once the recalibration process is complete.

##### 3.1.1. Reconfiguring the Output Clock for a Small Change in Frequency

For output changes less than  $\pm 3500$  ppm from the center frequency configuration, the DCO frequency is the only value that needs reprogramming. Since  $f_{DCO} = f_{XTAL} \times \text{RFREQ}$ , and that  $f_{XTAL}$  is fixed, changing the DCO frequency is as simple as reconfiguring the RFREQ value as outlined below:

1. Using the serial port, read the current RFREQ value (addresses 7–12 for all Si571 devices and Si570 devices with 20 ppm and 50 ppm temperature stability; or addresses 13–18 for Si570 devices with 7 ppm temperature stability).
2. Calculate the new value of RFREQ given the change in frequency.

$$\text{RFREQ}_{\text{new}} = \text{RFREQ}_{\text{current}} \times \frac{f_{\text{out\_new}}}{f_{\text{out\_current}}}$$

3. Using the serial port, write the new RFREQ value (addresses 7–12 for all Si571 devices and Si570 devices with 20 ppm and 50 ppm temperature stability; or addresses 13–18 for Si570 devices with 7 ppm temperature stability).

Example:

An Si570 generating a 148.35 MHz clock must be reconfigured "on-the-fly" to generate a 148.5 MHz clock. This represents a change of +1011.122 ppm, which is well within the  $\pm 3500$  ppm window.

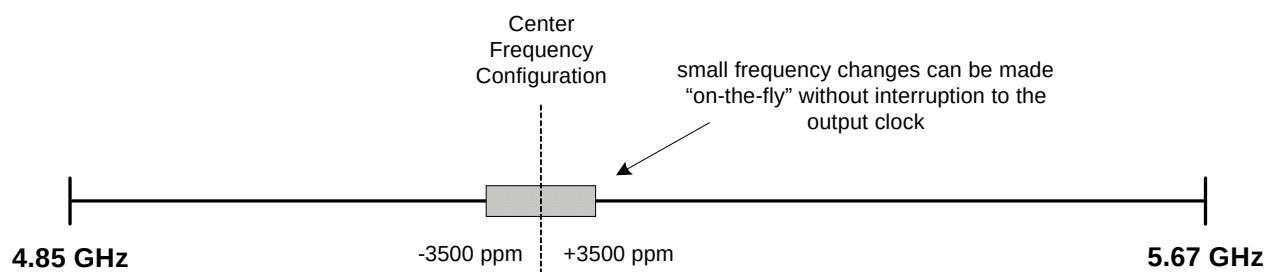


Figure 3. DCO Frequency Range

A typical frequency configuration for this example:

$\text{RFREQ}_{\text{current}} = 0x2EBB04CE0$

$F_{\text{out\_current}} = 148.35 \text{ MHz}$

$F_{\text{out\_new}} = 148.50 \text{ MHz}$

Calculate  $\text{RFREQ}_{\text{new}}$  to change the output frequency from 148.35 MHz to 148.5 MHz:

$$\begin{aligned}\text{RFREQ}_{\text{new}} &= 0x2EBB04CE0 \times \frac{148.50 \text{ MHz}}{148.35 \text{ MHz}} \\ &= 0x2EC71D666\end{aligned}$$

**Note:** Performing calculations with RFREQ requires a minimum of 38-bit arithmetic precision.

Even relatively small changes in output frequency may require writing more than 1 RFREQ register. Such multi-register RFREQ writes can impact the output clock frequency on a register-by-register basis during updating.

Interim changes to the output clock during RFREQ writes can be prevented by using the following procedure:

1. Freeze the “M” value (Set Register 135 bit 5 = 1).
2. Write the new frequency configuration (RFREQ).
3. Unfreeze the “M” value (Set Register 135 bit 5 = 0)

### 3.1.2. Reconfiguring the Output Clock for Large Changes in Output Frequency

For output frequency changes outside of  $\pm 3500$  ppm from the center frequency, it is likely that both the DCO frequency and the output dividers need to be reprogrammed. Note that changing the DCO frequency outside of the  $\pm 3500$  ppm window will cause the output to momentarily stop and restart at any arbitrary point in a clock cycle. Devices sensitive to glitches or runt pulses may have to be reset once reconfiguration is complete.

The process for reconfiguring the output frequency outside of a  $\pm 3500$  ppm window first requires reading the current RFREQ, HSDIV, and N1 values. Next, calculate  $f_{\text{XTAL}}$  for the device. Note that, due to slight variations of the internal crystal frequency from one device to another, each device may have a different RFREQ value or possibly even different HSDIV or N1 values to maintain the same output frequency. It is necessary to calculate  $f_{\text{XTAL}}$  for each device. Third, write the new values back to the device using the appropriate registers (addresses 7–12 for all Si571 devices and Si570 devices with 20 ppm and 50 ppm temperature stability; or addresses 13–18 for Si570 devices with 7 ppm temperature stability) sequencing as described in “3.1.2.1. Writing the New Frequency Configuration”.

$$f_{\text{XTAL}} = \frac{F_{\text{out}} \times \text{HSDIV} \times \text{N1}}{\text{RFREQ}}$$

Once  $f_{\text{XTAL}}$  has been determined, new values for RFREQ, HSDIV, and N1 are calculated to generate a new output frequency ( $f_{\text{out\_new}}$ ). New values can be calculated manually or with the Si57x-EVB software, which provides a user-friendly application to help find the optimum values.

The first step in manually calculating the frequency configuration is to determine new frequency divider values (HSDIV, N1). Given the desired output frequency ( $f_{\text{out\_new}}$ ), find the frequency divider values that will keep the DCO oscillation frequency in the range of 4.85 to 5.67 GHz.

$$f_{\text{DCO\_new}} = f_{\text{out\_new}} \times \text{HSDIV}_{\text{new}} \times \text{N1}_{\text{new}}$$

Valid values of HSDIV are 4, 5, 6, 7, 9 or 11. N1 can be selected as 1 or any even number up to 128 (i.e. 1, 2, 4, 6, 8, 10 ... 128). To help minimize the device's power consumption, the divider values should be selected to keep the DCO's oscillation frequency as low as possible. The lowest value of N1 with the highest value of HS\_DIV also results in the best power savings.

Once HS\_DIV and N1 have been determined, the next step is to calculate the reference frequency multiplier (RFREQ).

$$\text{RFREQ}_{\text{new}} = \frac{f_{\text{DCO\_new}}}{f_{\text{XTAL}}}$$

RFREQ is programmable as a 38-bit binary fractional frequency multiplier with the first 10 most significant bits (MSBs) representing the integer portion of the multiplier, and the 28 least significant bits (LSBs) representing the fractional portion.

Before entering a fractional number into the RFREQ register, it must be converted to a 38-bit integer using a bitwise left shift operation by 28 bits, which effectively multiplies RFREQ by  $2^{28}$ .

Example:

$\text{RFREQ} = 46.043042064d$

Multiply RFREQ by  $2^{28} = 12359584992.1$

Discard the fractional portion = 12359584992

Convert to hexadecimal = 02E0B04CE0h

In the example above, the multiplication operation requires 38-bit precision. If 38-bit arithmetic precision is not available, then the fractional portion can be separated from the integer and shifted to the left by 28-bits. The result is concatenated with the integer portion

to form a full 38-bit word. An example of this operation is shown in Figure 4.

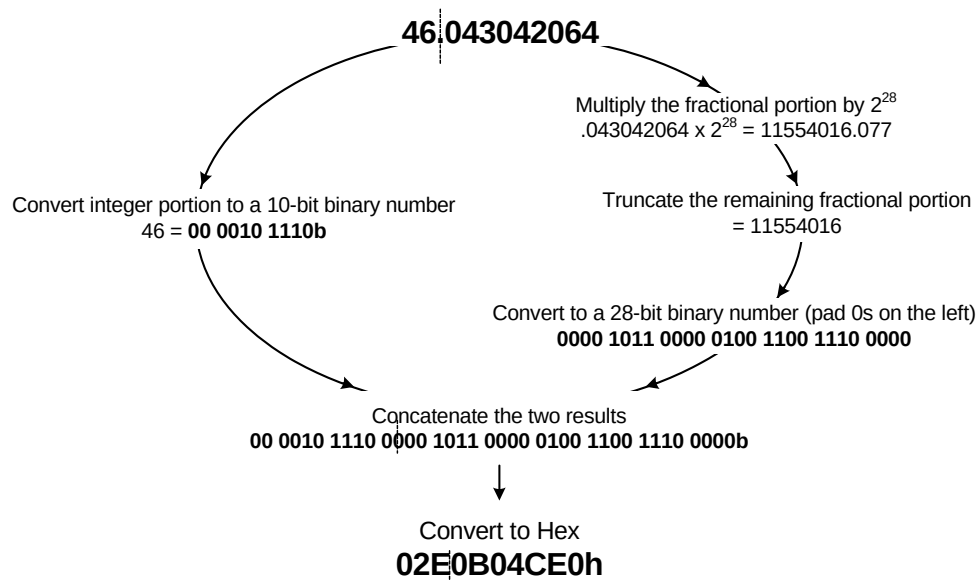


**Figure 4. Example of RFREQ Decimal to Hexadecimal Conversion**

#### 3.1.2.1. Writing the New Frequency Configuration

Once the new values for RFREQ, HSDIV, and N1 are determined, they can be written directly into the device from the serial port using the following procedure:

1. Freeze the DCO (bit 4 of Register 137)
2. Write the new frequency configuration (RFREQ, HSDIV, and N1) to addresses 7–12 for all Si571 devices and Si570 devices with 20 ppm and 50 ppm temperature stability; or addresses 13–18 for Si570 devices with 7 ppm temperature stability.
3. Unfreeze the DCO and assert the NewFreq bit (bit 6 of Register 135) within the maximum Unfreeze to NewFreq Timeout specified in Table 11, “Programming Constraints and Timing,” on page 13.

The process of freezing and unfreezing the DCO will cause the output clock to momentarily stop and start at any arbitrary point during a clock cycle. This process can take up to 10 ms. Circuitry that is sensitive to glitches or runt pulses may have to be reset after the new frequency configuration is written.

Example:

An Si570 generating 156.25 MHz must be re-configured to generate a 161.1328125 MHz clock (156.25 MHz x 66/64). This frequency change is greater than ±3500 ppm.

$f_{\text{out}} = 156.25 \text{ MHz}$

Read the current values for RFREQ, HS\_DIV, N1:

$\text{RFREQ}_{\text{current}} = 0x2BC011EB8h = 11744124600d, 11744124600d \times 2^{28} = 43.7502734363d$

$\text{HS\_DIV} = 4$

$N1 = 8$

Calculate  $f_{\text{XTAL}}, f_{\text{DCO\_current}}$

$$f_{\text{DCO\_current}} = f_{\text{out}} \times \text{HSDV} \times N1 = 5.000000000 \text{ GHz}$$

$$f_{\text{XTAL}} = \frac{f_{\text{DCO\_current}}}{\text{RFREQ}_{\text{current}}} = 114.285 \text{ MHz}$$

# Si570/Si571

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Given  $f_{\text{out\_new}} = 161.1328125$  MHz, choose output dividers that will keep  $f_{\text{DCO}}$  within the range of 4.85 to 5.67 GHz. In this case, keeping the same output dividers will still keep  $f_{\text{DCO}}$  within its range limits:

$$\begin{aligned} f_{\text{DCO\_new}} &= f_{\text{out\_new}} \times \text{HSDV}_{\text{new}} \times N1_{\text{new}} \\ &= 161.1328125 \text{ MHz} \times 4 \times 8 = 5.156250000 \text{ GHz} \end{aligned}$$

Calculate the new value of RFREQ given the new DCO frequency:

$$\begin{aligned} \text{RFREQ}_{\text{new}} &= \frac{f_{\text{DCO\_new}}}{f_{\text{XTAL}}} = 45.11746948 \\ &= 0x2D1E127AD \end{aligned}$$

### 3.2. Si570 Programming Procedure

This following example was generated using *Si514/70/71/98/99 Programmable Oscillator Software V4.0.1* found under the **Tools** tab at the following web page.

<http://www.siliconlabs.com/products/clocksoscillators/oscillators/Pages/i2c-oscillator.aspx>

On that same web page, the *AN334 Si57x I2C XO/VCXO ANSI C Reference Design* contains example **C** code for calculating register settings on the fly.

1. Read start-up frequency configuration (RFREQ, HS\_DIV, and N1) from the device after power-up or register reset.

#### Registers for the Current Configuration

| Register | Data |
|----------|------|
| 7        | 0x01 |
| 8        | 0xC2 |
| 9        | 0xBC |
| 10       | 0x01 |
| 11       | 0x1E |
| 12       | 0xB8 |

```
RFREQ  = 0x2BC011EB8
        = 0x2BC011EB8 / (2^28) = 43.75027344
HS_DIV = 0x0 = 4
N1     = 0x7 = 8
```

2. Calculate the actual nominal crystal frequency where f0 is the start-up output frequency.

```
fxtal = ( f0 x HS_DIV x N1 ) / RFREQ
        = (156.250000000 MHz x 4 x 8) / 43.750273436
        = 114.285000000 MHz
```

3. Choose the new output frequency (f1).

```
Output Frequency (f1) = 161.132812000 MHz
```

4. Choose the output dividers for the new frequency configuration (HS\_DIV and N1) by ensuring the DCO oscillation frequency (fdco) is between 4.85 GHz and 5.67 GHz where  $fdco = f1 \times HS\_DIV \times N1$ . See the Divider Combinations tab for more options.

```
HS_DIV = 0x0 = 4
N1     = 0x7 = 8
fdco   = f1 x HS_DIV x N1
        = 161.132812000 MHz x 4 x 8
        = 5.156249984 GHz
```

5. Calculate the new crystal frequency multiplication ratio (RFREQ) as  $RFREQ = fdco / fxtal$

$$\begin{aligned} RFREQ &= fdco / fxtal \\ &= 5.156249984 \text{ GHz} / 114.285000000 \text{ MHz} \\ &= 45.11746934 \\ &= 45.11746934 \times (2^{28}) = 0x2D1E12788 \end{aligned}$$

6. Freeze the DCO by setting Freeze DCO = 1 (bit 4 of register 137).  
7. Write the new frequency configuration (RFREQ, HS\_DIV, and N1)

## Registers for the New Configuration

| Register | Data |
|----------|------|
| 7        | 0x01 |
| 8        | 0xC2 |
| 9        | 0xD1 |
| 10       | 0xE1 |
| 11       | 0x27 |
| 12       | 0x88 |

8. Unfreeze the DCO by setting Freeze DCO = 0 and assert the NewFreq bit (bit 6 of register 135) within 10 ms.

## 3.3. Si570 Troubleshooting FAQ

### 1. Is the I<sup>2</sup>C bus working correctly and using the correct I<sup>2</sup>C address?

Probing the device I<sup>2</sup>C pins with an oscilloscope can sometimes reveal signal integrity problems. Si570/Si571 I<sup>2</sup>C communication is normally very robust, so if other devices on the I<sup>2</sup>C bus are communicating successfully, then the Si570/Si571 should also work.

You can confirm the specific I<sup>2</sup>C address expected by an Si570/Si571 device by using the part number lookup utility available on the Silicon Laboratories web site.

<http://www.silabs.com/custom-timing>

### 2. Is the correct register bank being written based on device stability?

Si570/Si571 devices use different configuration registers for 7 ppm temperature stability devices than they do for 20 ppm or 50 ppm temperature stability devices. The temperature stability of a Si570/Si571 device can be confirmed using the part number lookup utility available on the Silicon Laboratories web site or by referencing the 2nd ordering option code in the part number.

<http://www.silabs.com/custom-timing>

2nd Ordering Option Code:

A : 50 ppm temperature stability, 61.5 ppm total stability => Configuration Registers 7-12

B : 20 ppm temperature stability, 31.5 ppm total stability => Configuration Registers 7-12

C : 7 ppm temperature stability, 20 ppm total stability => Configuration Registers 13-18

### 3. Is the part-to-part variation in FXTAL included in calculations?

It is required that one determine the internal crystal frequency for each individual part before calculating a new output frequency. The procedure for determining the internal crystal frequency from the register values of a device is described elsewhere in this data sheet. See Section 3.2.

$$FXTAL = (FOUT \times HSDIV \times N1) / RFREQ$$
 <= note that RFREQ used here is the register value divided by 2<sup>28</sup>

It is a common error to calculate the internal crystal frequency for one device and then use that same crystal frequency for all later devices. This will lead to offset errors in the output frequency accuracy from part-to-part. The internal crystal frequency must be calculated for each individual device.

### 4. Is the Unfreeze to NewFreq timeout spec being exceeded?

The Si570/Si571 requires the DCO to be 'frozen' when changing register values and then 'unfrozen' and a calibration initiated by writing the 'NewFreq' bit to restart it properly. If the 'unfreeze' and 'NewFreq' writes are delayed by 10 ms or more, the internal state machine can timeout and cause the configuration to revert to default values.

This 'unfreeze' and 'NewFreq' timing requirement is not usually a problem since the writes are done back-to-back, but if there is an interrupt or other system delay that may cause this 10 ms timing to be exceeded, it should be considered as a possible source of issues reprogramming the Si570/Si571.

## 3.4. I<sup>2</sup>C Interface

The control interface to the Si570 is an I<sup>2</sup>C-compatible 2-wire bus for bidirectional communication. The bus consists of a bidirectional serial data line (SDA) and a serial clock input (SCL). Both lines must be connected to the positive supply via an external pullup. Fast mode operation is supported for transfer rates up to 400 kbps as specified in the I<sup>2</sup>C-Bus Specification standard.

Figure 5 shows the command format for both read and write access. Data is always sent MSB. Data length is 1 byte. Read and write commands support 1 or more data bytes as illustrated. The master must send a Not Acknowledge and a Stop after the last read data byte to terminate the read command. The timing specifications and timing diagram for the I<sup>2</sup>C bus can be found in the I<sup>2</sup>C-Bus Specification standard (fast mode operation). The device I<sup>2</sup>C address is specified in the part number.

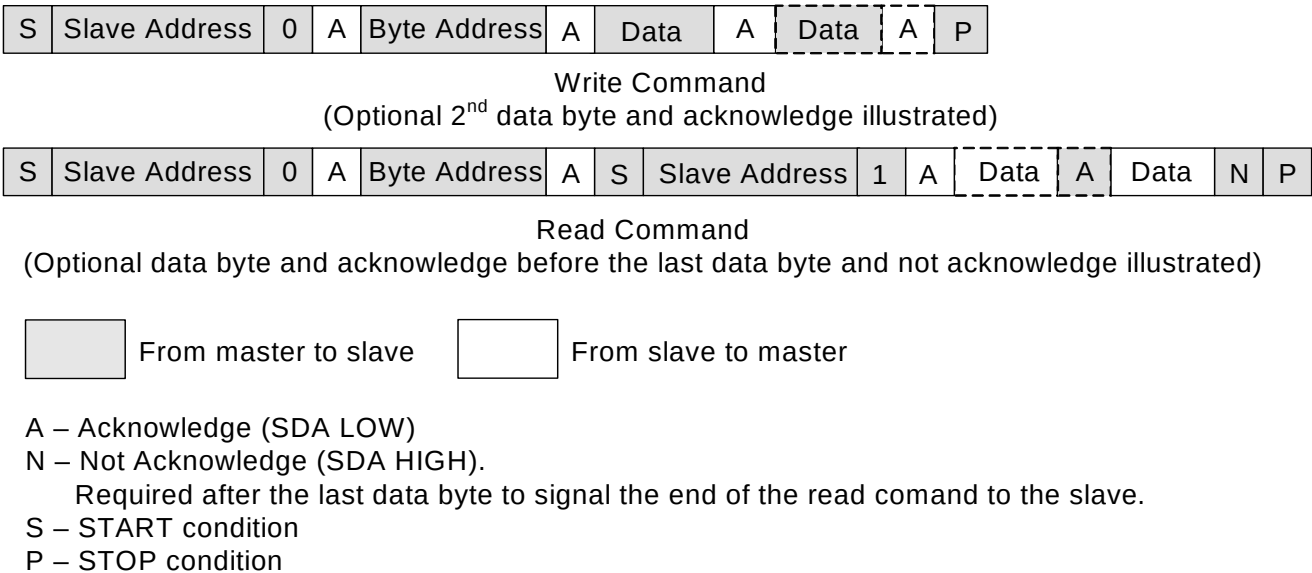


**Figure 5. I<sup>2</sup>C Command Format**

## 4. Serial Port Registers

**Note:** Any register not listed here is reserved and must not be written. All bits are R/W unless otherwise noted.

| Register | Name                            | Bit 7             | Bit 6   | Bit 5             | Bit 4           | Bit 3 | Bit 2 | Bit 1 | Bit 0  |
|----------|---------------------------------|-------------------|---------|-------------------|-----------------|-------|-------|-------|--------|
| 7        | High Speed/<br>N1 Dividers      | HS_DIV[2:0]       |         |                   | N1[6:2]         |       |       |       |        |
| 8        | Reference<br>Frequency          | N1[1:0]           |         | RFREQ[37:32]      |                 |       |       |       |        |
| 9        | Reference<br>Frequency          | RFREQ[31:24]      |         |                   |                 |       |       |       |        |
| 10       | Reference<br>Frequency          | RFREQ[23:16]      |         |                   |                 |       |       |       |        |
| 11       | Reference<br>Frequency          | RFREQ[15:8]       |         |                   |                 |       |       |       |        |
| 12       | Reference<br>Frequency          | RFREQ[7:0]        |         |                   |                 |       |       |       |        |
| 13       | High Speed/<br>N1 Dividers      | HS_DIV_7PPM[2:0]  |         |                   | N1_7PPM[6:2]    |       |       |       |        |
| 14       | Reference<br>Frequency          | N1_7PPM[1:0]      |         | RFREQ_7PPM[37:32] |                 |       |       |       |        |
| 15       | Reference<br>Frequency          | RFREQ_7PPM[31:24] |         |                   |                 |       |       |       |        |
| 16       | Reference<br>Frequency          | RFREQ_7PPM[23:16] |         |                   |                 |       |       |       |        |
| 17       | Reference<br>Frequency          | RFREQ_7PPM[15:8]  |         |                   |                 |       |       |       |        |
| 18       | Reference<br>Frequency          | RFREQ_7PPM[7:0]   |         |                   |                 |       |       |       |        |
| 135      | Reset/Freeze/<br>Memory Control | RST_REG           | NewFreq | Freeze M          | Freeze<br>VCADC |       |       |       | RECALL |
| 137      | Freeze DCO                      |                   |         |                   | Freeze<br>DCO   |       |       |       |        |

## Register 7. High Speed/N1 Dividers

| Bit  | D7          | D6 | D5 | D4      | D3  | D2 | D1 | D0 |
|------|-------------|----|----|---------|-----|----|----|----|
| Name | HS_DIV[2:0] |    |    | N1[6:2] |     |    |    |    |
| Type | R/W         |    |    |         | R/W |    |    |    |

| Bit | Name        | Function                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7:5 | HS_DIV[2:0] | <b>DCO High Speed Divider.</b><br>Sets value for high speed divider that takes the DCO output $f_{OSC}$ as its clock input.<br>000 = 4<br>001 = 5<br>010 = 6<br>011 = 7<br>100 = Not used.<br>101 = 9<br>110 = Not used.<br>111 = 11                                                                                                                                                                     |
| 4:0 | N1[6:2]     | <b>CLKOUT Output Divider.</b><br>Sets value for CLKOUT output divider. Allowed values are [1] and [2, 4, 6, ..., $2^7$ ]. Illegal odd divider values will be rounded up to the nearest even value. The value for the N1 register can be calculated by taking the divider ratio minus one. For example, to divide by 10, write 0001001 (9 decimal) to the N1 registers.<br>0000000 = 1<br>1111111 = $2^7$ |

## Register 8. Reference Frequency

| Bit  | D7      | D6 | D5           | D4 | D3  | D2 | D1 | D0 |
|------|---------|----|--------------|----|-----|----|----|----|
| Name | N1[1:0] |    | RFREQ[37:32] |    |     |    |    |    |
| Type | R/W     |    |              |    | R/W |    |    |    |

| Bit | Name         | Function                                                                                                                                                                                                                                                                                                                                                                                            |
|-----|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7:6 | N1[1:0]      | <b>CLKOUT Output Divider.</b><br>Sets value for CLKOUT output divider. Allowed values are [1, 2, 4, 6, ..., $2^7$ ]. Illegal odd divider values will be rounded up to the nearest even value. The value for the N1 register can be calculated by taking the divider ratio minus one. For example, to divide by 10, write 0001001 (9 decimal) to the N1 registers.<br>0000000 = 1<br>1111111 = $2^7$ |
| 5:0 | RFREQ[37:32] | <b>Reference Frequency.</b><br>Frequency control input to DCO.                                                                                                                                                                                                                                                                                                                                      |

**Register 9. Reference Frequency**

| Bit  | D7           | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|--------------|----|----|----|----|----|----|----|
| Name | RFREQ[31:24] |    |    |    |    |    |    |    |
| Type | R/W          |    |    |    |    |    |    |    |

| Bit | Name         | Function                                                       |
|-----|--------------|----------------------------------------------------------------|
| 7:0 | RFREQ[31:24] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

**Register 10. Reference Frequency**

| Bit  | D7           | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|--------------|----|----|----|----|----|----|----|
| Name | RFREQ[23:16] |    |    |    |    |    |    |    |
| Type | R/W          |    |    |    |    |    |    |    |

| Bit | Name         | Function                                                       |
|-----|--------------|----------------------------------------------------------------|
| 7:0 | RFREQ[23:16] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

**Register 11. Reference Frequency**

| Bit  | D7          | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|-------------|----|----|----|----|----|----|----|
| Name | RFREQ[15:8] |    |    |    |    |    |    |    |
| Type | R/W         |    |    |    |    |    |    |    |

| Bit | Name        | Function                                                       |
|-----|-------------|----------------------------------------------------------------|
| 7:0 | RFREQ[15:8] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

## Register 12. Reference Frequency

| Bit  | D7         | D6 | D5                                                             | D4 | D3 | D2 | D1 | D0 |
|------|------------|----|----------------------------------------------------------------|----|----|----|----|----|
| Name | RFREQ[7:0] |    |                                                                |    |    |    |    |    |
| Type | R/W        |    |                                                                |    |    |    |    |    |
| Bit  | Name       |    | Function                                                       |    |    |    |    |    |
| 7:0  | RFREQ[7:0] |    | <b>Reference Frequency.</b><br>Frequency control input to DCO. |    |    |    |    |    |

## Register 13. High Speed/N1 Dividers

| Bit  | D7               | D6 | D5 | D4           | D3  | D2 | D1 | D0 |
|------|------------------|----|----|--------------|-----|----|----|----|
| Name | HS_DIV_7PPM[2:0] |    |    | N1_7PPM[6:2] |     |    |    |    |
| Type | R/W              |    |    |              | R/W |    |    |    |

| Bit | Name             | Function                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7:5 | HS_DIV_7PPM[2:0] | <b>DCO High Speed Divider.</b><br>Sets value for high speed divider that takes the DCO output $f_{OSC}$ as its clock input.<br>000 = 4<br>001 = 5<br>010 = 6<br>011 = 7<br>100 = Not used.<br>101 = 9<br>110 = Not used.<br>111 = 11                                                                                                                                                                     |
| 4:0 | N1_7PPM[6:2]     | <b>CLKOUT Output Divider.</b><br>Sets value for CLKOUT output divider. Allowed values are [1] and [2, 4, 6, ..., $2^7$ ]. Illegal odd divider values will be rounded up to the nearest even value. The value for the N1 register can be calculated by taking the divider ratio minus one. For example, to divide by 10, write 0001001 (9 decimal) to the N1 registers.<br>0000000 = 1<br>1111111 = $2^7$ |

## Register 14. Reference Frequency

| Bit  | D7           | D6 | D5                | D4 | D3  | D2 | D1 | D0 |
|------|--------------|----|-------------------|----|-----|----|----|----|
| Name | N1_7PPM[1:0] |    | RFREQ_7PPM[37:32] |    |     |    |    |    |
| Type | R/W          |    |                   |    | R/W |    |    |    |

| Bit | Name              | Function                                                                                                                                                                                                                                                                                                                                                                                              |
|-----|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7:6 | N1_7PPM[1:0]      | <b>CLKOUT Output Divider.</b><br>Sets value for CLKOUT output divider. Allowed values are [1, 2, 4, 6, ..., $2^7$ ]. Illegal odd divider values will be rounded up to the nearest even value. The value for the N1 register can be calculated by taking the divider ratio minus one. For example, to divide by 10, write 0001001 (9 decimal) to the N1 registers.<br>$0000000 = 1$<br>$1111111 = 2^7$ |
| 5:0 | RFREQ_7PPM[37:32] | <b>Reference Frequency.</b><br>Frequency control input to DCO.                                                                                                                                                                                                                                                                                                                                        |

---

**Register 15. Reference Frequency**


---

| Bit  | D7                | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|-------------------|----|----|----|----|----|----|----|
| Name | RFREQ_7PPM[31:24] |    |    |    |    |    |    |    |
| Type | R/W               |    |    |    |    |    |    |    |

| Bit | Name              | Function                                                       |
|-----|-------------------|----------------------------------------------------------------|
| 7:0 | RFREQ_7PPM[31:24] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

---

**Register 16. Reference Frequency**


---

| Bit  | D7                | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|-------------------|----|----|----|----|----|----|----|
| Name | RFREQ_7PPM[23:16] |    |    |    |    |    |    |    |
| Type | R/W               |    |    |    |    |    |    |    |

| Bit | Name              | Function                                                       |
|-----|-------------------|----------------------------------------------------------------|
| 7:0 | RFREQ_7PPM[23:16] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

---

**Register 17. Reference Frequency**


---

| Bit  | D7               | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|------------------|----|----|----|----|----|----|----|
| Name | RFREQ_7PPM[15:8] |    |    |    |    |    |    |    |
| Type | R/W              |    |    |    |    |    |    |    |

| Bit | Name             | Function                                                       |
|-----|------------------|----------------------------------------------------------------|
| 7:0 | RFREQ_7PPM[15:8] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

---

**Register 18. Reference Frequency**

---

| Bit  | D7              | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|------|-----------------|----|----|----|----|----|----|----|
| Name | RFREQ_7PPM[7:0] |    |    |    |    |    |    |    |
| Type | R/W             |    |    |    |    |    |    |    |

| Bit | Name            | Function                                                       |
|-----|-----------------|----------------------------------------------------------------|
| 7:0 | RFREQ_7PPM[7:0] | <b>Reference Frequency.</b><br>Frequency control input to DCO. |

**Register 135. Reset/Freeze/Memory Control**

| Bit         | D7      | D6      | D5       | D4           | D3  | D2 | D1 | D0     |
|-------------|---------|---------|----------|--------------|-----|----|----|--------|
| <b>Name</b> | RST_REG | NewFreq | Freeze M | Freeze VCADC | N/A |    |    | RECALL |
| <b>Type</b> | R/W     | R/W     | R/W      | R/W          | R/W |    |    | R/W    |

Reset settings = 00xx xx00

| Bit | Name         | Function                                                                                                                                                                                                                                                                                                                                                          |
|-----|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7   | RST_REG      | <b>Internal Reset.</b><br>0 = Normal operation.<br>1 = Reset of all internal logic. Output tristated during reset.<br>Upon completion of internal logic reset, RST_REG is internally reset to zero.<br><b>Note:</b> Asserting RST_REG will interrupt the I <sup>2</sup> C state machine. It is not the recommended approach for starting from initial conditions. |
| 6   | NewFreq      | <b>New Frequency Applied.</b><br>Alerts the DSPLL that a new frequency configuration has been applied. This bit will clear itself when the new frequency is applied.                                                                                                                                                                                              |
| 5   | Freeze M     | <b>Freezes the M Control Word.</b><br>Prevents interim frequency changes when writing RFREQ registers.                                                                                                                                                                                                                                                            |
| 4   | Freeze VCADC | <b>Freezes the VC ADC Output Word.</b><br>May be used to hold the nominal output frequency of an Si571.                                                                                                                                                                                                                                                           |
| 3:1 | N/A          | Always Zero.                                                                                                                                                                                                                                                                                                                                                      |
| 0   | RECALL       | <b>Recall NVM into RAM.</b><br>0 = No operation.<br>1 = Write NVM bits into RAM. Bit is internally reset following completion of operation.<br><b>Note:</b> Asserting RECALL reloads the NVM contents in to the operating registers without interrupting the I <sup>2</sup> C state machine. It is the recommended approach for starting from initial conditions. |

**Register 137. Freeze DCO**

| Bit         | D7  | D6 | D5 | D4         | D3 | D2 | D1 | D0 |
|-------------|-----|----|----|------------|----|----|----|----|
| <b>Name</b> |     |    |    | Freeze DCO |    |    |    |    |
| <b>Type</b> | R/W |    |    |            |    |    |    |    |

Reset settings = 00xx xx00

| Bit | Name       | Function                                                                                |
|-----|------------|-----------------------------------------------------------------------------------------|
| 7:5 | Reserved   |                                                                                         |
| 4   | Freeze DCO | <b>Freeze DCO.</b><br>Freezes the DSPLL so the frequency configuration can be modified. |
| 3:0 | Reserved   |                                                                                         |

## 5. Si570 (XO) Pin Descriptions

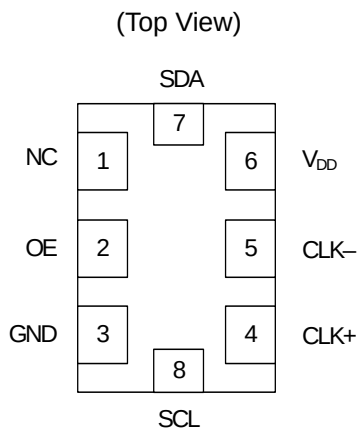


**Table 14. Si570 Pin Descriptions**

| Pin                                                                      | Name                   | Type                        | Function                                                    |
|--------------------------------------------------------------------------|------------------------|-----------------------------|-------------------------------------------------------------|
| 1                                                                        | NC                     | N/A                         | No Connect. Make no external connection to this pin.        |
| 2                                                                        | OE                     | Input                       | Output Enable:<br>See "7. Ordering Information" on page 32. |
| 3                                                                        | GND                    | Ground                      | Electrical and Case Ground.                                 |
| 4                                                                        | CLK+                   | Output                      | Oscillator Output.                                          |
| 5                                                                        | CLK-<br>(NC for CMOS*) | Output<br>(N/A for CMOS*)   | Complementary Output.<br>(NC for CMOS*).                    |
| 6                                                                        | V <sub>DD</sub>        | Power                       | Power Supply Voltage.                                       |
| 7                                                                        | SDA                    | Bidirectional<br>Open Drain | I <sup>2</sup> C Serial Data.                               |
| 8                                                                        | SCL                    | Input                       | I <sup>2</sup> C Serial Clock.                              |
| *Note: CMOS output option only: make no external connection to this pin. |                        |                             |                                                             |

## 6. Si571 (VCXO) Pin Descriptions

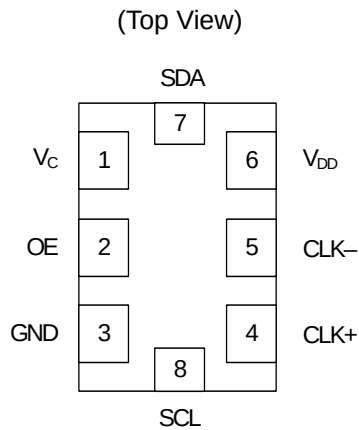


**Table 15. Si571 Pin Descriptions**

| Pin                                                                             | Name                   | Type                        | Function                                                    |
|---------------------------------------------------------------------------------|------------------------|-----------------------------|-------------------------------------------------------------|
| 1                                                                               | $V_C$                  | Analog Input                | Control Voltage                                             |
| 2                                                                               | OE                     | Input                       | Output Enable:<br>See "7. Ordering Information" on page 32. |
| 3                                                                               | GND                    | Ground                      | Electrical and Case Ground                                  |
| 4                                                                               | CLK+                   | Output                      | Oscillator Output                                           |
| 5                                                                               | CLK-<br>(NC for CMOS*) | Output<br>(N/A for CMOS*)   | Complementary Output.<br>(NC for CMOS*).                    |
| 6                                                                               | $V_{DD}$               | Power                       | Power Supply Voltage                                        |
| 7                                                                               | SDA                    | Bidirectional<br>Open Drain | I <sup>2</sup> C Serial Data                                |
| 8                                                                               | SCL                    | Input                       | I <sup>2</sup> C Serial Clock                               |
| <b>*Note:</b> CMOS output option only: make no external connection to this pin. |                        |                             |                                                             |

## 7. Ordering Information

The Si570/Si571 supports a wide variety of options including frequency range, start-up frequency, temperature stability, tuning slope, output format, and  $V_{DD}$ . Specific device configurations are programmed into the Si570/Si571 at time of shipment. Configurations are specified using the Part Number Configuration chart shown below. Silicon Labs provides a web browser-based part number configuration utility to simplify this process. Refer to [www.siliconlabs.com/VCXOPartNumber](http://www.siliconlabs.com/VCXOPartNumber) to access this tool and for further ordering instructions. The Si570/Si571 XO/VCXO series is supplied in an industry-standard, RoHS compliant, 8-pad, 5 x 7 mm package. Tape and reel packaging is an ordering option.

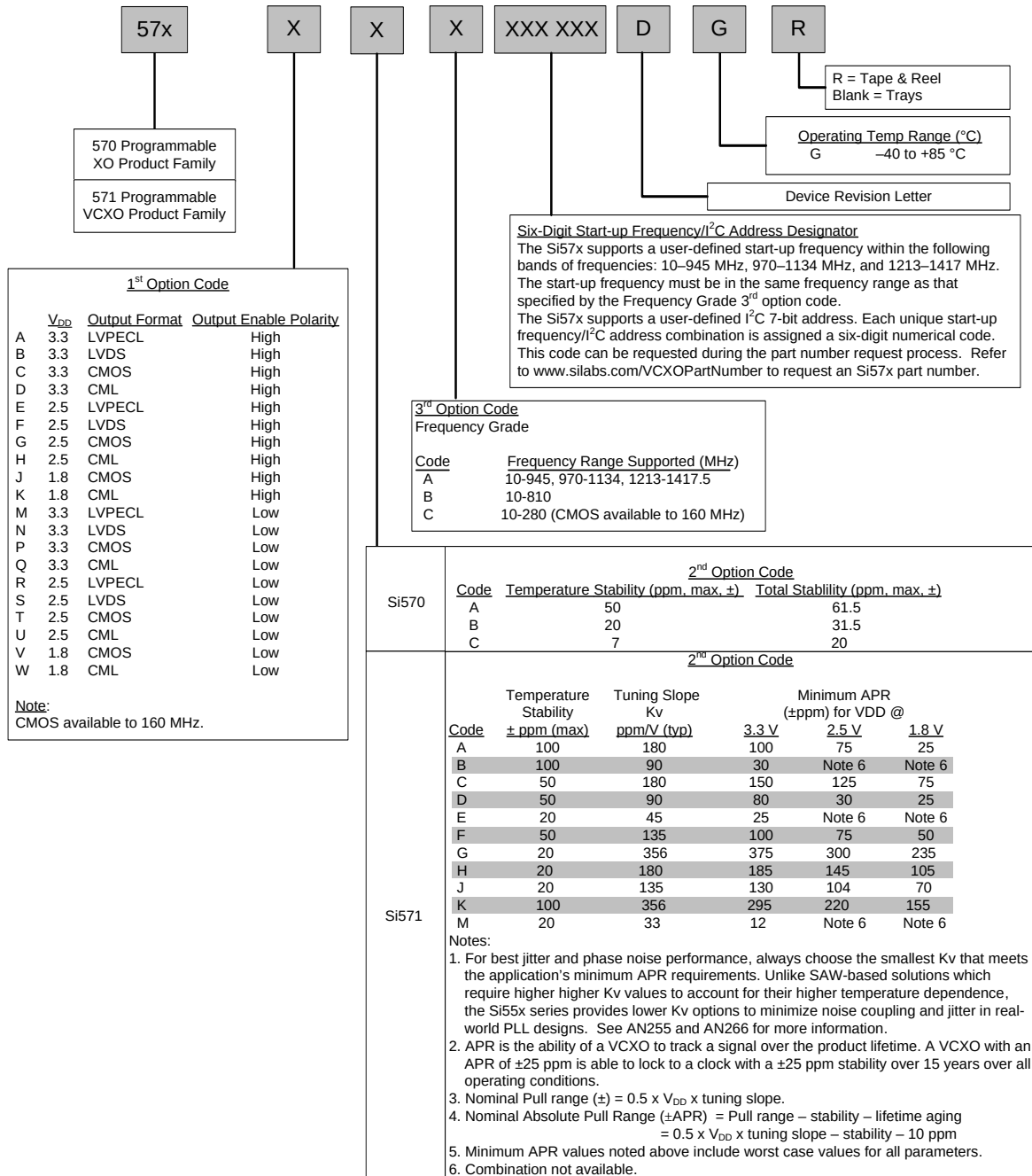


Figure 6. Part Number Convention

## 8. Si57x Mark Specification

Figure 7 illustrates the mark specification for the Si57x. Table 16 lists the line information.

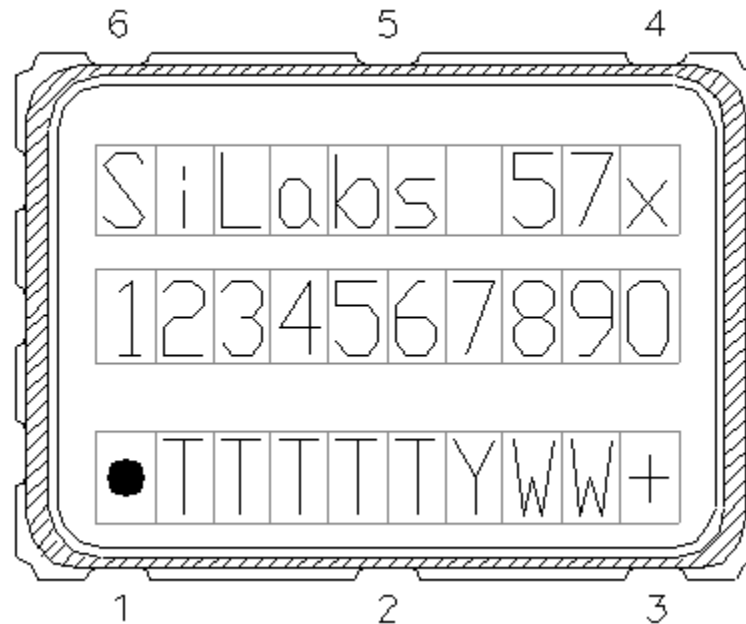


**Figure 7. Mark Specification**

**Table 16. Si57x Top Mark Description**

| Line | Position          | Description                                                                                                                               |
|------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | 1–10              | “SiLabs”+ Part Family Number, 57x (First 3 characters in part number where x = 0 indicates a 570 device and x = 1 indicates a 571 device) |
| 2    | 1–10              | Si570, Si571: Option1 + Option2 + Option3 + ConfigNum(6) + Temp                                                                           |
| 3    | <b>Trace Code</b> |                                                                                                                                           |
|      | Position 1        | Pin 1 orientation mark (dot)                                                                                                              |
|      | Position 2        | Product Revision (D)                                                                                                                      |
|      | Position 3–6      | Tiny Trace Code (4 alphanumeric characters per assembly release instructions)                                                             |
|      | Position 7        | Year (least significant year digit), to be assigned by assembly site (ex: 2007 = 7)                                                       |
|      | Position 8–9      | Calendar Work Week number (1–53), to be assigned by assembly site                                                                         |
|      | Position 10       | “+” to indicate Pb-Free and RoHS-compliant                                                                                                |

## 9. Outline Diagram and Suggested Pad Layout

Figure 8 illustrates the package details for the Si570/Si571. Table 17 lists the values for the dimensions shown in the illustration.

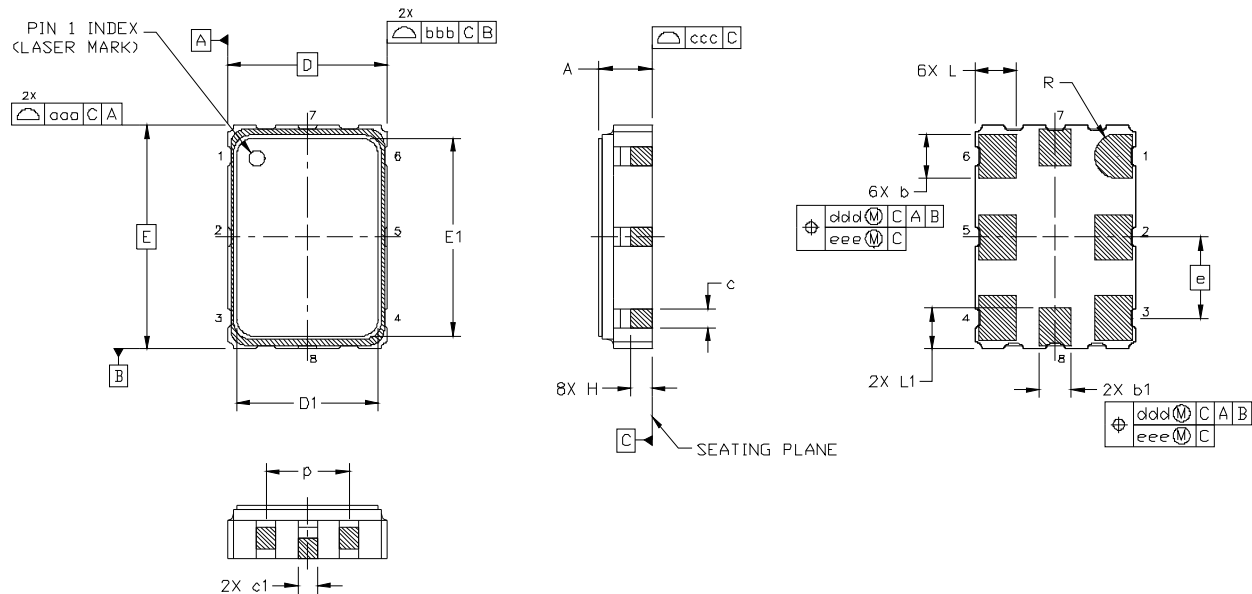


**Figure 8. Si570/Si571 Outline Diagram**

**Table 17. Package Diagram Dimensions (mm)**

| Dimension | Min      | Nom  | Max  |
|-----------|----------|------|------|
| A         | 1.50     | 1.65 | 1.80 |
| b         | 1.30     | 1.40 | 1.50 |
| b1        | 0.90     | 1.00 | 1.10 |
| c         | 0.50     | 0.60 | 0.70 |
| c1        | 0.30     | —    | 0.60 |
| D         | 5.00 BSC |      |      |
| D1        | 4.30     | 4.40 | 4.50 |
| e         | 2.54 BSC |      |      |
| E         | 7.00 BSC |      |      |
| E1        | 6.10     | 6.20 | 6.30 |
| H         | 0.55     | 0.65 | 0.75 |
| L         | 1.17     | 1.27 | 1.37 |
| L1        | 1.07     | 1.17 | 1.27 |
| p         | 1.80     | —    | 2.60 |
| R         | 0.70 REF |      |      |
| aaa       | —        | —    | 0.15 |
| bbb       | —        | —    | 0.15 |
| ccc       | —        | —    | 0.10 |
| ddd       | —        | —    | 0.10 |
| eee       | —        | —    | 0.05 |

**Note:**

1. All dimensions shown are in millimeters (mm) unless otherwise noted.
2. Dimensioning and Tolerancing per ANSI Y14.5M-1994.

## 10. 8-Pin PCB Land Pattern

Figure 9 illustrates the 8-pin PCB land pattern for the Si570/Si571. Table 18 lists the values for the dimensions shown in the illustration.

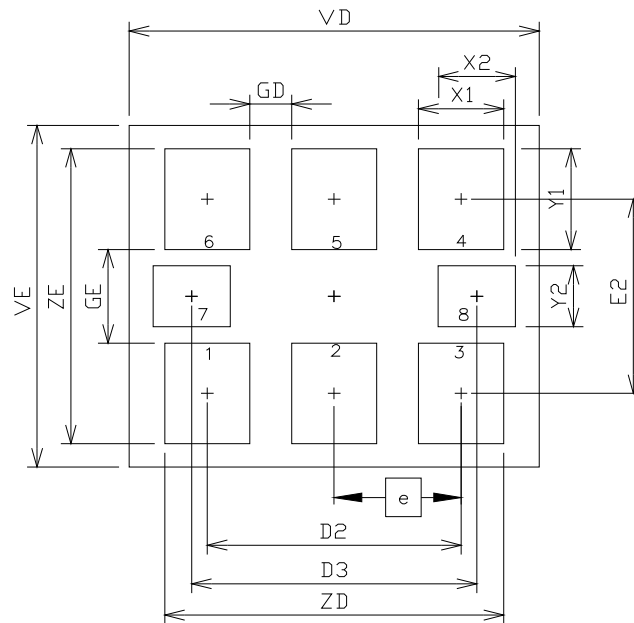


**Figure 9. Si570/Si571 PCB Land Pattern**

**Table 18. PCB Land Pattern Dimensions (mm)**

| Dimension | Min       | Max  |
|-----------|-----------|------|
| D2        | 5.08 REF  |      |
| D3        | 5.705 REF |      |
| e         | 2.54 BSC  |      |
| E2        | 4.20 REF  |      |
| GD        | 0.84      | —    |
| GE        | 2.00      | —    |
| VD        | 8.20 REF  |      |
| VE        | 7.30 REF  |      |
| X1        | 1.70 TYP  |      |
| X2        | 1.545 TYP |      |
| Y1        | 2.15 REF  |      |
| Y2        | 1.3 REF   |      |
| ZD        | —         | 6.78 |
| ZE        | —         | 6.30 |

**Note:**

1. Dimensioning and tolerancing per the ANSI Y14.5M-1994 specification.
2. Land pattern design follows IPC-7351 guidelines.
3. All dimensions shown are at maximum material condition (MMC).
4. Controlling dimension is in millimeters (mm).

## DOCUMENT CHANGE LIST

### Revision 1.0 to Revision 1.1

- Restored programming constraint information on page 15 and in Table 12, page 12.
- Clarified NC (No Connect) pin designations in Tables 13–14 on pages 22–23.

### Revision 1.1 to Revision 1.2

- Replaced “Unfreeze to Newfreq Delay” with the clearer terminology “Unfreeze to Newfreq Timeout” on page 15 and in Table 11 on page 13.
- Added Freeze M procedure on page 14 for preventing output clock changes during small frequency change multi-register RFREQ writes.
- Added Freeze M, Freeze VCADC, and RST\_REG versus RECALL information to Register 135 references in “4. Serial Port Registers” on pages 17 and 20.
- Added Si570 20 ppm Total Stability Ordering Option to Figure 6 on page 32.
- Updated Figure 8 and Table 17 on page 34 to include production test sidepads. This change is for reference only as the sidepads are raised above the seating plane and do not impact PCB layout.
- Corrected errors in Table 10 on page 12.

### Revision 1.2 to Revision 1.3

- Updated Table 3 on page 6 to include 7 ppm temperature stability and 20 ppm to stability parameters. Also changed aging test condition (frequency drift over life) from 15 years to 20 years.
- Updated 2.5 V/3.3 V and 1.8 V CML output level specification for Table 4 on page 7.
- Added footnotes clarifying max offset frequency test conditions in Table 5 on page 8.
- Updated ESD HBM sensitivity rating and the JEDEC standard in Note 2 in Table 13 on page 14.
- Updated Table 10 on page 12 to include “Moisture Sensitivity Level” and “Contact Pads” rows.
- Added Si570 7 ppm Total Stability Ordering Option to Figure 6 on page 32.
- Updated Figure 7 and Table 16 on page 33 to reflect specific marking information. Previously, Figure 7 was generic.
- Clarified “3.1.2. Reconfiguring the Output Clock for Large Changes in Output Frequency” on page 16 and added new registers 13-18 in “4. Serial Port Registers” on page 23 for the Si570 7 ppm temperature stability / 20 ppm total stability ordering option.

- Added text to “3. Functional Description” on page 15, paragraph 1, to state that the total output jitter complies to and exceeds strict requirements of various high-speed communication systems.

### Revision 1.3 to Revision 1.4

- Added Table 12, “Thermal Characteristics,” on page 13.

### Revision 1.4 to Revision 1.5

- Added Section 3.2 and 3.3.



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