Introduction

This application note will discuss some of the key parameters, measurements and concerns regarding the drive level specification, which is typically called high driving the crystal. With the advancement in quartz crystal technology, both the packages and the internal crystal blanks have continued to migrate to smaller sizes. This reduction in crystal blanks has led to the reduction in the drive level capability and datasheet specification of many of the crystal manufacturers. In the past, the standard package was HC49 which can handle a relatively large crystal blank with a common maximum drive level specification of 1mW. At the present time, surface mount crystal packages are as small as 1.6mm x 1.2mm which commonly specifies a 100uW maximum and 10uW typical for drive level.

This reduction in drive level has produced contrasting interest between the crystal manufacturers and the silicon circuit designers who design phase lock loops (PLL's) devices with integrated crystal oscillators. The circuit designers want to operate the crystal oscillator at relatively high drive levels for best phase noise performance. This is accomplished by maximizing the clock voltage across the crystal relative to the oscillator noise spectral density at the clock frequency. In contrast, the crystal manufactures are reducing the blank size in order to minimize the amount of quartz material used. This inherently reduces the drive level specifications. In addition, crystal manufacturers are using the smaller blanks and retrofitting them into larger packages like HC49. This has created issues in finding crystal manufacturers with higher drive level specifications especially for Legacy designs which many times are being forced to use lower drive level rated crystals. In many applications, lower drive level crystal can be used, but special attention must be given to some key parameters.

Crystal drive level is the amount of power dissipated in a crystal. It can be calculated by measuring the excitation current flowing through the crystal blank. It can affect, among others, the motional resistance, resonance frequency and phase-noise of the crystal. As the excitation current through the crystal increases, the drive level and the amplitude of crystals vibration also increase, causing changes in both the resistance and frequency.

A simple analysis in sweeping the drive level can be performed to verify changes in both resistance and frequency of the crystal. This analysis, typically called Drive Level Dependence (DLD), can be taken using a Saunders & Associates (S&A) 250B/C desktop network analyzer. Refer to figure 1. S&A manufacturers test and production systems for quartz crystals, oscillators, filters, and components. It has become an industry standard and preferred test system by many of the leading crystal manufactures. This desktop system is relatively inexpensive and is essential if designing or using silicon component, which require quartz crystals.

Figure 1. 250B/C Network Analyzer
DLD Sweep

Figure 2. DLD Sweep Result

The DLD sweep in figure 2 shows the effect of both the motional resistance and frequency shift for a drive level between 10µW and 1000µW. The left side Y axis is the motional resistance and the right side the PPM variation with the x axis being the drive level. This DLD sweep was done at room temperature.

Crystal Drive Level and Power Dissipation Example

The internal oscillator of an IDT clock synthesizer is to be used with an external crystal. A particular crystal is to be used and the compatibility of the crystal drive level with the current provided by the IDT oscillator must be checked.
Consider the crystal to have the following specifications:

**Table 1. Specification of Quartz Crystal Units**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nominal frequency (F&lt;sub&gt;n&lt;/sub&gt;)</td>
<td>27.000MHz</td>
</tr>
<tr>
<td>2</td>
<td>Holder type</td>
<td>SX-1 T/R</td>
</tr>
<tr>
<td>3</td>
<td>Mode of oscillation</td>
<td>Fundamental (AT)</td>
</tr>
<tr>
<td>4</td>
<td>Storage temperature range</td>
<td>-40°C to +85°C</td>
</tr>
<tr>
<td>5</td>
<td>Frequency calibration</td>
<td>±0.003% (±30ppm)</td>
</tr>
<tr>
<td>6</td>
<td>Frequency drift in operating temperature range</td>
<td>±0.003% (±30ppm)</td>
</tr>
<tr>
<td>7</td>
<td>Equivalent resistance (C&lt;sub&gt;i&lt;/sub&gt;)</td>
<td>40 ohms max.</td>
</tr>
<tr>
<td>8</td>
<td>Load capacitance (C&lt;sub&gt;L&lt;/sub&gt;)</td>
<td>20pF</td>
</tr>
<tr>
<td>9</td>
<td>Drive level (D/L)</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>Test impedance meter</td>
<td>SAUNDERS 250A</td>
</tr>
<tr>
<td>11</td>
<td>Shunt capacitance (C&lt;sub&gt;0&lt;/sub&gt;)</td>
<td>7.0 max. pF</td>
</tr>
<tr>
<td>12</td>
<td>Insulation resistance</td>
<td>500 MegaOhm min. / DC 100V</td>
</tr>
<tr>
<td>13</td>
<td>Aging rate a year</td>
<td>±0.0003%</td>
</tr>
</tbody>
</table>

From the above specifications it can be seen that the crystal is a 27 MHz Fundamental mode AT cut crystal. The recommended load capacitance is 20pF and the maximum drive level is specified to be 100uW.

When tested on Saunders 250B/C Network Analyzer the measured parameters for the crystal were:

- C<sub>L</sub> = 19.02pF
- Target Frequency FL = 27 MHz
- FL ppm error = 0ppm
- C<sub>0</sub> = 3.8pF
- RR (Rs) = 7.5ohms
- RL (Resistance at FL) = 10.8 ohms (RR * ((1+C<sub>0</sub>/C<sub>L</sub>)^2))
- C<sub>1</sub> (Cs) = 14.9fF
- L (Ls) = 2.33mH

The crystal was connected to the internal oscillator X1 and X2 pins of the IDT clock synthesizer IC and the tuning capacitors were adjusted to make the output frequency 0 ppm. No series resistor (Rx) on X2 was added at this time. The oscillations were stable every time on power-up.

The current on X2 was measured using an AC current probe and was found to be 27mA (Peak-Peak). This gives us 27 / (2*sqrt(2)) = 9.54 mA (rms current).

Power Dissipation = (9.54) ^ 2 * 7.5 = 683 uW.

At this point we can see that we will be violating the maximum power dissipation specification of the crystal (100uW). In order to address this issue the following steps are taken.

Insert a series resistor of 3.9 Kohms (by trial) on X2 to reduce the drive. The current on X2 with 3.9 Kohms series resistor = 7.2mA (Peak-Peak). This gives us roughly 2.545mA (rms). The power dissipation is (2.545) ^ 2 * 7.5 = nearly 50uW of power dissipation

The power dissipation of the crystal is well under the 100uW maximum power dissipation specification. The output frequency was monitored upon repeated power cycling (with the 3.9 Kohms resistor is place) and found to be within the accuracy specification. The output was verified to be a locked and stable square wave.
Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.

2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.

3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.

4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.

5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.

   - *Standard*: Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.
   - *High Quality*: Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.

   Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.

6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.

7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or disaster to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.

8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.

9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.

10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.

11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.

12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

(Note1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.

(Note2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:
www.IDT.com/go/support

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.

© 2019 Renesas Electronics Corporation. All rights reserved.