Quality-Technology-Series (*1):

Points for Preventing Abnormal Oscillation When Designing Oscillator Circuits

(*1) This series explains the specific examples (design, process, construction method, handling, etc.) in which the product function becomes impossible to maintain or becomes defective and the entire set becomes defective, as well as the reason why the product becomes defective.

1. For stable oscillation

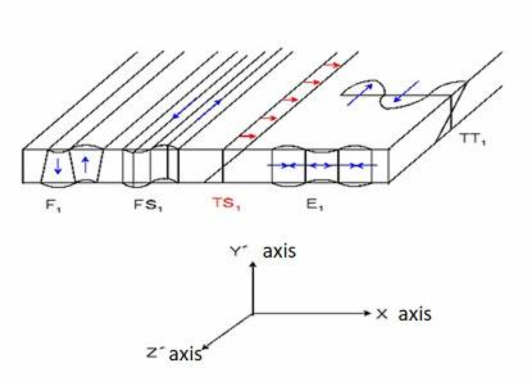
Crystal unit, which is a passive component, needs to optimize the oscillating condition with the customer's circuit. When designing an oscillator circuit, it is important to confirm beforehand that the crystal unit is matched with the oscillator circuit. Symptoms such as non-oscillation or frequency misalignment may occur if the matching is not appropriate. In particular, abnormal oscillation phenomenon may lead to unexpected problems in the market, etc. Based on past trouble cases, we propose preventive measures for abnormal oscillation.

2. What is abnormal oscillation?

When the crystal unit oscillates in modes other than normal oscillation modes, it is called abnormal oscillation. Other than the normal oscillation mode, there is oscillation by coupling with the spurious, overtone oscillation, etc.

3. Abnormal oscillation by coupling with spurious

The AT-cut crystal unit uses the thickness sliding mode as the oscillation mode, but there are many other spurious modes (flexure and face-shear etc.) in addition to this (Fig. 1).



TS_1 : Thickness-Shear
F_1 : Flexure
FS_1 : Face-Shear
E_1 : Extension
TT_1 : Thickness-Twister

Fig. 1 Vibration mode of AT-CUT crystal unit

The higher frequencies of these spurious can couple with the main oscillation and affect the frequency temperature characteristics of the main oscillation. The crystal unit equivalent circuit including the spurious is shown in Fig. 2.

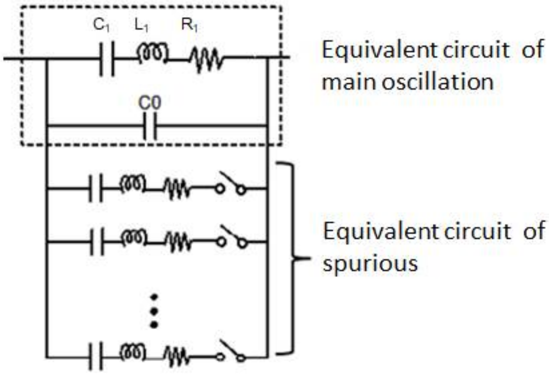
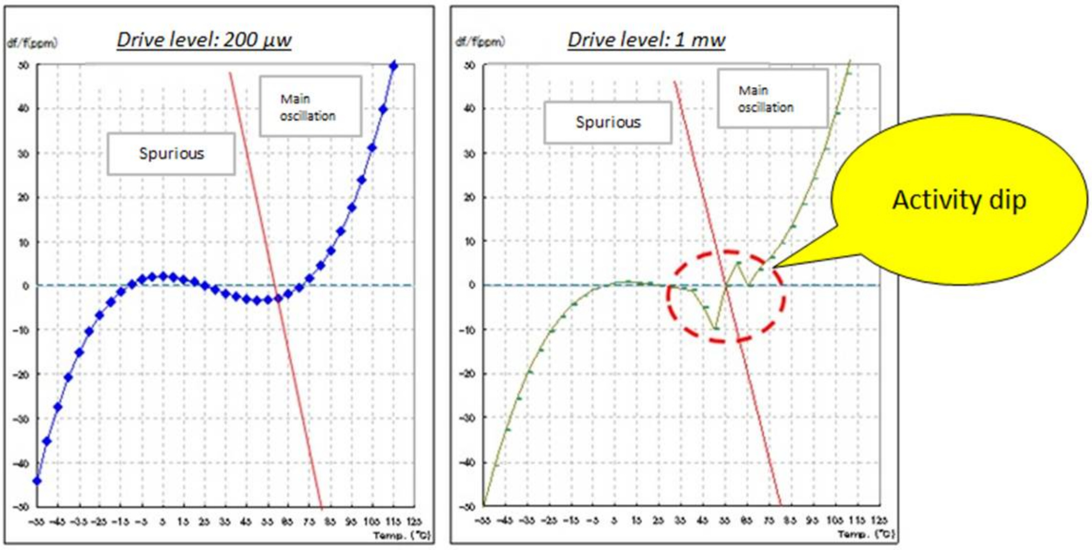


Fig. 2 Crystal unit equivalent circuit

Among the spurious, there is a high risk of coupling to the main vibration, which is flexure and face-shear, and the frequency changes by changing the dimensions depending on the crystal element dimensions. In addition, because the temperature characteristics of the main vibration and the bending vibration differ, coupling with the main vibration occurs at a certain temperature when the temperature is changed, causing a phenomenon (Activity dip) in which the oscillation frequency changes rapidly, resulting in abnormal oscillation (Fig. 3).



(a) Normal drive level (b) Excessive drive level

Fig. 3 Dependence of Activity dip on drive level (*2)

For this reason, NDK suppresses these spurious and prevents Activity dip by optimizing the crystal element and electrodes dimensions of the crystal unit. However, note that if a drive level exceeding the crystal unit specifications is applied when designing the oscillator, Activity dip may occur due to coupling of the main vibration with the spurious. When measuring drive level, the crystal current (i) flowing into the crystal unit can be measured with current probes and calculated from the crystal current (i), crystal unit equivalent circuit constants (R_1, C_0), and load capacitance (C_L) (*3).

(*2) drive level (DL): The power required for the crystal unit to oscillate.

(*3) How to calculate drive level:

$DL=R_L\times i^2$ $R_L=R_1\,(1+C_0/C_L)^2$

(R_L=load resonance resistance, R_1=equivalent series resistance, C_0=shunt capacitance, C_L=load capacitance)

Please contact us separately for details of the measurement method of the quartz current (i).

When controlling the drive level when designing the oscillator, select an appropriate Rd (Fig. 4). However, note that if the Rd-value is too large, the output level may be small, resulting in problems that the customer's subsequent circuits cannot be driven.

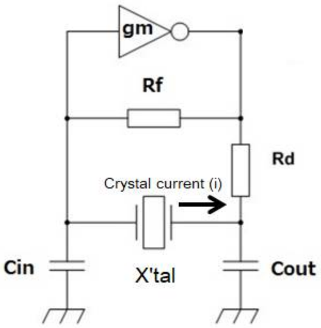


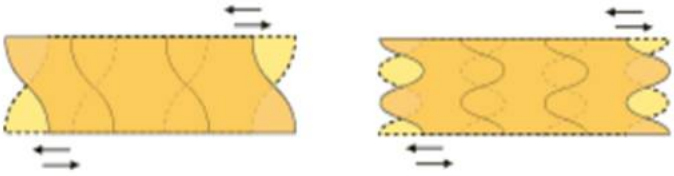
Fig.4 Oscillation Circuit and Crystal Current

4. Abnormal oscillation in crystal unit overtone mode

We have already stated that the AT-cut crystal unit uses the Thickness Slip mode, but the crystal element thickness and oscillating frequency can be calculated by the following formula:

F(MHz) = 1.67×n/t(mm) (n: overtone order, t: crystal element thickness)

For example, if the fundamental is 8 MHz, the third overtone is 24 MHz (Fig.5).



fundamental

third overtone

Fig.5 Thickness Sliding Vibration

Fig. 6 shows the equivalent circuits of the crystal oscillators..

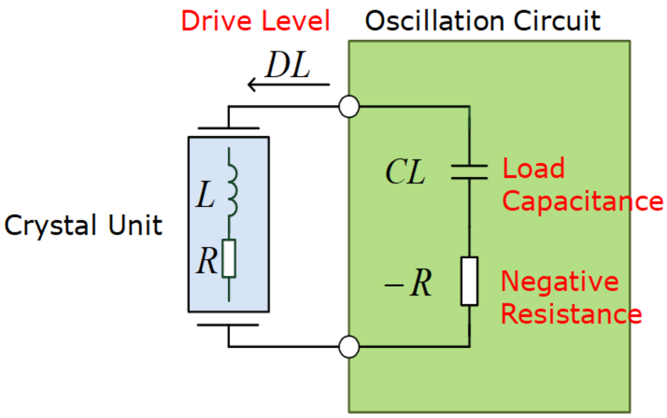


Fig.6 Equivalent circuits of crystal oscillators

The oscillator circuit-side is indicated by a negative resistor (-R) and load capacitance (C_L). The oscillator circuit-side does not start in the equivalent resistance below the crystal unit. Whether to oscillate with the fundamental wave or with the third-order overtone is determined by the negative resistance characteristics (-R) of the IC, but the negative resistance of the oscillation circuit has frequency characteristics, so we must consider it.

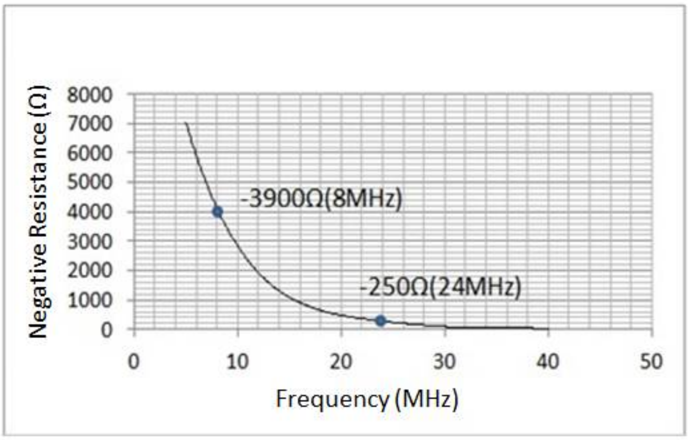


Fig.7. Frequency Characteristics of Negative Resistance

For example, when oscillating a crystal unit with a fundamental of 8 MHz only with a fundamental wave, the relationship shown in Fig. 7 lies in the negative resistance of the fundamental wave and the negative resistance of the third overtone. Therefore, the negative resistance of the fundamental wave must be sufficiently secured and oscillation must not occur with the third overtone. If the Typical value of the equivalent resistance is 120 Ω for the fundamental wave and 800 Ω for the third overtone at the SMD crystal unit of 8 MHz, oscillation is performed with the fundamental wave. In this case, there is no concern of oscillation with the third overtone.

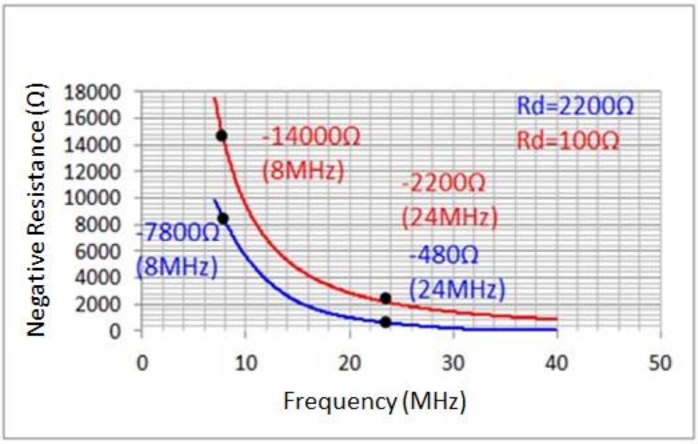


Fig.8 Frequency Characteristics of Negative Resistance (Effect of Rd)

However, as shown in Fig.8, if there is a negative resistance of -2200 Ω at 24 MHz as in the frequency characteristics of the negative resistance shown by the red line, oscillation of both the fundamental wave and the third overtone becomes possible. Normally, the oscillation occurs with the fundamental wave that starts quickly at the start of oscillation. However, the oscillation may occur with the third overtone depending on the temperature environment, etc., which may cause abnormal oscillation.

In this way, when using an IC with large negative resistance in a wide frequency range, the negative resistance must be appropriately suppressed. As a solution, add Rd in the oscillator circuit shown in Fig. 4 to control the current flowing into the crystal unit, and adjust the negative resistance. Fig.8 blue line shows the negative resistance when Rd 2200 Ω is added. The negative resistance is -480 Ω for a third overtone equivalent resistance of 800 Ω, indicating that abnormal oscillations can be prevented.

5. To prevent abnormal oscillation

We have explained some examples of abnormal oscillation, but when designing oscillator circuits, we can prevent problems by thoroughly examining the matching of crystal unit and ICs. For specific information on ICs and crystal unit matching, refer to the NDK website. If you can use the NDK’s circuit analyses service at the prototype stage, you will be able to propose an appropriate circuit constant.