Research on Miniaturization of Low –Frequency Range SMD Crystal Unit

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***Abstract*—In this paper, the realization of miniature design for Low-Frequency for SMD Crystal units has been presented. Increasing progress towards miniaturization of electronics part which includes ultra-small crystal units have evolved significantly in the last few years. However, miniaturization for crystal units categorically excluded designs for specific low-frequencies due to its extreme difficulties. This research explains the difficulties and introduce the a SMD crystal unit that is until recently unable to realize this complicated low-frequency (8MHz~4MHz range) in a package measuring 8.0x4.5x1.8mm which employs the thickness-shear vibration mode that features superior temperature characteristic.**

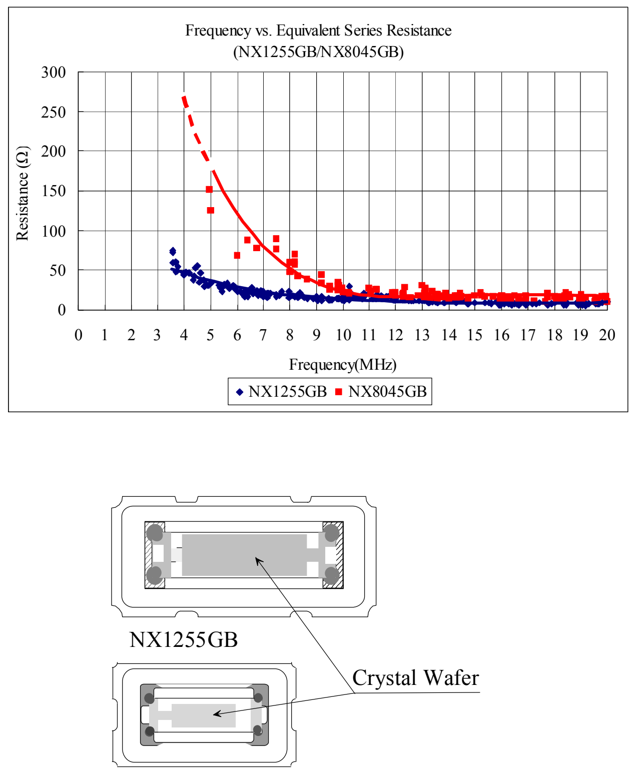
I. INTRODUCTION

It is no exaggeration to say that as for wearable electronic appliances, besides its compact features, "power saving" also plays as one of an important keyword. Also, it is obvious that the same electrical characteristic and reliability need to be maintain as equal to the existing product. In order to supply low frequency, there are several ways such as using directly "thickness-shear vibration mode" as the frequency source, or using other vibration modes, or by dividing a higher frequency and obtain the desired specified frequency. However, each method has its own merits and demerits in the point of temperature characteristic, cost, power consumption and price range.

Oscillation frequency (F_0) of a thickness-shear crystal unit can be expressed as below equation.

$$Fo(KHz) = 1670 / t\,(mm)\,. \quad (1)$$

However, along with the dimension becomes small, as an oscillator, influence around the vibration area increase. From above equation (1), the lower the frequency gets, thickness (t) is thicker and at the same time the side ratio (width, w / thickness, t) value becomes smaller and unwanted spurious mode is easier to occur. As a result, stable frequency can not be obtained and causes an increase of equivalent resistance, one of the conditions for determining how easily a crystal can oscillate. Design that keeps vibration loss to a minimum need to be develops to ensure stable oscillation even on a mass-production scale. This increase in equivalent resistance is shown in Figure 1 on comparison data of a previous package size 11.8x5.5x2.5mm package SMD crystal unit. This pattern, developed from the extension of current design, shows that within low-frequency range, not only equivalent resistance value increase, but also as for the structure/characteristic of the crystal unit itself, supporting method, electrode formations and connection between external terminals etc also can interferes characteristic, making commercialization more difficult.



a. Data from our Crystal unit product

Figure 1. Comparison Equivalent Resistance on Crystal size

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II. Specification

The target specification for this design is shown in Table I.

TABLE I. NX8045GB 4MHz Target Specification

Target Specification	
Item	***Spec***
Nominal Frequency	4.000MHz
Overtone	Fundamental
Frequency Tolerance(25±3°C)	±30 x 10^{-6}
Temperature Characteristics (in reference to +25°C)	±180 x 10^{-6}
Operating Temperature Range	-40°C~ 125°C
Equivalent Series Resistance	280Ω max (Avg 100Ωbelow)
Drive Level	50µW
Operable Temperature Range	-40°C~ 125°C

III. Device Design

A. NX8045GB Design outline

Along with the package miniaturization, the inside crystal wafer became small which make it difficult to realize low frequency. Therefore, products are generally made in higher frequency at first and then miniaturized. However, the power consumption of the circuit increases when making it to the high frequency and thus miniaturization and electrical power saving did not go together. Competing demands for miniaturization and electrical power saving are balanced only by miniaturizing "low frequency range."

There are some other vibration modes other than "thickness-shear vibration mode" to realize lower frequency. However, we aimed to develop it in "thickness-shear vibration mode" which has the superior temperature characteristics, possessing high reliability, and in which by adopting an 8.0x 4.5mm SMD package, we can realize the conventional electrical characteristics and price range. External Dimension and Internal Construction drawing are shown in Figure 2 and 3.

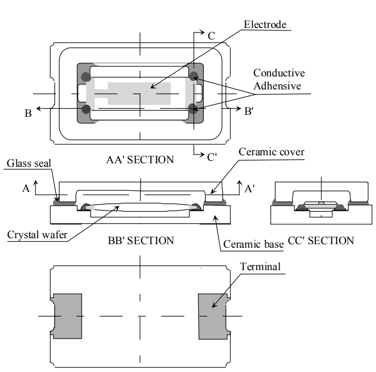


Figure 2. Internal Construction Drawing.

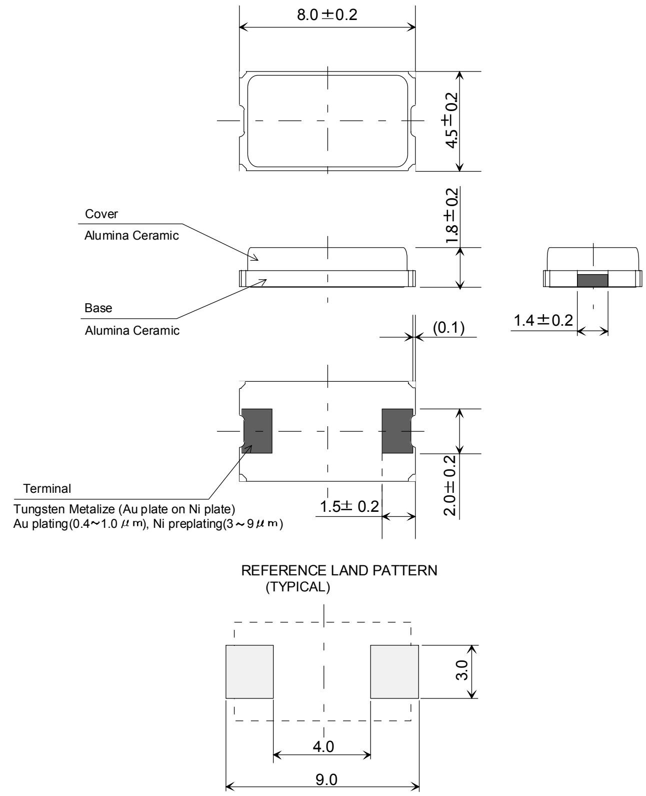


Figure 3. Internal Construction Drawing.

In order to realize this NX8045GB 4MHz's electrical characteristic equivalent to those of its predecessor, the NX1255GB, we have revised the design of crystal wafer and its production method.

By using the design developed from our original IT technology and design simulations results, new highly precise crystal wafer production method for miniature crystal wafer was applied and continuous feedback of testing , results an optimum design that able to overcome the bad effects against the equivalent resistance value characteristic.

B. Simulation of NX8045GB 4MHz

Simulation result by Finite Element Method(FEM) using ANSYS software is shown in Figure 4. This simulation is a guideline for the optimum beveling condition in order to minimize the effect from the construction to hold crystal wafer that will fit into a 8.0x 4.5 x 1.8mm package and to keep away unwanted spurious due to miniaturization, optimum beveling condition.

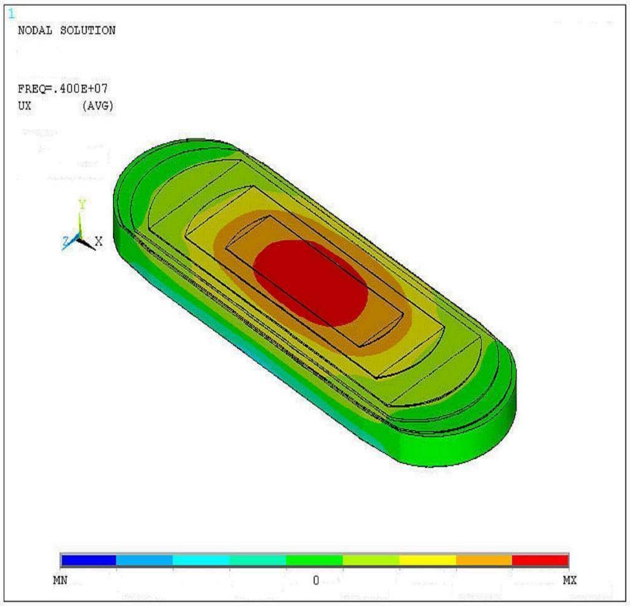
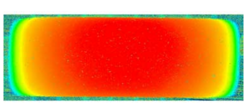
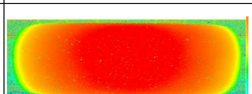


Figure 4. Side View of Crystal Wafer

C. Evaluation on beveling form

Measurement result one beveling form which gives big influence to crystal unit's characteristic is shown in Figure 5 and Table II. By knowing the right amount of beveling form on testing sample, bevel condition which gives bad effect on equivalent resistance can be minimize.

TABLE II. MEASUREMENT RESULT ON BEVEL FORM

	Testing 1	***Testing 2***
Flat length	L_1	$L_2 = L_1 \times 0.9$
Bevel depth	D_1	$D_2 = D_1 \times 1.3$
Surface Photo		
Equivalent Series Resistance	600Ω	100Ω

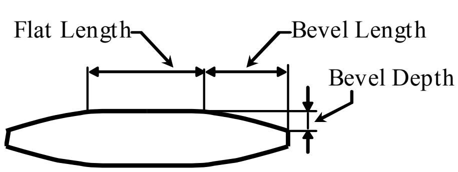


Figure 5. Side view of crystal wafer:

IV. MEASUREMENT RESULTS

Measurement results on testing result of NX8045GB 4MHz are shown as below.

A. Temperature Characteristic

Temperature characteristic results are shown in Figure 6. Equivalent Resistance value maintained the same characteristic as the current product of 100Ω which kept the excellent temperature characteristic of Thickness-shear vibration mode.

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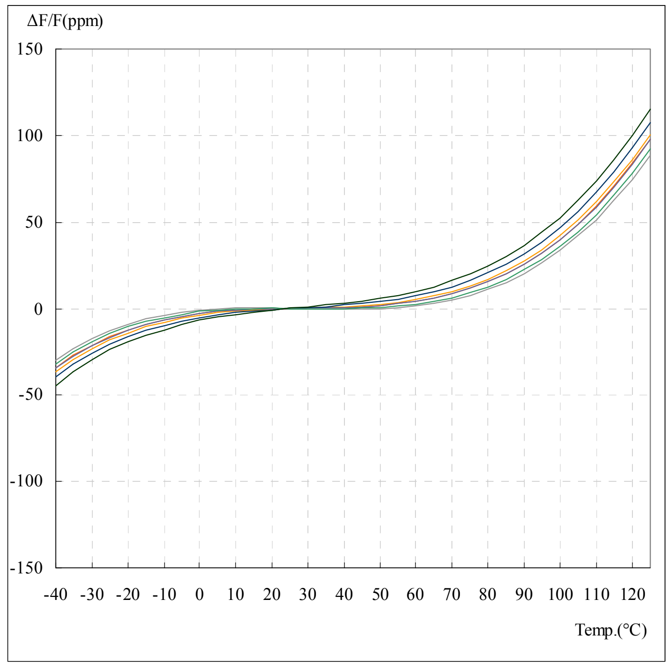

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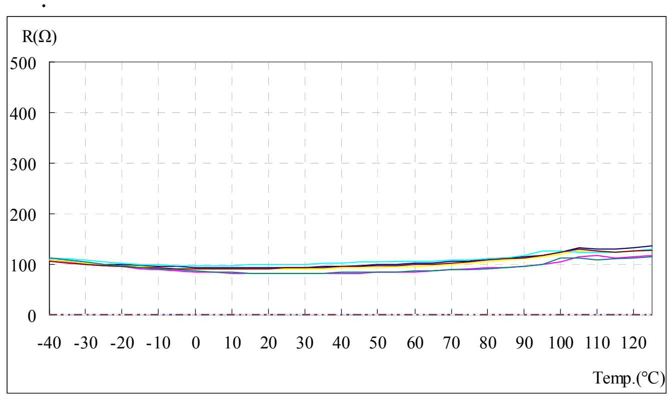

Figure 6. Temperature Characteristic

B. Equivalent Constant

Electric equivalent constant result is shown in Table 7 ~9. In Table V, capacitance ratio shows equal characteristic of only increment of 1.3 times despite of the size difference.

TABLE III. ELECTRIC EQUIVALENT CONSTANT (TYP)

Item	*NX1255GB*	*NX8045GB*
Series Resistance, R(Ω)	46.7	97.2
Shunt Capacitance, C0(pF)	1.51	1.33
Motional Capacitance, C1(fF)	4.67	3.19
Series Inductance, L(mH)	341	497
Quality factor, Q	181k	118k
Capacitance ratio, C0/C1	324	417

TABLE IV. EQUIVALENT RESISTANCE

<table>
<tr><th>R(Ω)</th><th>NX1255GB</th><th>NX8045GB</th></tr>
<tr><td>240</td><td></td><td></td></tr>
<tr><td>220</td><td></td><td></td></tr>
<tr><td>200</td><td></td><td></td></tr>
<tr><td>180</td><td></td><td></td></tr>
<tr><td>160</td><td></td><td></td></tr>
<tr><td>140</td><td></td><td></td></tr>
<tr><td>120</td><td></td><td>||||||||</td></tr>
<tr><td>100</td><td></td><td>||||||||||||||||||||||</td></tr>
<tr><td>80</td><td>||</td><td></td></tr>
<tr><td>60</td><td>||||||||||||||||||||||||||</td><td></td></tr>
<tr><td>40</td><td>||</td><td></td></tr>
<tr><td>20</td><td></td><td></td></tr>
<tr><td>AVG</td><td>46.7</td><td>97.2</td></tr>
<tr><td>STD DEV.</td><td>4.2</td><td>8.1</td></tr>
<tr><td>MAX</td><td>67.6</td><td>118.2</td></tr>
<tr><td>MIN</td><td>39.6</td><td>80.1</td></tr>
<tr><td>N</td><td>30</td><td>30</td></tr>
</table>

TABLE V. CAPACITANCE RATIO

<table>
<tr><th>C0/C1</th><th>NX1255GB</th><th>NX8045GB</th></tr>
<tr><td>520</td><td></td><td></td></tr>
<tr><td>500</td><td></td><td></td></tr>
<tr><td>480</td><td></td><td></td></tr>
<tr><td>460</td><td></td><td></td></tr>
<tr><td>440</td><td></td><td>||||||||||</td></tr>
<tr><td>420</td><td></td><td>|||||||||||||||||</td></tr>
<tr><td>400</td><td></td><td>|||</td></tr>
<tr><td>380</td><td></td><td></td></tr>
<tr><td>360</td><td>|</td><td></td></tr>
<tr><td>340</td><td>|||||||||||||||||</td><td></td></tr>
<tr><td>320</td><td>||||||||||||</td><td></td></tr>
<tr><td>300</td><td></td><td></td></tr>
<tr><td>AVG</td><td>324</td><td>417</td></tr>
<tr><td>STD DEV.</td><td>7</td><td>9</td></tr>
<tr><td>MAX</td><td>341</td><td>438</td></tr>
<tr><td>MIN</td><td>314</td><td>398</td></tr>
<tr><td>N</td><td>30</td><td>30</td></tr>
</table>

C. New NX8045GB Photo

New low-frequency NX8045GB (8.0x4.5x1.8mm) and our conventional model NX1255GB (11.8x5.5x2.5mm) comparison photo is shown in Figure 7. Comparing with the former model, a capacity of 40% smaller and smaller base area of 55% miniaturization has been realized.

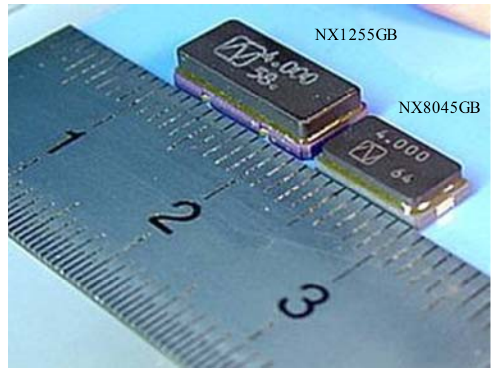

Figure 7. New NX8045GB Photo

V. CONCLUSION

By using our original IT technology, continuous feedback of testing results was optimized to gain an ideal design which eliminates any bad influence factors against equivalent resistance and satisfies our target specification. As for crystal wafer process, we also use our original new improved method with a satisfactory mass production capability. This low-frequency range SMD crystal unit has already been commercialize as our NDK model name NX8045GB. The reliability of this product was kept equally the same characteristic with the other same type products and the fact that the NX8045GB series meets AEC-Q200 standard, make it applicable for use in automotive electronics device.

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