10^{-10}-LEVEL SIMPLE SINGLE-OVEN OCXO

Manabu Ito*, Hiroyuki Mitome, and Takeo Oita
Nihon Dempa Kogyo Co., Ltd., Saitama, Japan
1275-2, Kamihirose, Sayama-shi, Saitama 350-1321, Japan
E-mail :** ***itom@ndk.com

Abstract

Combination of the Finite Element Method for thermal analysis and Harmonic Balance oscillation analysis can achieve a highly frequency/temperature-stable OCXO with 10^{-10}-level frequency/temperature performance for a wide temperature range using a simple single oven. We examined one with a single oven assuming operating temperatures up to +85 deg C. In this paper, we are able to see the possibility of the realization of a simple single-oven OCXO corresponding to the wide temperature range of a double-oven-type OCXO of equivalent frequency stability.

1. INTRODUCTION

LTE (Long Term Evolution) for next-generation mobile communication network systems has been requiring a higher frequency stable reference clock, covering a wide temperature range, with an OCXO as a reference oscillator. The double-oven-type OCXO (DOCXO) has been widely used, though it is applicable for a higher temperature range such as +85 deg C by reason of difficulties getting the particular temperature difference between both the inner and outer oven cavities. So usually the maximum operating temperature range of the DOCXO is +70 deg C. On the other hand, there is a single-oven-type OCXO that can be applied to the higher temperature range of up to +85 deg C, but its frequency stability performance is about a few ppb. To complement these two situations of OCXO technology to requirements of LTE application, the design optimization by the combination of the Finite Element Method (FEM) for thermal analysis and Harmonic Balance oscillation analysis can achieve a single-oven OCXO with a frequency temperature characteristic at the 10^{-10} level over the wide temperature range from -40 to +85 deg C.

2. TEMPERATURE COEFFICIENT "TEMPCO"

The frequency temperature characteristic of OCXO is composed of the oscillation circuit temperature characteristic and the quartz-crystal temperature characteristic itself **[1]**. In other words, the temperature coefficient **[2]** "Tempco" of oscillator is composed of the "Tempco" of the quartz crystal itself and all the components of the sustaining circuit **[3]**.

The temperature coefficient of the quartz crystal shown in formula (1) is based on the premise of the temperature characteristic of the crystal oscillator in the secondary equation.

$$Yc = -AT^2 + BT + C \qquad (1)$$

$$(Yc : \text{Freq.}, T : \text{Amb. Temp.})$$

Formula (2) shows the Turnover point (zTc) of the crystal.

$$0 = -2A(zTc) + B \rightarrow zTc = B/2A \qquad (2)$$

The temperature characteristic of the circuit (Ycct) is generally expressed in a negative linear equation, as in formula (3).

$$Ycct = -bT + c \qquad (3)$$

The composite temperature characteristic Y of the whole oscillation circuit becomes Yc + Ycct, as in formula (4).

$$Y = -AT^2 + (B - b)T + (C - c) \qquad (4)$$

The Turnover Point (zTo) of the whole oscillation circuit can be calculated by the following formulas (5) and (6).

$$-2A(zTo) + (B - b) = 0 \qquad (5)$$

$$zTo = -(B - b)/2A \qquad (6)$$

As a result, the gap (ΔzT) between the Turnover Point of the whole oscillation circuit and the Turnover Point of the crystal itself is shown by formula (7).

$$\Delta zT = zTc - zTo = B/2A - (B - b)/2A = b/2A \qquad (7)$$

In other words, as for the zTo of the whole oscillation circuit, only the value that divided a primary coefficient by the double of the second coefficient of the crystal of the circuit temperature characteristic moves to the lower temperature side. We can suppose a temperature coefficient only for circuits if we compare the zTc of the crystal with the zTo of the whole oscillator. Figure 1 shows the image of these relations. We know that there is an easy way to use the positive temperature coefficient chip capacitor to compensate the "Tempco." But it is generally known that it will make the frequency aging characteristic get worse, because of the high dielectric ratio material used in it. We studied how to achieve "Tempco zero" of the circuit by the combination of FEM for thermal analysis and Harmonic Balance oscillation analysis to get the higher stability wide temperature range.

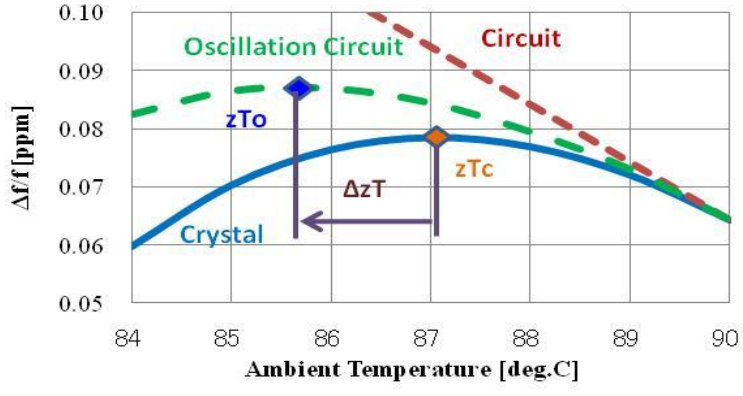

Figure 1. Schematic view of the frequency-temperature characteristics (crystal and oscillation circuit).

3. HARMONIC BALANCE OSCILLATION ANALYSIS

The temperature characteristic of the oscillation circuit depends upon the "Tempco" of each individual component of the sustaining circuit. Figure 2 shows the "Tempco" of the typical device of the sustaining circuit. It is necessary to grasp that the influence which each device gives an oscillation frequency change, so that the effect on an element's sensitivity is different from the characteristic of each device.

Figure 3 shows the frequency sensitivity simulated by the Harmonic Balance oscillation analysis with the "Tempco" of the typical device of the oscillation sustaining circuit. It is important that the frequency sensitivity should be as low as that of the circuitry to achieve the stable temperature performance for the wide temperature range.

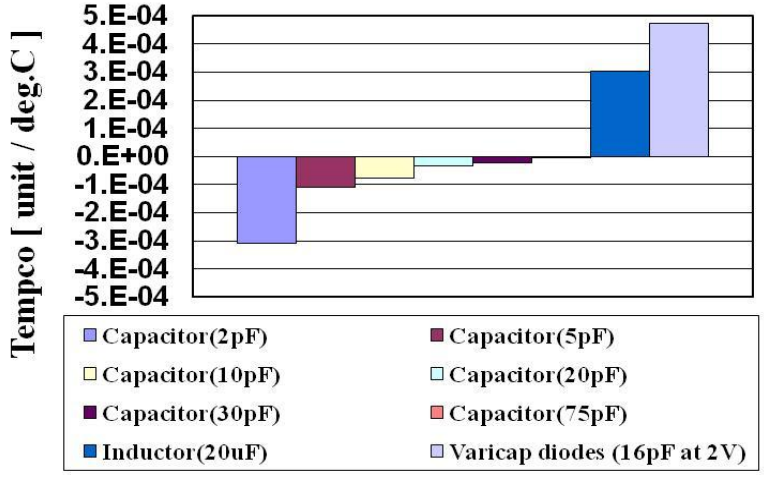

Figure 2. " Tempco" of the typical device of the sustaining circuit.

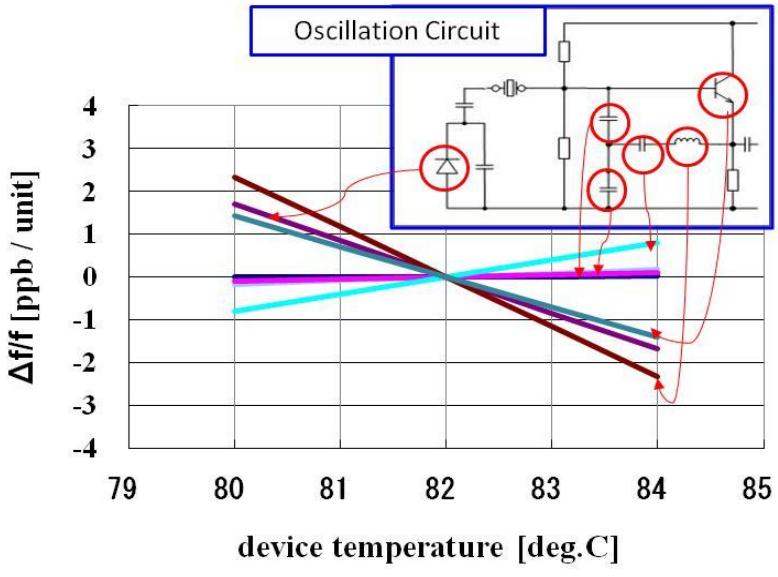

Figure 3. The frequency sensitivity simulated by the Harmonic Balance oscillation analysis.

4. FEM THERMAL ANALYSIS

Considering precisely the temperature of the inside of the oven cavity, it is very easy to understand that the temperature is not the same throughout the area inside of the oven cavity, and additionally it will be changed as a consequence of changing the ambient temperature. Since the temperature change of each device caused by the ambient temperature change depends upon the location of the devices inside the oven cavity area, so that the frequency temperature performance of the OCXO can be fixed by these complex situations of the designed locations. So it is very important to know both the temperature stability of each location by thermal analysis, and the temperature coefficient of each device by Harmonic Balance analysis, and then to combine both of them to optimize the frequency stability.

Figures 4 and 5 show the OCXO thermal model of the FEM thermal analysis.

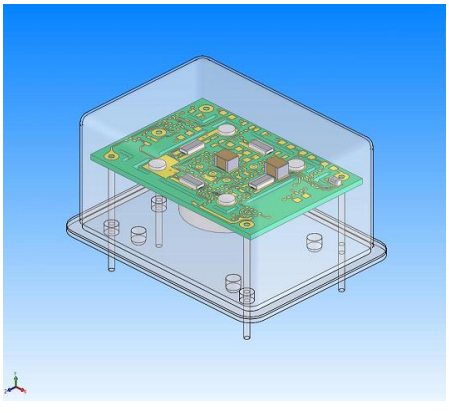

Figure 4. Inside view of OCXO (top side).

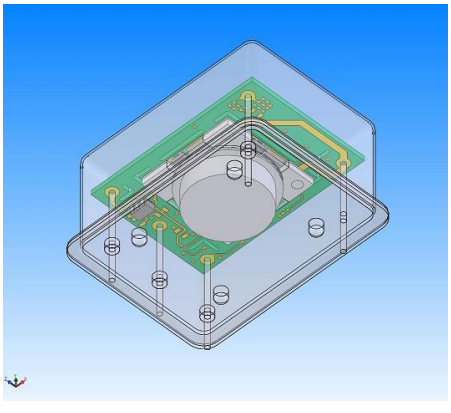

Figure 5. Inside view of OCXO (under side).

Comparing Figure 6 to Figure 9, we can see the temperature behavior inside of the oven cavity, at the four ambient temperature points of -40, +25, +70, and +85 deg C. There are some ideas to get the wider flat temperature plane in the cavity area, such as heater arrays, thermal metal via positions/numbers, etc.

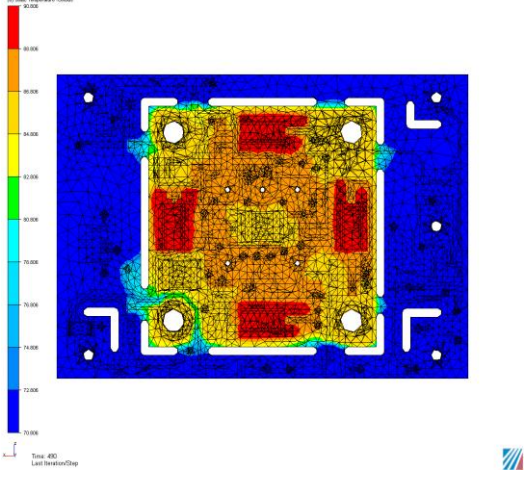

Figure 6. Thermal map of PCB (at -40 deg C).

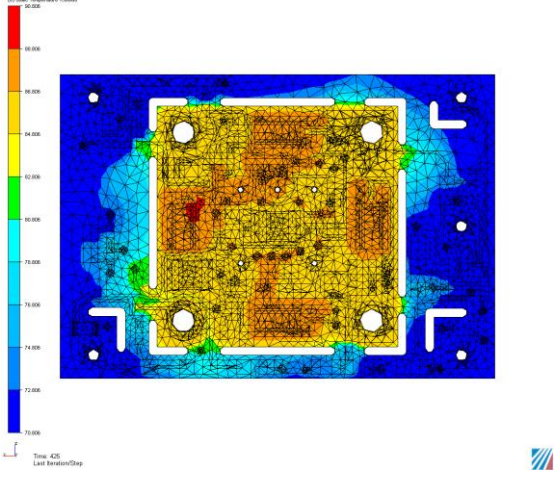

Figure 7. Thermal map of PCB (at 25 deg C).

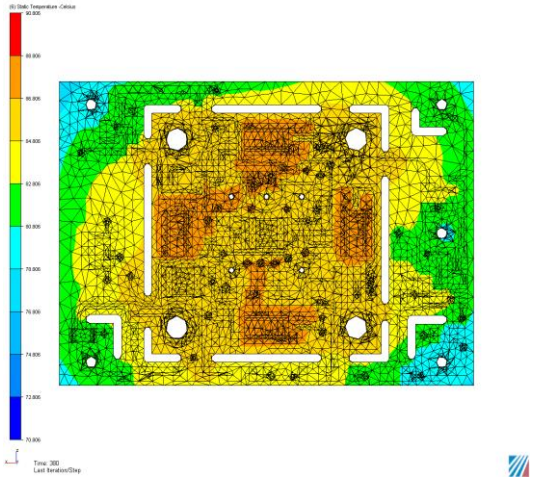

Figure 8. Thermal map of PCB (at +70 deg C).

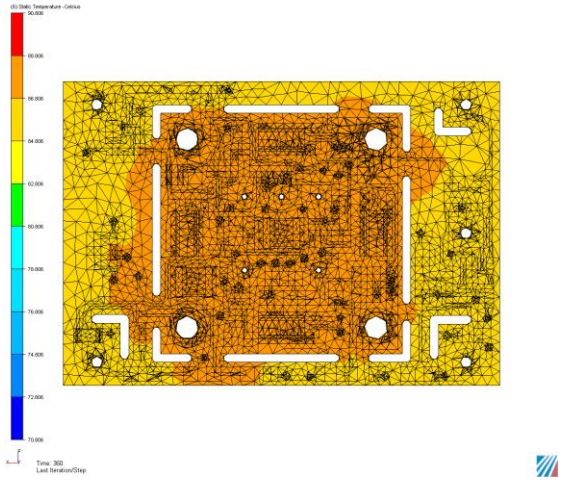

Figure 9. Thermal map of PCB (at +85 deg C).

Figure 10 shows the temperature dependency of the oven area components by ambient temperature. We can predict the temperature change of each device.

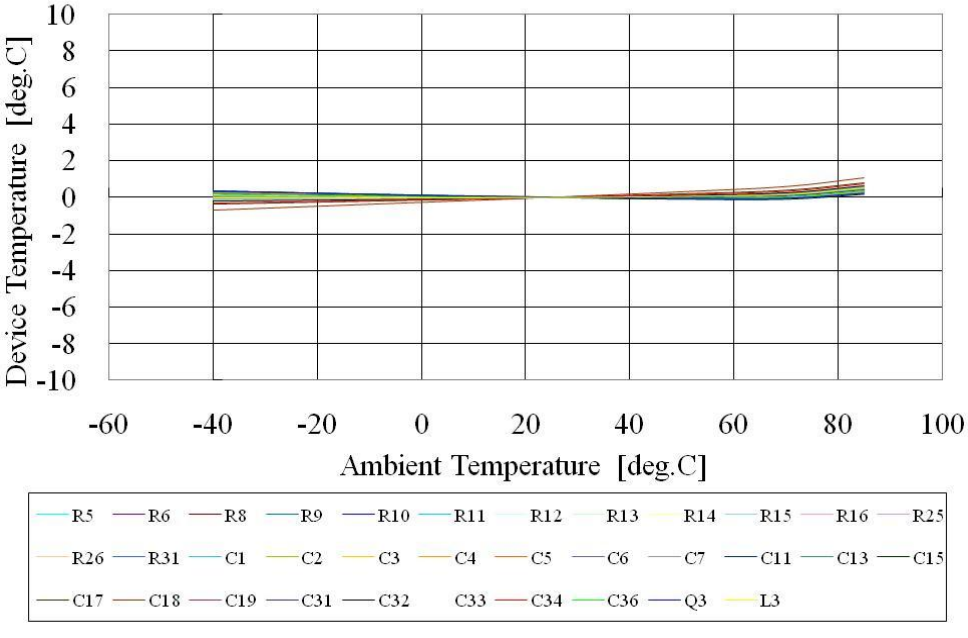

Figure 10. Simulation analysis of the temperature dependency in the oven area components by ambient temperature change.

5. DESIGN OF THE OCXO PHYSICAL STRUCTURE

We simulated the frequency temperature characteristic by using results of the FEM thermal analysis and Harmonic Balance oscillation analysis. Care should be taken about the priority of the temperature stable location for the high frequency sensitive components so that we can decide where each device should be located to optimize the printed circuit board pattern and their components' layout.

Figure 11 shows the frequency temperature characteristic calculated by the simulation. This result suggests to us that we would be able to achieve a frequency temperature characteristic in sub-ppb frequency stability over the wide temperature range from -40 to +85 deg C that we aimed for.

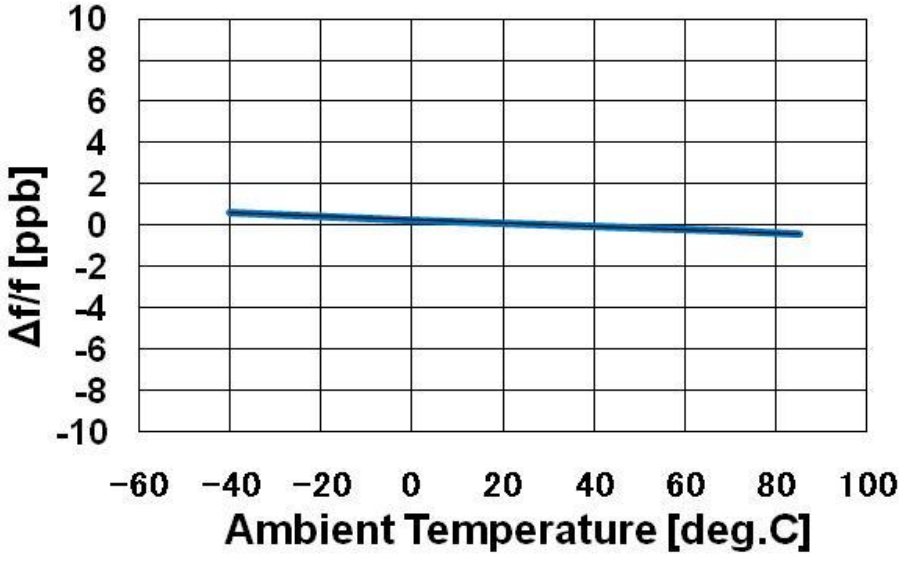

Figure 11. The simulated frequency-temperature characteristic.

6. EXPERIMENTAL RESULTS

We fabricated several 10 MHz OCXOs for the evaluation following the simulation results of both the FEM thermal and Harmonic Balance Analysis.

Figure 12 shows the completed OCXO for the experiments, in a resistance-welded hermetically sealed package, whose size is 36×27×19 mm.

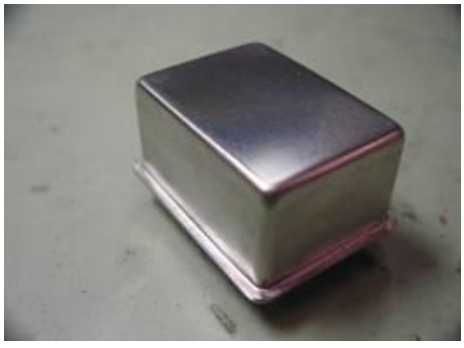

Figure 12. The fabricated OCXO.

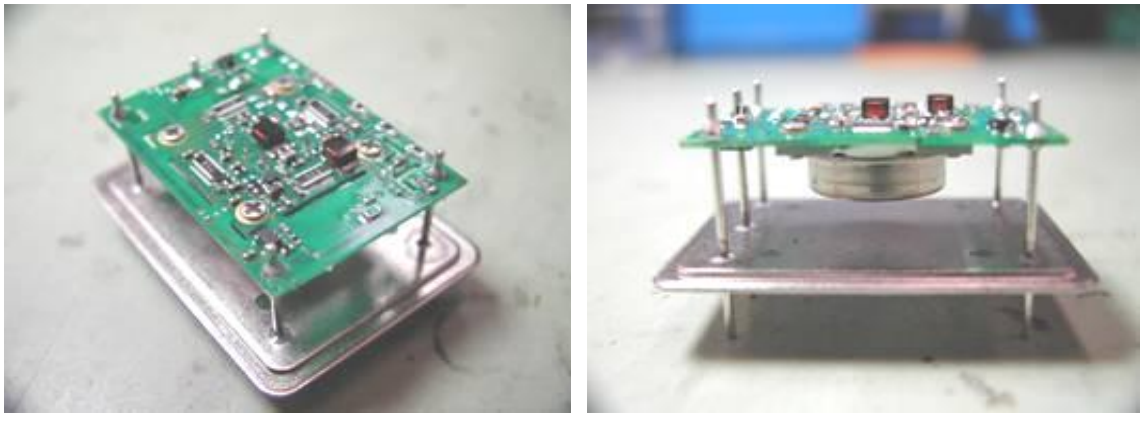

Figure 13. Inside the OCXO.

Figure 14 shows the experimental measured results of the frequency temperature characteristic. It shows that the OCXO has achieved a 10^{-10}-level frequency stability over the wide temperature range from -40 to +85 deg C with a simple single oven. Comparing the simulation results of both FEM and Harmonic Balance, the experimental results in Figure 11 show the good agreement.

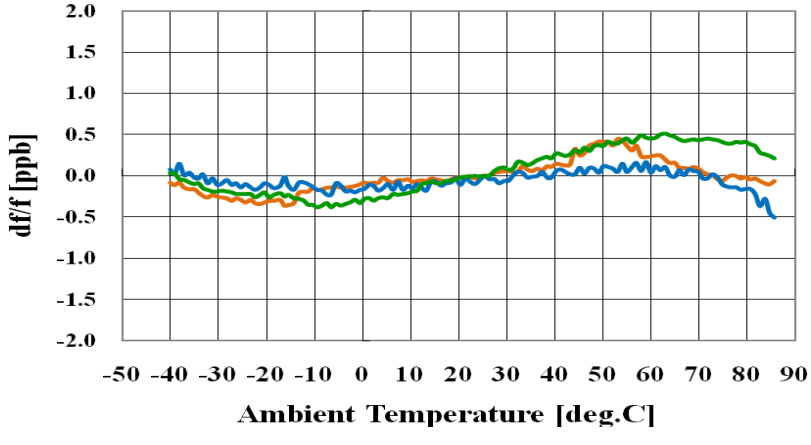

Figure 14. Experimental results for the frequency/temperature performance of the OCXO.

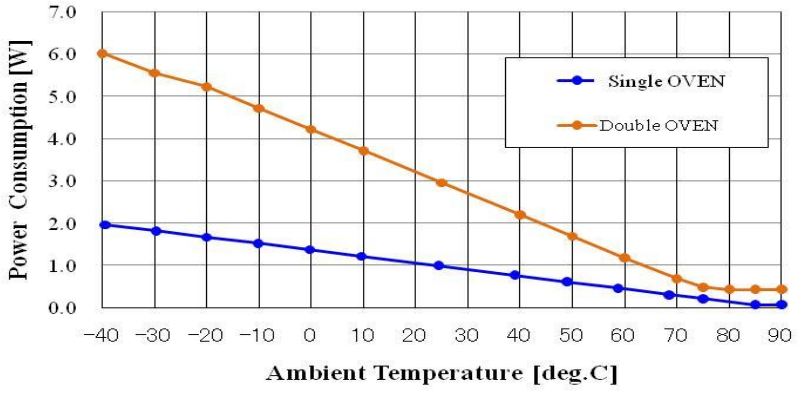

Figure 15. Power consumption of a single-oven OCXO and a double-oven OCXO.

Figure 15 shows the comparison of the power consumption of a single-oven OCXO and a double-oven OCXO. The single-oven OCXO had a 1/3 power consumption in comparison with the double-oven OCXO. Figure 16 shows the frequency deviation vs. supply voltage change. Figure 17 shows the short-term stability test results of the simple single-oven OCXO having a 10^{-10}-level frequency temperature stability.

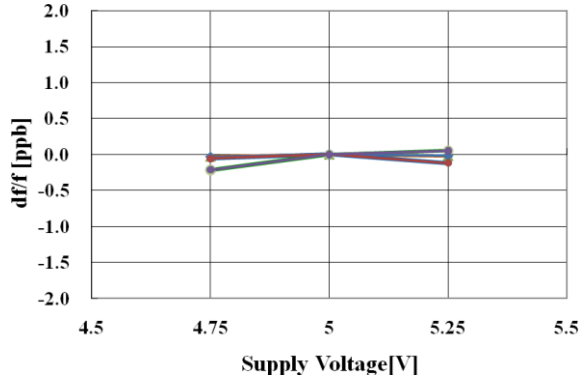

Figure 16. Frequency vs. supply voltage.

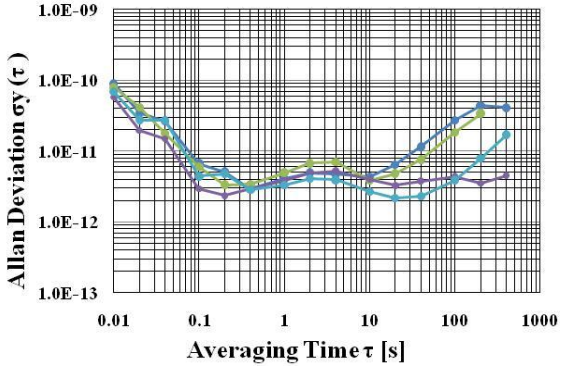

Figure 17. Short-term stability performance.

7. CONCLUSION

We have achieved the sophisticated design method of a high-stability OCXO with a 10^{-10} level frequency/ temperature stability using a simple single oven by the combination of the Finite Element Method of thermal analysis, and the Harmonic Balance method of high Q SC-cut quartz-crystal oscillator analysis. This design method can make possible a simple manufacturing production line of 10^{-10}-level OCXOs to compare with the complex DOCXO assembling and tuning process line. It would be very possible to produce a simple single-oven OCXO with NDK's high Q synthetic quartz and SC-cut quartz crystal.

REFERENCES

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[4] M. Ito, H. Mitome, and T. Oita, 2010, *"Combination of FEM/Harmonic Balance Analysis of OCXO,"* in Proceedings of the 2010 IEEE International Frequency Control Symposium, 1-4 June 2010, Newport Beach, California, USA (IEEE), pp. 31-34.