Dual Mode SC-Cut Crystal Oscillator

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Abstract — **The simultaneous dual mode oscillation circuit of the 5MHz 3rd overtone SC-Cut Crystal is designed using mode-selective linear phase crystal filters for each C and B mode. The perturbable dual mode oscillation has been successfully eliminated over the temperature range from –20deg.C to +90deg. C.**

Temperature regulation is also achieved using B mode oscillation frequency, which provides the temperature information of the SC-Cut Quarts Crystal itself. Over the temperature range of –20deg.C to +70deg.C, the temperature of the SC-Cut crystal has been locked within +/-0.002deg.C converted by the beat frequency between C and B modes.

The total power consumption at supply voltage of 12V, is less than 2.4W at +25deg.C in still air.

Keywords-Dual-Mode; B-Mode; C-Mode; SC-Cut; Perturbation; CPLD; Temperture Regulation

I. INTRODUCTION

To eliminate the seesaw effect of the C and B-Mode is very important to get the simultaneous dual mode oscillation upon temperature and supply voltage variation. Two oscillator circuits for each C and B mode should be independent to each other, but these are connected to one SC-Cut crystal commonly.

The required oscillating conditions Gain>1, and 180-degree phase shift of the feed back loop for each C and B mode frequency, should be always satisfied independently.

II. SIMULTANEOUS DUAL MODE OSCILLATION

It has been discussed with this perturbable oscillation, and we had tried especially the mode-selective filters or phase shifters, such as LC network, or ceramic filters and etc. These components are not to be used in their way, caused by its lower Q value of LC network or higher Q for the B-Mode with existing uncontrolled frequency spurious of the ceramic resonators to get the simultaneous dual mode oscillation. For these reasons, we have decided to design the particular pass band width and phase linear crystal filters, and these devices should be set at the front end of the feed back loop to keep the simultaneous dual mode oscillation conditions.

Fig.1 shows the basic block diagram of the dual mode oscillator.

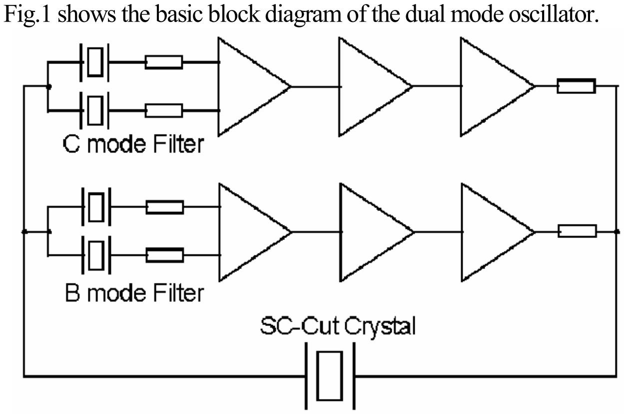

Fig.1 Basic Block Diagram – Dual Mode Oscillator

Each C and B mode selective filters are combined with two crystals and one differential pre-amplifier which composite two signal phases through the filter crystals. The transformers of the phase composition can be eliminated in the oscillator circuit by using this differential pre-amplifier.

Table 1 shows the equivalent circuit constants of the SC-Cut crystal that performs no frequency dips between wide temperature range such as -40 to +90deg.C for the experimental use.

Table 1. Equivalent Circuit constant SC-Cut Crystal

	C mode	B mode
Freq.[MHz]	5.000	5.456
Mode	3rd Overtone	3rd Overtone
R1[Ohm]	68.3	47.4
L1[mH]	4670.34	1857.57
C1[fF]	0.217	0.458
C0[pF]	2.44	2.46

*The constant values were measured at +85deg.C

The C-Mode frequency vs. temperature characteristics is shown in Fig. 2, and the B-Mode is shown in Fig.3.

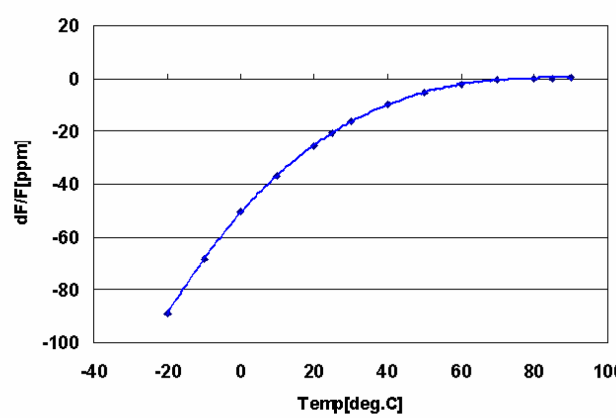

Fig.2 C-Mode Temp. Characteristics

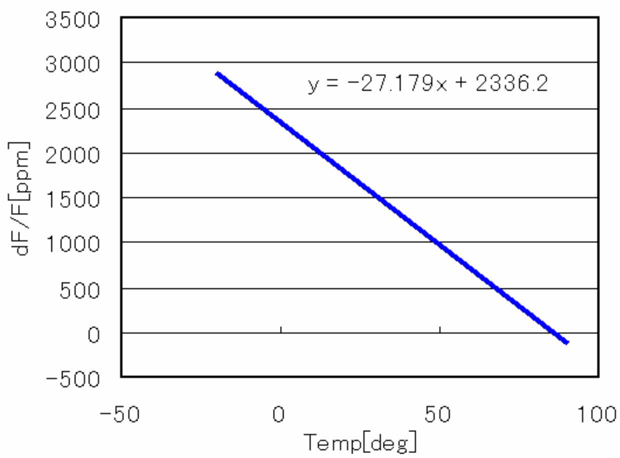

Fig.3 B-Mode Temp. Characteristics

Since the B mode frequency-temperature coefficient is about -27ppm/deg.C, and it means 17.55kHz frequency variation from -40 to +90deg.C temperature range, the B-Mode filter should have wider frequency pass band performance. We used the AT-Cut crystal's equivalent circuit constants as the filter parameters.

Fig. 4 shows the optimized simulation results of the B-Mode gain AC analysis.

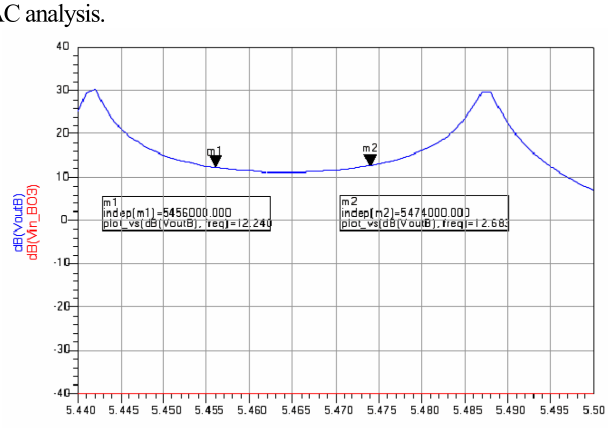

Fig.4 B-Mode Gain

Fig.5 shows the optimized simulation results of the B-Mode phase AC analysis.

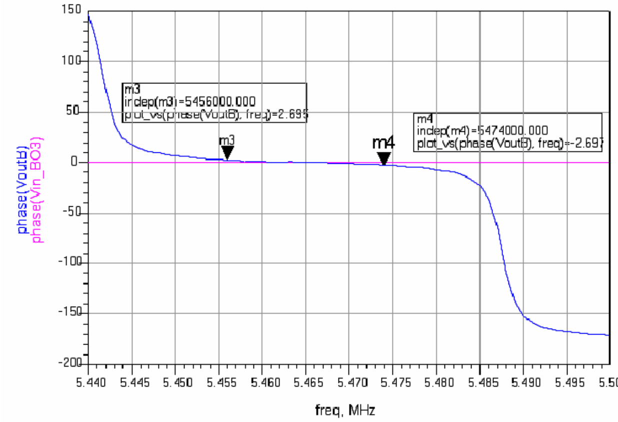

Fig.5 B-Mode Phase

The optimized AC simulation results are as follows.

Pass band width : +/-9kHz

Pass band gain : +15dB

Pass band phase linearity : +/-3 degree

The C-Mode simulation was also done as well as the B-Mode, and it is similar result to the above. These results suggest that each single mode oscillator can oscillate individually.

For the simultaneous excitation of both C and B-Mode, we simulated the signal level influence behavior to each mode using the harmonic balance method.

Fig.6 shows the simulation results how the B-Mode signal input level at C-Mode oscillator, influence to the C-Mode signal output level. Little influence on the C-Mode output level at any input level of the B-Mode signal level can be seen.

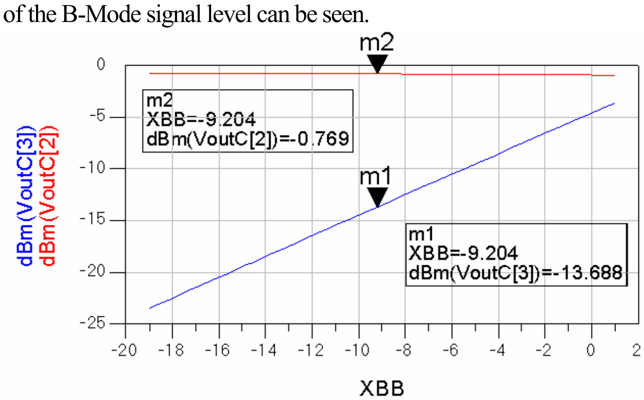

Fig.6 Influence of B-Mode Input Level On C-Mode Output

Fig.7 shows the simulation results how the C-Mode signal input level at B-Mode oscillator, influence to the B-Mode signal output level. As well as the previous simulation result, little influence on the B-Mode output level at any input level of the C-Mode signal level can be seen.

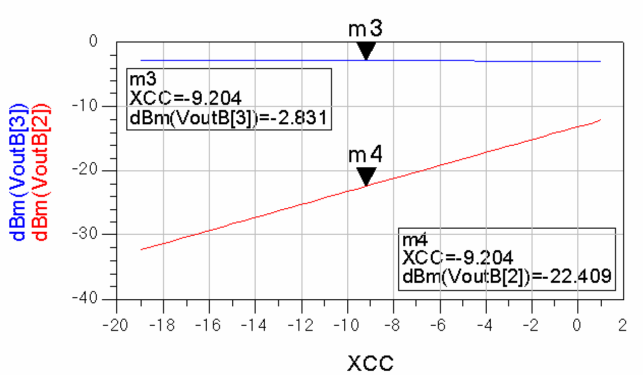

Fig.7 Influence of C-Mode Input Level On B-Mode Output

Followed by the results of both analysis, it is suggested that each mode oscillation circuits will be able to operate simultaneously.

III. Experimental Results of Dual Mode Oscillation

We have provided the experimental dual mode oscillator circuit followed by the analysis results. Fig.8 shows the successful simultaneous dual mode oscillation frequency spectrum of the oscillator output at room temperature.

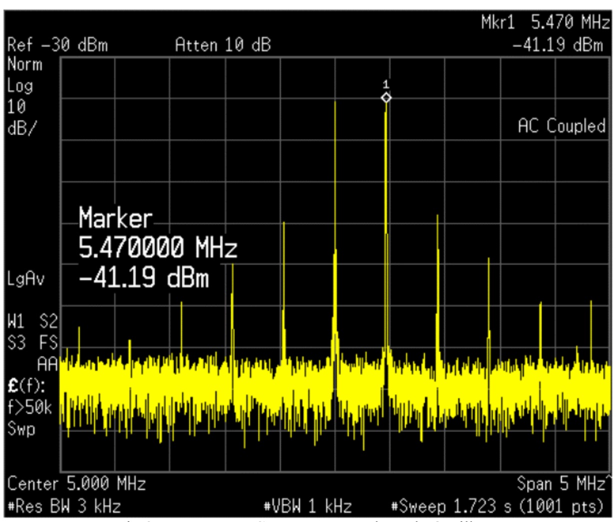

Fig.8 Frequency Spectrum – Dual Mode Oscillator

There are many mixed signals caused by the non-linear performance of active devices in the oscillator circuits, and this means that those output signals are including 460kHz beat frequency that is B minus C-Mode frequency.

This signal that provides the temperature information can be used for the temperature regulation without extra signal mixing circuit. Fig.9 shows the output level behavior vs. temperature and it has wide temperature range simultaneous dual mode oscillation from -20 to +90deg.C.

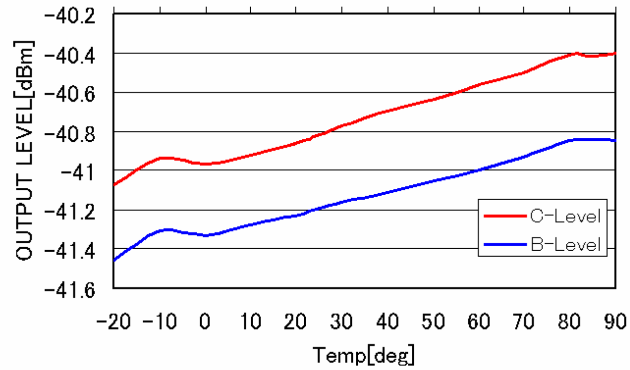

Fig.9 Output Level vs. Temp. – Dual Mode Oscillator

Fig.10 shows the output level behavior vs. supply voltage at room temperature, and it has wide supply voltage range simultaneous dual mode oscillation from 3.4V to 5.4V.

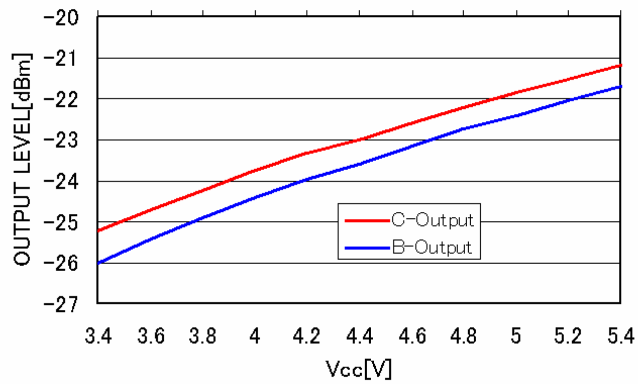

Fig. 10 Output Level vs. Supply Voltage - Dual Mode Oscillator

IV. Signal Extraction

Since the dual mode oscillator has been including various frequency spectrum of its common output, it is needed to extract the pure C-Mode signal and the temperature information signal. To extract the C-Mode signal, we have provided the buffer amplifier which pass-band is very narrow. Fig.11 shows the block diagram of the C-Mode buffer amplifier module.

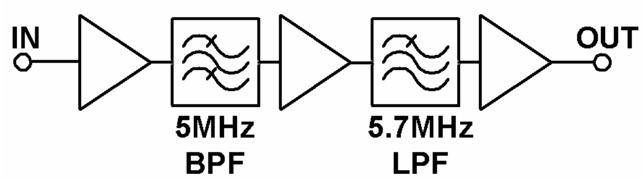

Fig.11 Block Diagram, C-Mode Buffer Module

A 5MHz BPF has very narrow pass band, and not only to extract the C-Mode signal, but also to suppress the B-Mode signal by using 5MHz crystal filter. The LC LPF (5.7MHz Cut-Off) is for the upper harmonics suppression. The pure output C-Mode signal will be used for the reference frequency of the temperature regulation and for the output signal of the oscillator itself.

The test result of this C-Mode buffer module is shown in Fig.12. The output level is +8dBm at 50ohms loads, and the second harmonics is suppressed -32dB.

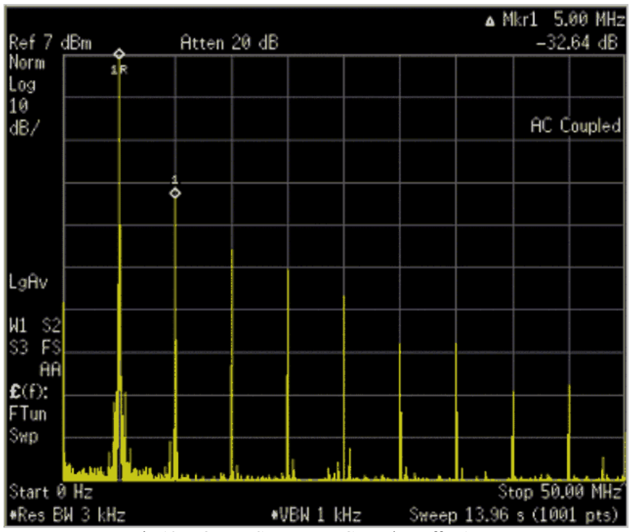

Fig.12 Output Spectrum – C-Mode Buffer Amp.

Fig.13 shows the B-Mode suppression performance of this module. The B-Mode is successfully suppressed -77.63dB compared with the C-Mode.

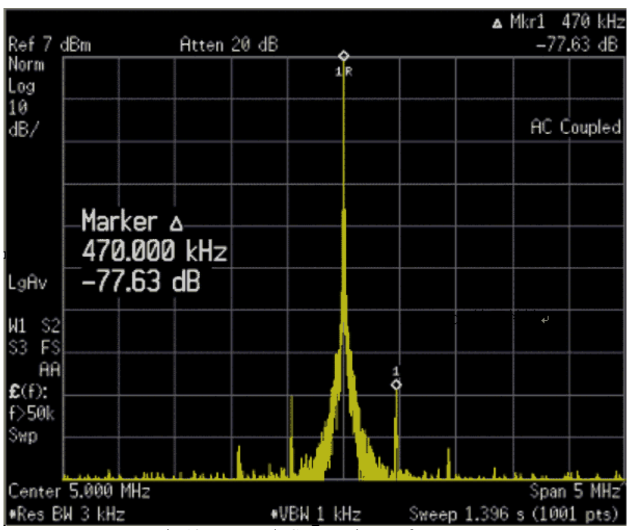

Fig.13 B-Mode Suppression Performance

V. Temperature Information Signals

We have decided the beat frequency (B-C) as the temperature information signal, since it has been already including in the output signal of the dual mode oscillator.

Formula (1) is the relation of the frequency-temperature sensitivity of each mode frequency-temperature characteristics.

$$\Delta Fbeat(t) = \frac{\Delta Fb(t) - \Delta Fc(t)}{Fb(t) - Fc(t)} \quad \text{……….} (1)$$

Fig.14 shows the block diagram of the beat frequency extraction module. To extract B-C beat frequency, a LPF (1.2MHz Cut-Off) is used to suppress the higher frequency harmonics, and a CMOS inverter is used for the output amplifier for the logic interface to the temperature regulation module.

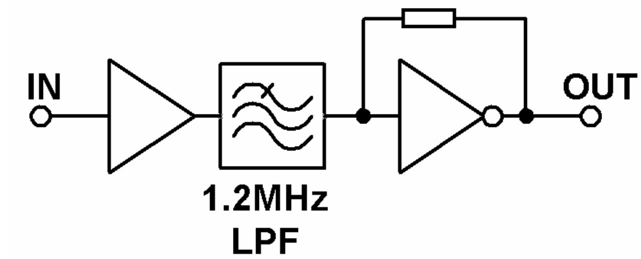

Fig.14 Block Diagram - Beat Freq. Extraction

Fig.15 shows the measured beat frequency (B-C) vs. temperature.

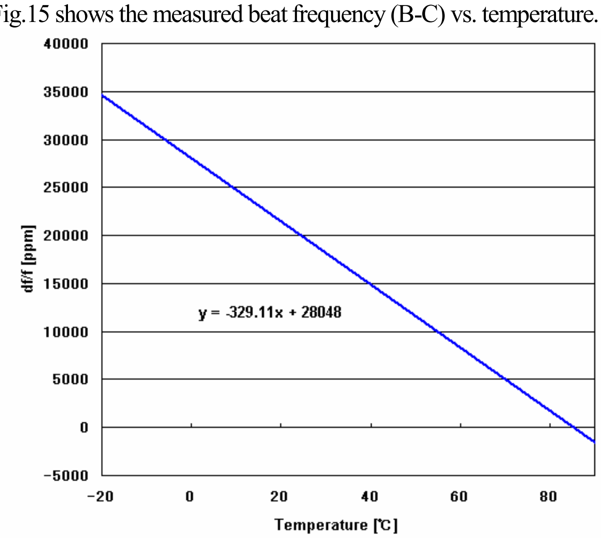

Fig.15 Beat Frequency Sensitivity vs. Temp.

Since the B-Mode signal has been frequency heterodyned with the C-Mode signal to the lower frequency in the dual mode oscillator itself, the temperature sensitivity was expanded from -27ppm/deg.C to -329ppm/deg.C. The output frequency of this module was 457.205417kHz at +85deg.C. To get the higher resolution of the quick cycle time to count this signal pulse, it is easy to multiply to the higher frequency by using one chip IC of the PLL+VCO.

VI. Temperature Regulation

We have chosen a digitally temperature regulator for its many advantages. It is not only convenient to compare with the C-Mode reference frequency and temperature information frequency, but also it is available to adjust the loop gain, time constant depended upon the oven, and the temperature set point by the software.

Fig.16 shows the block diagram of temperature regulation module that we considered for this experiment.

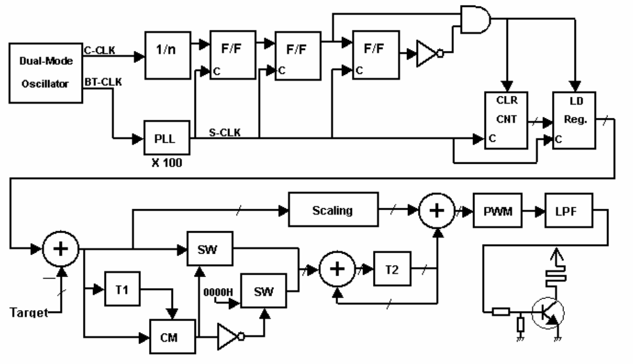

Fig.16 Block Diagram – Temp. Regulation Module

The C-Mode frequency is divided by 2^{19}, and generates 104.85 milliseconds gate time to count the temperature information signal. And the beat frequency which is about 457kHz, multiplied by 100. So the temperature information frequency becomes 47.5MHz. The frequency counter counts this frequency every 104.85 milliseconds. The error signal is generated to compare with this result and the target data, which is written in EEPROM by the software.

The temperature regulation system is one of the long period thermal phase locked-loop. In the thermal PLL, the time constant is decided by the physical design of the oven. To shorten the lock up time that means to shorten warm up time, and get the high precision temperature regulation, the time delay function is also very important. The software with some logic synthesis creates this function.

We also roughly measured the actual time constant of the oven in advance, and it was used for the initial running test.

The CPU generates PWM (Pulse Width Modulation) signal depended on the error data. The thermal source is driven by this PWM signal through the LPF to reduce the ripple noise and the power transistor.

One CPLD (Configurable Programmable Logic Device) is used for the logic synthesis by VHDL, and an 8bit CPU is used to control the whole logic sequence. The CPU generates the PWM signal to control the thermal source current precisely, which eliminates an expensive high resolution DAC (Digital to Analog Converter). These two devices are available to communicate with the outside PC over the serial port. The assembler is used for the CPU software. We also have provided two thermal switches inside of the oven, one is +75deg.C switching for the quick warm-up sensing, and the other is +95deg.C switching for the over- temperature alarm sensing.

Fig.17 is the photograph of the top view of the assembled printed circuit board, that includes temperature regulator, C-Mode buffer amplifier, the beat frequency extracting module, and some DC power supply components.

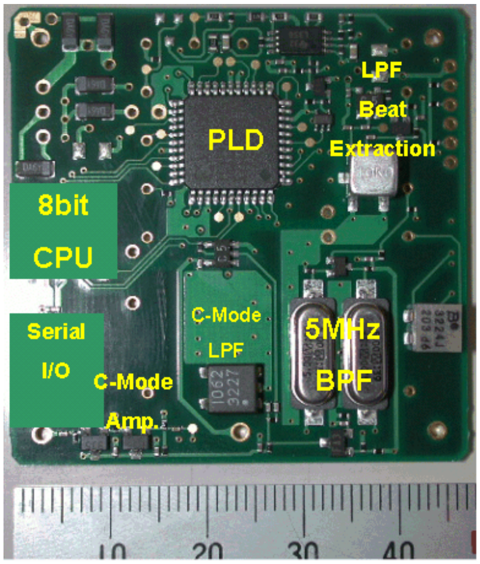

Fig.17 Assembled Printed Circuit Board

VII. Thermal Sources

A very thin disk type monolithic resistive-heater on the ceramic substrate is used as the thermal source. The current flows from the center to the circumference of the disk so that the heat distribution is equalized.

Fig.18 is the photograph of TO-9 SC-Cut crystal on the left side, and the disk heater on the right side.

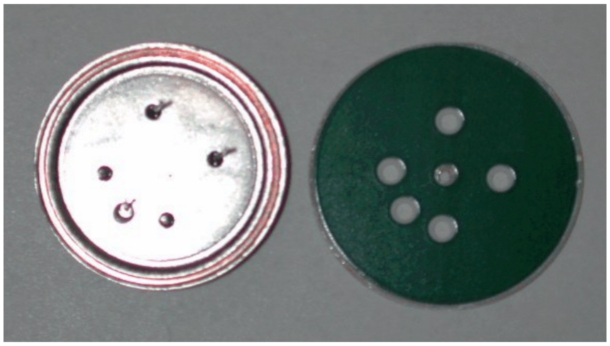

Fig.18 Disk Heater and TO-9 Crystal

The epoxy sheet grew which aluminum nitride permeates attaches the disk heater to the base metal of the SC-Cut crystal to get the high thermal conductivity and proper heat distribution. To save the power consumption and get the proper thermal gain, the power-transistor, which drive the disk heater is also thermally connected to the top of the SC-Cut crystal with the aluminum heat sink.

Fig.19 is the photograph of the sandwiched SC-Cut crystal between the power transistor (Top) and disk heater (Bottom).

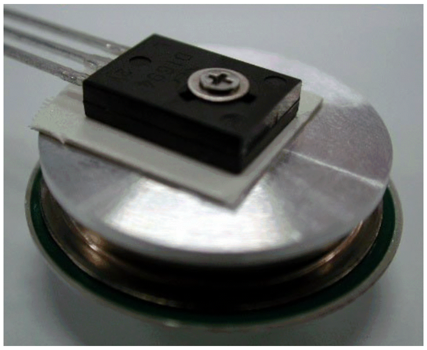

Fig.19 Crystal, sandwiched by Thermal Sources

VIII. THERMAL INSULATION

The vacuum-sealed metal package is used for the dual mode oscillator module to get the effective thermal insulation and reduce the total power consumption. This vacuum-sealed metal package is set on the printed circuit board of the thermal regulator. The finished package size is 50 square mm by 28mm in height.

Fig.20 shows the photograph of the vacuum-sealed metal package of the Dual Mode Oscillator Module (Left side) which was seam-welded in the vacuum chamber and the finished package (Right side).

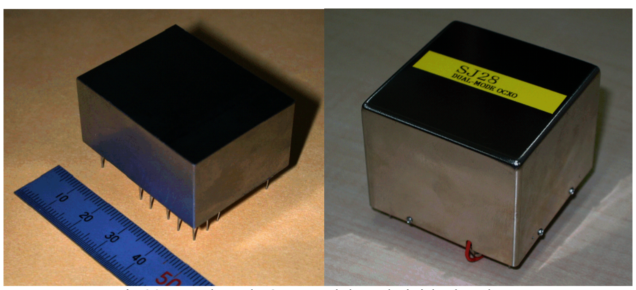

Fig.20 Dual Mode Osc. Module and Finished package

IX. TEMPERATURE REGULATION TEST RESULTS

To shift the loop-gain, the delay time, or the target temperature has been re-writing the software by the outside PC communicating through the serial input/output port of the oscillator printed circuit board. To monitor the temperature is counting the beat frequency, and converted to the relative temperature. The measurement was done at +25deg.C in still air.

Fig.21 shows the warm-up performance of the experimental dual mode oscillator. It has reached +85deg.C in 400 seconds. The temperature convergence behaves that the loop gain and time constant are properly adjusted.

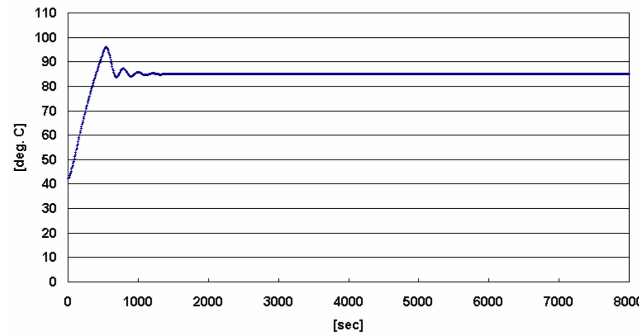

Fig.21 Warm-Up performance

Fig.22 shows the expanded graph of Fig.21 around +85deg.C. to look up the details of the temperature convergence. The vertical division is +/-0.002deg.C.

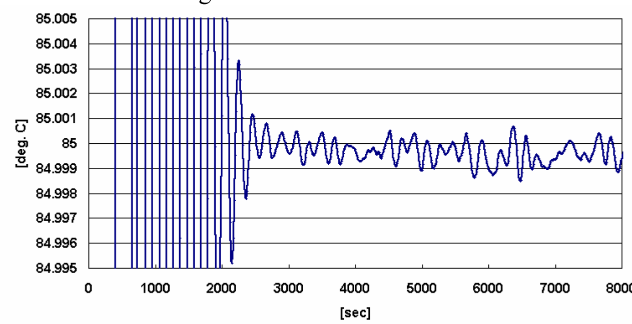

Fig.22 Temperature Convergence Performance

The temperature has been locked with in +/-0.002deg.C after 2,300 seconds, and continuously controlled.

Fig.23 shows the power consumption performance.

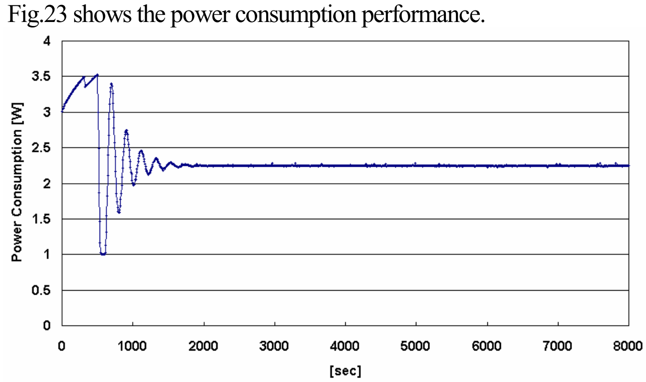

Fig. 23 Power Consumption

After temperature locked, the power consumption has been keeping less than 2.3W at 12V DC.

Fig.24 shows an hour 10deg.C-step temperature transient response of the regulation performance from –20deg.C to +70deg.C. The vertical division is +/-0.002deg.C.

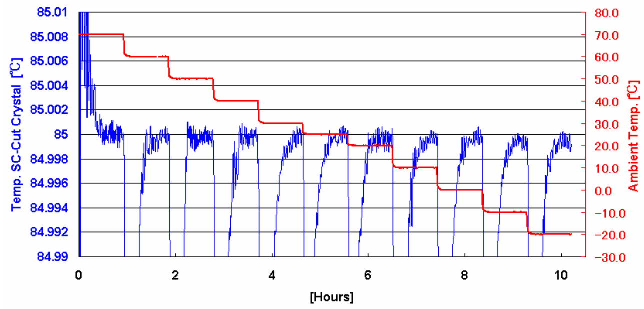

Fig.24 Step temperature Transient Response

The temperature of the SC-Cut crystal was locked within +/-0.002deg.C of each temperature steps from –20deg.C to +70deg.C.

X. CONCLUSION

The dual mode oscillation circuit of the 5MHz 3rd overtone SC-Cut Crystal oscillator has been designed and obtained the simultaneous oscillation for wide temperature and supply voltage variation. It will be able to apply another kinds of multi-mode oscillator such as fundamental-overtone, third overtone-fifth overtone and etc.

The high-resolution temperature regulation by using the CPLD and CPU with the algorithm in software has been also obtained and it has performed to lock the SC-Cut crystal temperature within +/-0.002deg.C over the range from –20deg.C to +70deg.C. This regulator is able to eliminate the cost expensive DAC such as 24bit or more.

For the further development to the high precision OCXO, the low temperature coefficient of the oscillator circuit with uniform temperature oven structure, and the transient response improvement of the temperature regulation to the ambient temperature are the subjects.

XI. ACKNOWLEDGMENT

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XII. REFERENCES

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