# A DUAL MODE OSCILLATOR BASED ON NARROW-BAND CRYSTAL OSCILLATORS WITH RESONATOR FILTERS

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***Abstract*** - A dual mode crystal oscillator using two narrow-band transistor Colpitts circuits has been developed. This oscillator excites arbitrary two-modes in a common resonator even if the modes are close to each other. The practical circuit structure and analysis of the proposed oscillator, and the experimental results are described.

## 1. Introduction

Dual mode crystal oscillators are applied to high-stability TCXOs employing both the B and C modes of SC-cut quartz resonators and quartz sensors for detection of various physical values[1-4]. Generally, these oscillators have a circuit structure in which the two modes, in one quartz resonator, are simultaneously excited by two active circuits with L-C passive filter elements. However, it is difficult to apply this structure to the modes of very close frequencies because of a low Q value of the passive elements, and also because the structure has a weak point in that it takes a great deal of time to adjust the passive elements to achieve a reliable dual mode oscillation.

This paper describes a dual mode crystal oscillator that has the following advantages; 1) a very simple circuit structure, 2) easy adjustment of tuning frequencies, and 3) high frequency-selectivity. This oscillator is based on a low phase-noise transistor Colpitts circuit that we reported on at the 1996 IEEE FCS[5].

This circuit, employing a piezoelectric resonator filter, has a very narrow gain-band width; thus it can excite any mode in a resonator even if the mode is very close to other modes. The dual mode oscillator can be achieved by connecting two narrow-band Colpitts oscillators of different tuning frequencies, and the quartz resonator having several resonant modes in parallel.

First, we describe the analysis method, based on an algebraic formula, for the proposed dual mode oscillator circuit and show the calculated and experimental examples of the frequency characteristics of negative resistance and equivalent load capacitance of the oscillator. Good agreement between the calculated and measured results shows the validity of the analysis method for designing the proposed dual mode oscillator. Next, we apply the proposed circuit to dual mode oscillation for the fundamental and proximate inharmonic-modes of a 12 MHz AT-cut crystal resonator. In this trial, we used ceramic resonators as frequency selection devices. From the results, it is shown that both the modes are excited by the proposed circuit, and that the dual mode oscillation can be realized even if the frequency difference of the two modes is less than 0.5 %.

## 2. Equivalent Model and Analysis Procedure

Figure 1 shows the transistor Colpitts crystal oscillator with a resonator filter[5]. We apply a previously reported analysis-technique[6] to this circuit. To analyze the active impedance $Z_{IN}$, the right side impedance of the dotted line in Fig.1, we introduce a high-frequency equivalent circuit model as shown in Fig.2. In this figure, $g_m$ represents trans-conductance controlled by VBE. $Z_a$, $Z_b$ and $Z_l$ are given by,

$$Z_a = \frac{1}{\frac{1}{R_{12}} + \frac{1}{X_{cin}} + \frac{X_{c2}}{X_{c1} * X_{c5} + X_{c2} * X_{c5} + X_{c1} * X_{c2}}} \quad (1)$$

$$Z_b = \frac{1}{\frac{1}{R_E} + \frac{X_{c1}}{X_{c1} * X_{c5} + X_{c2} * X_{c5} + X_{c1} * X_{c2}}} \quad (2)$$

$$Z_1 = \frac{X_{c1} * X_{c5} + X_{c2} * X_{c5} + X_{c1} * X_{c2}}{X_{c5}} \quad (3)$$

where $X_{c1}$ is the reactance of the capacitance $C_1$, $X_{c2}$ is the reactance of the capacitance $C_2$, $X_{c5}$ is the series impedance of the piezoelectric resonator filter and capacitance $C_B$, $R_{12}$ is the parallel impedance of $R_A$ and $R_B$, $X_{cin}$ is the reactance of the transistor B-E capacitance $C_{in}$, and $X_{cu}$ is the reactance of the transistor B-C capacitance $C_u$. According to ref. [7], diffusion and junction capacitance of the transistor is included in $C_{in}$ and $C_u$.

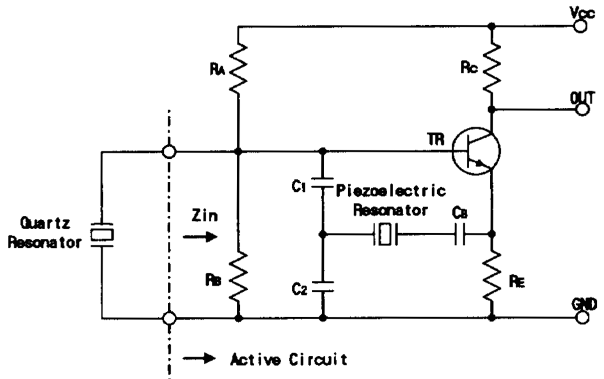



Fig. 1 A transistor Colpitts crystal oscillator with a piezoelectric resonator filter.

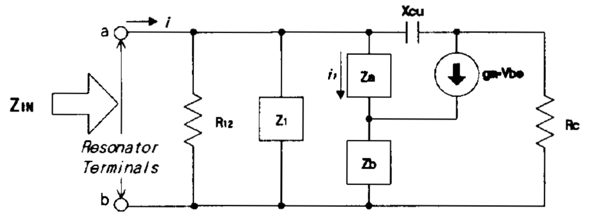



Fig. 2 A high-frequency equivalent model for transistor Colpitts oscillators.

$Z_{IN}$ can be represented by the following formula,

$$ZIN = \frac{1}{\frac{1}{R_{12}} + \frac{1}{Z_1} + \frac{1}{Za + Zb + Za * Zb * gm} + \frac{1}{Xcu + Rc} + \frac{Rc * Za * gm}{(Xcu + Rc)(Za + Zb + Za * Zb * gm)}} \quad \cdots (4)$$

When a high-frequency current is supplied to terminal a-b in Fig. 2, $g_m$ changes with $V_{BE}$ and $V_{BE}$ changes with $g_m$. Therefore we used an iterative calculation to obtain the active impedance $Z_{IN}$ from equation 4. The negative resistance and equivalent reactance of the active side are easily obtained from the real and imaginary part of $Z_{IN}$, respectively. UBASIC[8] is used for practical calculations.

## 3. Results

The proposed analysis was evaluated by using a 10MHz SC-cut crystal oscillator having an AT-cut resonator filter in accordance with reference[1]. Oscillator circuit parameters, equivalent parameters of the SC-cut resonator and the AT-cut resonator are shown in Tables 1, 2 and 3, respectively. The experimental results are obtained by a reflection (S11) method using a vector network analyzer[9]. The calculation was carried out under the same conditions as was the experiment.

Figure 3 (a) and (b) show the frequency characteristics of the equivalent resistance and the equivalent reactance of the active circuit. The drive voltage applied to the active circuit was adjusted to 31.6 mV for setting the driving current to 0.3 mA at 10 MHz.

Table 1 Circuit Parameters of Fig. 1.

| Elements | Value |
|---|---|
| $R_A[\Omega]$ | 1000 |
| $R_B[\Omega]$ | 1000 |
| $R_C[\Omega]$ | 300 |
| $R_E[\Omega]$ | 510 |
| $C_1$[pF] | 51 |
| $C_2$[pF] | 51 |
| $C_B$[pF] | 20 |
| TR | 2SC3128 |

Table 2 Equivalent parameters of the SC-cut quartz resonator.

| Parameters | Value |
|---|---|
| Resonant Freq. [Hz] | 9807950 |
| $R_1[\Omega]$ | 63.59 |
| $L_1$[H ] | 2.27 |
| $C_1$[fF] | 0.116 |
| $C_0$[pF] | 3.7 |
| Quality Factor | 2200000 |

Table 3 Equivalent parameters of the AT-cut quartz resonator filter.

| Parameters | Value |
|---|---|
| Resonant Freq. [Hz] | 9994931 |
| $R_1[\Omega]$ | 5.02 |
| $L_1$[mH] | 10.1 |
| $C_1$[fF] | 25.1 |
| $C_0$[pF] | 5.47 |
| Quality Factor | 20100 |

Figure 4 (a) and (b) show similar results when the high-frequency drive voltage is adjusted to 101 mV for setting the drive current to 1 mA at 10 MHz. From these figures, it is clear that the calculated results agree well with the experiments and that proposed technique can precisely predict the drive level characteristics of the active impedance besides frequency characteristics of the Colpitts crystal oscillators with resonator filters.

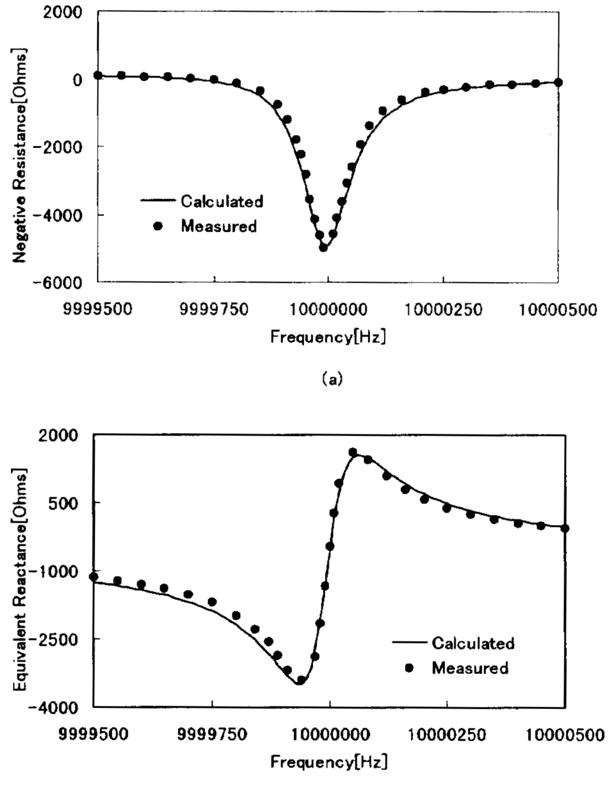



Fig.3 Frequency characteristics of (a) negative resistance and (b) equivalent reactance, where the AT-cut quartz crystal resonator filter was tuned to 10 MHz.(Drive voltage=31.9mV)

## 4. Application to Dual-mode Crystal Oscillator

In this section, we apply the above-mentioned narrow-band crystal oscillator and its analysis technique to dual-mode crystal oscillator design. A dual-mode crystal oscillator generates two individual oscillation frequencies corresponding to two resonance frequencies in a crystal resonator. Because the crystal oscillators using a resonator filter have very narrow gain-band width, a dual-mode crystal oscillator can be realized by connecting two oscillators tuned at different frequencies, in parallel even if the two target modes are very close to each other.

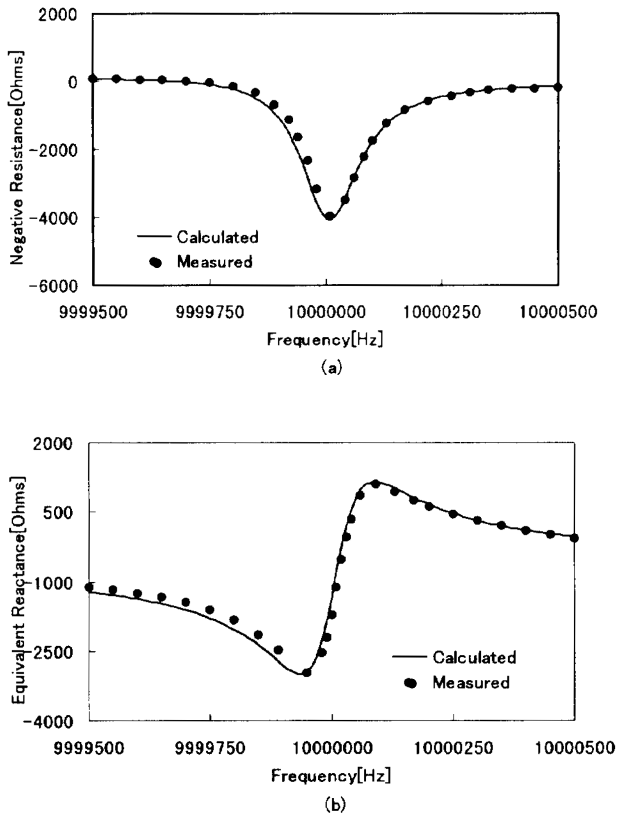



Fig.4 Frequency characteristics of (a) negative resistance and (b) equivalent reactance, where the AT-cut quartz crystal resonator filter was tuned to 10 MHz.(Drive voltage=101mV)

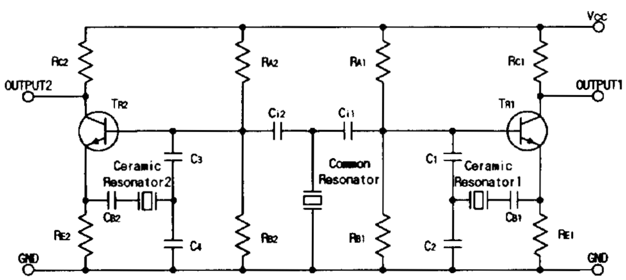



Fig.5 Dual-mode Oscillator circuit employing two narrow-band Colpitts oscillators.

Figure 5 shows a schematic of a dual-mode crystal oscillator using two Colpitts narrow-band oscillators. The two symmetrical circuits have a common resonator. The center frequencies of the gain-band width in each oscillation loop are determined by the series resonant frequencies of the resonator filter branches. Active impedance of this circuit is easily calculated from the parallel impedance of each circuit.

In this study, we have employed 12MHz ceramic resonators as the filters, and a 12MHz AT-cut crystal resonator as the common resonator. The frequency response of the AT-cut resonator is shown in Fig. 6. We tried to simultaneously oscillate at the fundamental mode and at the closest inharmonic-mode. Tables 4 and 5 show the equivalent parameters of ceramic resonators and each mode of the AT-cut resonator. The circuit parameters of the dual-mode oscillator are determined as high-frequency currents supplying the two modes agree with each other.

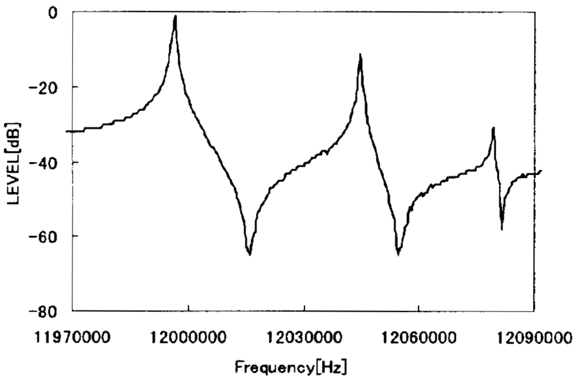



Fig.6 Frequency characteristics of 12MHz AT-cut quartz crystal resonator used for a dual-mode oscillator.

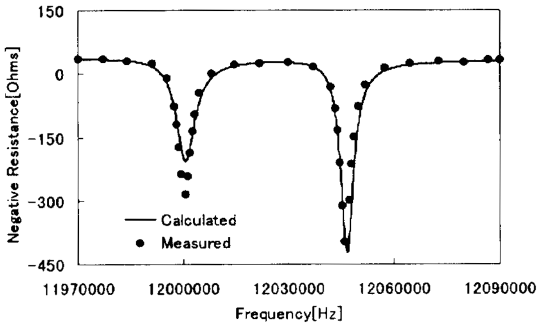
Table 4 Equivalent parameters of ceramic resonators

| Parameters | Value |
|---|---|
| Resonant Freq. [Hz] | 11955000 |
| $R_1[\Omega]$ | 26 |
| $L_1$[mH] | 1 |
| $C_1$[fF] | 170 |
| $C_0$[pF] | 2.4 |
| Quality Factor | 3000 |

Table 5 Equivalent parameters of the AT-cut quartz resonator for dual mode oscillator.

| Parameters | Fundamental | Inharmonic |
|---|---|---|
| Resonant Freq. [Hz] | 11996423 | 11996423 |
| $R_1[\Omega]$ | 6.87 | 55.5 |
| $L_1$[mH] | 7.63 | 29.0 |
| $C_1$[fF] | 23.1 | 6.03 |
| $C_0$[pF] | 6.94 | 6.94 |
| Quality Factor | 83700 | 39500 |

Figure 7(a) and (b) show the frequency characteristics of the equivalent resistance and equivalent reactance of the active circuit. The experimental results are measured by similar methods as in the previous section. The drive voltage applied to the active circuit was adjusted to 100 mV.



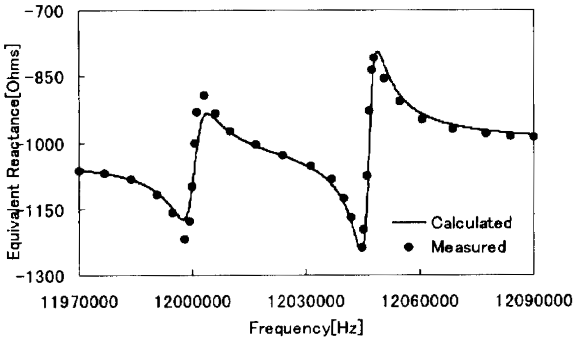




Fig.7 Frequency characteristics of (a) negative resistance and (b) equivalent reactance in Dual-mode oscillation circuits.(Drive voltage=100mV)

From these figures, it is clear that the proposed technique can precisely predict the frequency characteristics of the active impedance in the dual-mode crystal oscillators using resonator filters. Figure 8 shows the frequency spectrum of the collector voltage (Output 1) when the oscillator is actually operating. It is clearly understood from this figure that two individual frequencies, corresponding to the two responses in the AT-cut quartz resonator, are simultaneously generated.

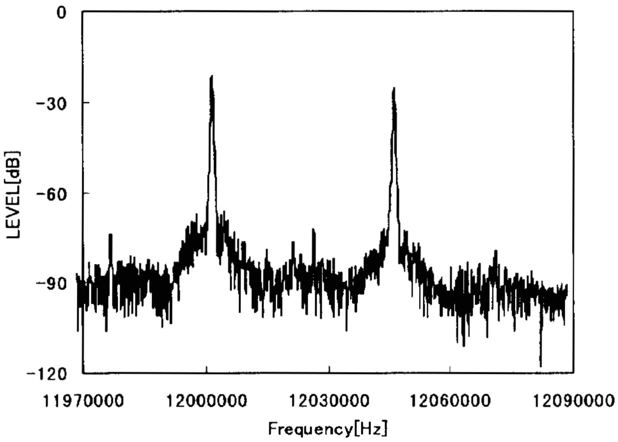



Fig.8 Spectrum of output1 of the dual-mode oscillator.

## 5. Conclusions

The proposed method predicts the active impedance characteristics of transistor Colpitts oscillators with resonator filters precisely, and can be used as design tool for narrow-band crystal oscillators. This method also can apply to designing dual-mode oscillators employing two Colpitts oscillators with resonator filters. The remaining problems to be solved are (1) whether this method can be used to estimate the oscillating condition in dual-mode oscillation, and (2) temperature compensation of the resonator filters.

## References


[1] Robert Rubach, "Dual mode digitally temperature compensated crystal oscillator," Proc. 36th Annual Symposium on Frequency Control, pp. 571-575.

[2] S. S. Schodowski "Resonator self-temperature-sensing using a dual-harmonic-mode crystal oscillator, " Proc. 43rd Annual Symposium on Frequency Control, pp. 2-7.

[3] A. Benjaminson and S. C. Stallings, "A Microcomputer-compensated crystal oscillator using a dual-mode resonator," Proc. 43rd Annual Symposium on Frequency Control, pp.20-26.

[4] A. V. Kosykh, I. V. Abramson, V. P. Bagaev, "Dual-mode crystal oscillators with resonators excited on b and c modes," Proc. 1994 IEEE International Frequency Control Symposium, pp.578-586.

[5] T. Uchida, M. Koyama, Y. Watanabe, H. Sekimoto and Y. Oomura; "A low phase-noise oscillator design for high stability OCXOs," Proc.1996 IEEE International Frequency Control Symposium, pp.749-751, June,1996.

[6] M. Hanazawa, Y. Watanabe and H. Sekimoto, "Negative-resistance analysis of Colpitts crystal oscillators with a tank circuit," IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences, Vol. E79-A, No.11, pp.811-817, Nov.1996.

[7] T. Shoji, T. Adachi and Y. Tsuzuki,"Analysis of equivalent capacitance of crystal oscillator," IEEJ Technical report on elctronic circuits, ECT-96-56, pp.33-39, Sept.1996 (in Japanese)

[8] U.Kida, "UBASIC86 Users Manual," Nihon Hyoronsha, 1994 (in Japanese)

[9] Y.Watanabe and Y.Oomura, "Frequency characteristic measurement of negative resistance of crystal oscillator circuits with floating resonator terminals," Trans. IEICE C-II, Vol.J78-C-II, No.2, pp.83-85, Feb. 1995 (in Japanese)