KOGA ISSAC (1899-1982); "Invention of a Temperature-Insensitive Quartz Oscillation Plate"
古賀逸策(1899-1982) 「温度に影響されない水晶発振器の発明」

1. Bio of Issac Koga

Born December 5, 1899 in Saga Prefecture. Graduated from the Department of Electrical and Electronic Engineering, Tokyo Imperial University in 1923. 1923 Research on wireless technology at Tokyo Electric Research Institute, 1929 Associate Professor at Tokyo Institute of Technology, 1930 Ph.D. from Tokyo Imperial University. Professor at Tokyo Institute of Technology in 1939, professor at Tokyo Imperial University in 1944, and emeritus professor from Tokyo Institute of Technology and Tokyo Imperial University in 1960. Advisor to KDD (now KDDI) until 1982. 1948 Japan Academy Prize, 1963 Order of Culture Award, 1971 Japan Academy Prize, 1963-1968 President of the International Radio Science Association (URSI). September 2, 1982, URSI established the Issac Koga Gold Medal in 1984 to commemorate it.

KOGA Issac

2. Abstract

In April 1933, Issac Koga invented the R_1 crystal unit, which is not affected by temperature. The R_1 plate is a crystal oscillator plate cut out in parallel with the X axis at an angle of 54°45' from the z axis to the Y-axis. The present invention was first used in wireless transmitters, later in watches, and is still used in most wireless communication systems and many information and electronic devices.

3. Research Achievement

3.1 History of discovery of zero temperature coefficient R_1 plate

At the beginning of the 20th century, accurate and stable radio frequency sources were needed, and radio engineers were looking for a way to do so. Walter Guyton Cady discovered that quartz resonates with excellent temperature stability as a small device, and in 1921 realized the first crystal oscillator. From the latter half of 1929 to the beginning of 1930, several proposals were made to realize a crystal unit with a zero temperature-coefficient. Among them, the ring type plate was considered to be promising, but due to the delicate design restrictions, it could not be used in an actual transmitter.

Issac Koga started research on crystal oscillators at Tokyo Institute of Technology. In parallel, he examined the characteristics of the R-cut plate cut out parallel to the r-plane in Fig. 1 and the R'-cut plate cut out parallel to the r'-plane (the back side of the r-plane). He noticed that the R'-cut plate showed a negative temperature-coefficient, and the Y-cut plate showed a positive temperature coefficient. From these experiments, we hypothesized that there is a zero temperature-coefficient plate between those cutting angles.

The cutting angle was gradually changed from the R'-plate to the Y-plate, and the temperature characteristics were investigated. From the normal angle of the r'-plane (51°47' from the z-axis) toward the Y-axis, the result is -2.5×10^{-6}/K at 55°16' and $+6.0\times10^{-6}$/K at 55°33' obtained. From this result, it was inferred that the temperature coefficient was 10^{-7}/K near the above angle [1]. In this way, the existence of a crystal diaphragm with almost zero temperature coefficient was predicted.

3.2 Vibration equation and its solution

At the same time, Koga felt the need for some kind of guiding theory to find an appropriate cutting angle. Therefore, he tried to make the vibration theory of the crystal plate [2] and started to establish the theory of vibration analysis of quartz plates. In 1932, Koga succeeded in an accurate theoretical analysis of the thickness vibration of anisotropic quartz [2]. Koga's theory suggests a method of rotating the cutting angle around the crystal axis and has been widely used all over the world. It led to the discovery of an oscillator with a zero coefficient in 1933.

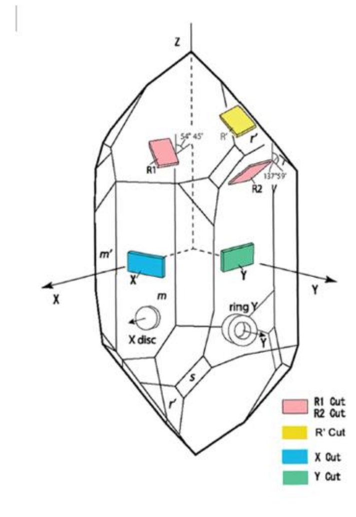

Fig. 1 Quartz crystal

In August 1932, Koga showed that there could be three normal thickness vibration modes. Then, the equivalent elastic constant c^{eq} corresponding to the thickness vibration of the quartz plate cut parallel to the X-axis at the rotation angle θ from the z-axis was obtained [1].

$$c^{eq} = \frac{1}{2}(c_{11} - c_{12})\sin^2\theta + c_{44}\cos^2\theta - c_{14}\sin 2\theta \tag{1}$$

Here, i and j take 1, 2, and 4. c_{ij} is the adiabatic constant in each direction. As the resonance frequency *f*, the anisotropic resonance frequency can be easily expressed by using c^{eq} instead of *c* in the resonace frequeny of isotropic vifration.

The following equation was obtained by differentiating equation (1) with respect to temperature *T*.

$$\frac{1}{2}(\dot{c}_{11} - \dot{c}_{12})\sin^2\theta + \dot{c}_{44}\cos^2\theta - \dot{c}_{14}\sin 2\theta = 0 \tag{2}$$

Here, the dot means $\partial/\partial T$. This is a transcendental equation that includes trigonometric functions, which Koga and Takagi solved numerically using the Tiger calculator in the latter half of 1933 [3]. The authors' views are described in Reference [5].

3.3 Cutting angle and temperature dependence details

Subsequent detailed studies revealed the exact angle of 54°45' reported on October 10, 1933 [3] In Reference [3], the angle is taken from the normal of the R plate, so it is indicated as 2°58'.

This cut-out angle plate was later called the R_1 plate. It is shown in the upper left of Figure. The paper [1] also suggests the existence of the R_2 plate, which is the opposite surface. Koga et al. experimentally confirmed the existence of a possible zero temperature coefficient angle of 137°59'. The results were published in December 1933 [4] . These cuts were later named R_1 and R_2 cuts. Figure 2 shows a redrawn picture including the R_2 cut.

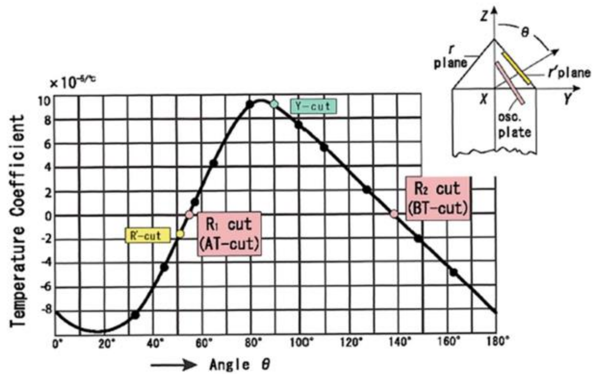

Fig. 2 Rotation angle θ vs. temperature coefficients

3.4 Applicable to wireless communication

Koga's R_1 cut was used experimentally at the Yosami Radio Transmission Station (Fig. 3) in the summer of 1933. One hour after transmission, a German receiver responded about frequency stability. They noticed a sudden stabilization of the transmission frequency and wondered what had happened and asked.

The Yosami Radio Transmitting Station, which was established in 1929 for wireless communication between Japan and Europe using long waves, was certified as another IEEE milestone in 2009. Short-wave communications have emerged as an alternative to long-waves since the mid-1920s, and Koga's temperature-sensitive quartz demonstrates its importance in its transmission.

Fig. 3 Yosami radio station

Fig. 4 Quartz clock KQ1

3.5 Quartz clock

Koga invented the frequency divider in 1927, and in 1936 prototyped the Koga-type quartz watch KQ1 (Fig. 4). In the same year, it was exhibited at the Tokyo Institute of Technology Open Campus and the 1937 Paris World's Fair. It was also donated to the National Astronomical Observatory of Japan and a time standard experiment was conducted. The improved KQ6 was installed in the KDD for frequency standards and standard clocks in 1955 and was used for international communications without problems until 1968 (Fig. 4).

4. Notices

Even after World War II, Koga's pioneering research on theory and technology was carried out by the successors; Hitohiro Fukuyo, et al. of Tokyo Institute of Technology, Yasuo Tsuzuki of Yokohama National University, Takahito Saito of Defense Academy, Yoshimasa Omura of Tokyo Metropolitan University, KDD Institute, and related companies. These achievements have greatly contributed to the development of current crystal oscillator technology and industry. This achievement was recognized as an IEEE milestone, and a nameplate was awarded to Tokyo Institute of Technology in March 2017 (Fig. 5). It is placed at Suzukakedai-Campus of Tokyo Institute of Technology.

Fig. 5 IEEE Milestone

5. References

[1] Issac Koga and Koji Ichinose: "Crystal Oscillator for Shortwaves with Small Temperature Coefficient", IEIC/IEICE/Illuminating Engineering Institute of Japan, 8th Joint Conference, pp.205-206, Apr. 3, 1933.

[2] Issac Koga, "Thickness Vibrations of Piezoelectric Oscillating Crystals," J. Appl. Phys., vol. 3, pp. 70-80, Aug. 1932.

[3] Issac Koga and Noboru Takagi: "Crystal oscillator with temperature coefficient of 10^{-7}/K or less", Institute of Electrical Engineers of Japan, vol. 53, 10, p. 940, Oct. 10, 1933.

[4] Issac Koga and Noboru Takagi: "Temperature Coefficient of Crystal Elasticity", Institute of Electrical Engineers of Japan, vol. 53, 12, p. 1141, Dec. 1933.

[5] Kenichi Iga and Akinori Nishihara, "Invention of a Temperature-Insensitive Quartz Oscillation Plate", 2017 IEEE HISTory of ELectrotechnolgy CONference (HISTELCON), Xplore, pp. 87-90, Aug. 2017.

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