

"OSCILLATOR CIRCUIT"

This invention relates to oscillator circuits.

One known crystal oscillator circuit has a trimmer capacitor to control the oscillation frequency, so its construction is complex.

5 The oscillation frequency drifts with change of temperature, so it can be used only over a narrow temperature range. An oscillator circuit whose frequency drift rate is about $\pm 2\text{ppm}$ in the temperature range 5 to 35° has a far higher frequency drift rate outside this temperature range.

10 According to the present invention there is provided an oscillator circuit comprising: a piezoelectric vibrator for use as a frequency standard; a plurality of electrodes on the surface of the piezoelectric vibrator jointly defining an electrode area; pulse generator means for generating pulses having a variable duty ratio;
15 and switching circuit means responsive to the pulses for switching the effective electrode area of the piezoelectric vibrator for controlling the oscillation frequency thereof.

The pulse generator means may include a frequency divider for dividing the output frequency of the piezoelectric vibrator, and a
20 control circuit for controlling the pulse width of the output pulses from the frequency divider.

Preferably the oscillator circuit includes temperature compensating means for varying the duty ratio of the switching pulses as a function of temperature.

25 In one embodiment the pulse generator means includes a ring oscillator consisting of C-MOS inverters connected in a circle.

In another embodiment the pulse generator means includes a CR

oscillator with a thermistor.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:

Figure 1 shows schematically one embodiment of an oscillator circuit according to the present invention;

Figure 2 shows front and rear views of a piezoelectric vibrator of the oscillator circuit of Figure 1;

Figure 3 illustrates graphically the frequency-temperature characteristics of the piezoelectric vibrator of Figure 2 with change in duty ratio of switching pulses applied thereto:

Figure 4 is a circuit diagram of another embodiment of an oscillator circuit according to the present invention;

Figures 5, 6, 7 and 8 are circuit diagrams of four further embodiments of oscillator circuits according to the present invention;

Figure 9 illustrates the frequency-temperature characteristics of the oscillator circuit of Figure 8;

Figure 10 is a circuit diagram of another oscillator circuit according to the present invention;

Figure 11 illustrates graphically the frequency-temperature characteristics of a ring oscillator of the oscillator circuit of Figure 10;

Figure 12 is a circuit diagram of a yet further embodiment of an oscillator circuit according to the present invention;

Figure 13 shows front and rear views of a piezoelectric

vibrator of an oscillator circuit according to the present invention and shown in Figure 14;

Figure 14 is a circuit diagram of an oscillator circuit according to the present invention including the piezoelectric vibrator of Figure 13; and

Figure 15 illustrates the frequency-temperature characteristics of the oscillator circuit of Figure 14.

Throughout the drawings like parts have been designated by the same reference numerals.

Referring first to Figures 1 and 2, an oscillator circuit according to the present invention has a piezoelectric vibrator A, for example a quartz crystal vibrator, with an electrode E_1 formed on one face thereof and electrodes E_2 , E_3 formed on the opposite face. The electrode E_1 is connected to a load capacitor C_1 , the electrode E_3 is connected to a load capacitor C_2 and the electrode E_2 is connected to the load capacitor C_2 via a switching circuit S. Between the load capacitors C_1 , C_2 a parallel arrangement of an inverter V_1 and a resistor R_1 is connected.

When the duty ratio t_p of switching pulses P is 1, the switching circuit S is maintained ON so the electrodes E_2 , E_3 are energised.. Thus the oscillation frequency of the oscillator circuit at room temperature is f_1 which is lower than a desired frequency f_0 , as a curve ℓ_1 in Figure 3 shows.

When the duty ratio t_p of the switching pulses is 0, the switching circuit S is OFF, so the electrode E_2 is not energised.

Thus the oscillation frequency at room temperature is f_2 which is higher than the desired frequency f_0 , as a curve ℓ_2 shows in Figure 3.

The connection of the electrodes E_2, E_3 into the oscillator circuit is controlled by supplying switching pulses P to a terminal a of the switching circuit S . Accordingly, the effective electrode area of the piezoelectric vibrator A is periodically changed, and the oscillation frequency of the oscillator circuit is controlled by the duty ratio of the pulses P . For example, when the duty ratio t_p is $1/2$, the oscillation frequency at room temperature is f_3 which is between the frequency f_1 and the frequency f_2 . as curve ℓ_3 shows in Figure 3. When the duty ratio t_p is $3/4$, the oscillation frequency at room temperature is equal to the desired frequency f_0 , as curve ℓ_4 shows in Figure 3.

The time constant T_c of the passive parts of the oscillator circuit is as follows:

$$T_c \approx 2Q/\omega_0$$

where, Q is the Q value of the quartz crystal vibrator A

$$\omega_0 = 2\pi f, \text{ and}$$

f is the oscillation frequency.

Accordingly, by arranging that the frequency f_p of the switching pulses P is much higher than $1/T_c$ ($f_p \gg 1/T_c$), the frequency f_p has a negligible effect upon the oscillation frequency spectrum of the oscillator circuit. In other words, the stability of the oscillation frequency of the piezoelectric vibrator A is not

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destroyed by the inclusion of the switching circuit S in the oscillator circuit and the oscillation frequency is controlled solely by the duty ratio of the switching pulses P.

For example, when the piezoelectric vibrator A has an
5 oscillation frequency of about 4.2 MHz and a Q value of about $3 \times 10^5 - 5 \times 10^5$ and the frequency f_p of the switching pulses P is about 10 KHz, the oscillation frequency is not influenced by the frequency f_p , but the oscillation frequency is controlled by the duty ratio of the switching pulses P. Accordingly, the
10 oscillation frequency of the oscillation circuit can be adjusted by varying the duty ratio of the switching pulses, without losing the stability of the oscillation frequency.

Another embodiment of an oscillator circuit according to the present invention is shown in Figure 4. A frequency divider D
15 divides the oscillation frequency from the oscillator circuit, and the output frequencies from the terminals d_1 , d_2 are $1/2^n$, $1/2^m$ ($n > m$) of the oscillation frequency, respectively. A differentiation circuit T differentiates the output frequency from the terminal d_1 , and the output pulses from the differentiation circuit T are
20 supplied to an input terminal PE of a K ($K = n-m$) bits presettable down counter CT. A gate circuit G receives the pulses from a terminal e of the counter CT and the pulses from the terminal d_2 pass through the gate circuit G. A desired value is set by a
25 digital switch DS, and it is memorized in a non-volatile memory circuit M.

The operation of the oscillator circuit of Figure 4 is as follows. A pulse from the differentiation circuit T causes the desired value memorized in the memory circuit M to be preset into the counter CT. Therefore, the terminal e becomes logic 1
5 so the pulses from the terminal d_2 pass through the gate circuit G and are supplied to the counter CT. The terminal e of the counter CT becomes logic 0 when the counter CT has counted the desired value. Then, the content of the memory circuit M is preset again in the counter CT by the next pulse from the terminal d_1 , and the
10 above-mentioned operation is repeated.

Consequently, from the terminal d_1 , pulses whose duty ratio corresponds to the desired value set by the digital switch DS are generated, and switch the switching circuit S. Thus the effective electrode area of the piezoelectric vibrator is switched
15 periodically and the oscillation frequency of the oscillator circuit is adjusted.

In Figure 4 all except the digital switch DS, the capacitors C_1 , C_2 , and the piezoelectric vibrator can be integrated, and a trimmer capacitor such as used in conventional oscillator circuits
20 is not needed. Thus the stability of the oscillation frequency improves.

In an embodiment of an oscillator circuit according to the present invention and shown in Figure 5, when the switching circuit S is ON, the electrodes E_1 , E_2 , E_3 are energised. When the
25 switching circuit S is OFF the electrode E_2 is not energised.

In the embodiments of oscillator circuits according to the present invention shown in Figures 6 and 7, the effective electrode area of the piezoelectric vibrator A is switched by switching the energization of the electrode E_1 .

5 Figure 8 illustrates a further embodiment of an oscillator circuit according to the present invention. In Figure 8, temperature is converted to a corresponding voltage by a thermistor Th and a resistance R_2 , and this voltage is supplied to comparison circuits $CM_1 \dots CM_R$. The respective terminals
10 $P_1 \dots P_R$ of the comparison circuits $CM_1 \dots CM_R$ are at predetermined different voltages. The outputs from the comparison circuits $CM_1 \dots CM_R$ are converted to binary coded data by an encoder E , and the binary coded data is supplied to the counter CT .

Consequently, data corresponding to temperature is preset in
15 the counter CT so determining the duty ratio of the switching pulses from the switching circuit S . Therefore, the duty ratio of the switching pulses is a function of temperature and the effective electrode area of the piezoelectric vibrator is switched in dependence upon temperature. Accordingly, the oscillation
20 frequency is temperature compensated as shown by line ℓ_5 in Figure 9. Accordingly, the frequency drift rate can be controlled to under $\pm 1 \text{ppm}$ over a relatively wide temperature range -30°C to 70°C .

Referring to Figure 10 there is illustrated another embodiment of an oscillator circuit according to the present
25 invention. A ring oscillator RG is composed of C-MOS inverters

V_2, V_3, V_4 connected in a circle and its output frequency is supplied to a mixer MR. A difference frequency equal to the difference between the output frequency of the ring oscillator RG and the frequency from the terminal d_3 of the frequency divider D is supplied to a data converter DT. The frequency-temperature characteristics of the ring oscillator are substantially linear as shown in Figure 11. The vertical axis in Figure 11 shows the frequency drift rate $\Delta f/f_{25^{\circ}\text{C}}$ (where $f_{25^{\circ}\text{C}}$ is the oscillation frequency at 25°C , $\Delta f = f_{T^{\circ}\text{C}} - f_{25^{\circ}\text{C}}$, and $f_{T^{\circ}\text{C}}$ is the oscillation frequency at $T^{\circ}\text{C}$.)

Since the oscillation frequency of the ring oscillator RG drifts linearly with temperature, the output frequency from the mixer MR varies with temperature, and is converted to binary coded data by the data converter DT. The data is supplied to the counter CT.

Consequently, the oscillation frequency of the piezoelectric vibrator A is temperature compensated as shown in Figure 9. All except the piezoelectric vibrator A and the capacitors C_1, C_2 can be integrated on to a C-MOS IC chip.

A yet further embodiment of an oscillator circuit according to the present invention is shown in Figure 12. The oscillation frequency of a CR oscillator OS, which includes a thermistor, is counted by a frequency counting circuit FC, and its content is converted to binary coded data by the data converter DT.

The oscillation frequency of the CR oscillator OS drifts with

temperature so the binary coded data from the data converter varies in dependence upon temperature.

Figure 14 shows a further embodiment of an oscillator circuit according to the present invention and Figure 13 shows, in detail, a piezoelectric vibrator B, for example a quartz crystal vibrator, thereof. The piezoelectric vibrator B is of the tuning fork type and has frequency-temperature characteristics represented by a quadratic curve. Electrodes F_1 , F_2 , F_3 are formed on one face of the piezoelectric vibrator B, and an electrode F_4 is formed on the opposite face.

The electrode F_3 is switched by the switching circuit S. When the duty ratio of the switching pulses P is 1, the oscillation frequency is lower than the desired frequency f_0 , as a curve λ_6 shows in Figure 15. Further, the oscillation frequency is higher than the desired frequency f_0 as curve λ_7 shows in Figure 15, when the duty ratio of the switching pulses is 0.

The oscillation frequency of the CR oscillator OS and the output frequency from the terminal d_3 of the divider circuit D are supplied to the mixer MR, and the difference frequency is converted to binary coded data by the data converter DT. The oscillation frequency of the CR oscillator OS is predetermined so that it is coincident with the frequency from the terminal d_3 at 25°C , namely at the centre line of the quadratic curve λ_6 in Figure 15. Therefore, the difference frequency from the mixer MR is 0 at 25°C and drifts symmetrically therefrom with increase or

decrease of temperature. Consequently, the temperature characteristics can be temperature compensated to less than $\pm 1 \text{ ppm}$ over a relatively wide temperature range as shown by line ℓ_8 in Figure 15.

5 In addition to the advantages already mentioned, the oscillator circuits according to the present invention also have the advantage that since the switch pulses are generated from a frequency divider which divides the oscillation frequency, the oscillation frequency and the switching pulses are not influenced
10 by ageing.



CLAIMS

1. An oscillator circuit comprising: a piezoelectric vibrator for use as a frequency standard; a plurality of electrodes on the surface of the piezoelectric vibrator jointly defining an electrode area; pulse generator means for generating pulses having a variable
5 duty ratio; and switching circuit means responsive to the pulses for switching the effective electrode area of the piezoelectric vibrator for controlling the oscillation frequency thereof.
2. An oscillator circuit as claimed in claim 1 in which the pulse generator means includes a frequency divider for dividing the
10 output frequency of the piezoelectric vibrator, and a control circuit for controlling the pulse width of the output pulses from the frequency divider.
3. An oscillator circuit as claimed in claim 1 or 2 which includes temperature compensating means for varying the duty ratio
15 of the switching pulses as a function of temperature.
4. An oscillator circuit as claimed in claim 3 in which the pulse generator means includes a ring oscillator consisting of C-MOS inverters connected in a circle.
5. An oscillator circuit as claimed in claim 3 in which the pulse
20 generator means includes a CR oscillator with a thermistor.
6. An oscillator circuit substantially as herein described with reference to and as shown in the accompanying drawings.

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