"OSCILLATOR CIRCUIT"

This invention relates to oscillator circuits.

For example, in known crystal oscillator circuits, a trimmer condenser is needed to control the oscillation frequency; so its construction is relatively complex, and the oscillation frequency drifts with temperature change, so that it can be used only over a narrow temperature range. One known oscillator circuit has a rate of frequency drift of about ± 2 parts per million in the temperature range 5 - 35°C but outside this temperature range, the rate of frequency drift is far greater.

According to the present invention there is provided an oscillator circuit comprising: a vibrator circuit comprising a load capacitor and a piezo-electric vibrator; a further capacitor connected in parallel with the load capacitor of the vibrator circuit; a switching circuit for controlling the connection of the further capacitor to the vibrator circuit; a pulse generator for generating pulses to switch the switching circuit, the pulse generator being arranged to generate pulses with a period which is shorter than the time constant τc of the vibrator circuit, where

$\tau c \doteq 2Q/\omega_o$,

Q is the Q value of the piezo-electric vibrator,

$\omega_o = 2\pi f_o$, and

f_o is the oscillation frequency.

The pulse generator may comprises a frequency divider for frequency dividing the oscillation frequency of the vibrator circuit.

and a control circuit for controlling the pulse width of the pulses from the frequency divider.

The oscillator circuit may include temperature compensating means for varying the duty ratio of the pulses in dependence upon temperature.

In one embodiment the temperature compensating means includes a ring oscillator consisting of a plurality of inverters connected in a circle, the control circuit being connected to control the pulse width of the pulses from the frequency divider in dependence upon the oscillation frequency of the ring oscillator.

In another embodiment the temperature compensating means comprises a CR oscillator including a thermistor, the control circuit being connected to control the pulse width of the pulses from the frequency divider in dependence upon the oscillation frequency of the CR oscillator.

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

Figure 1 is a block diagram of one embodiment of an oscillator circuit according to the present invention,

Figure 2 is a graph illustraing low capacitance as seen by a vibrator circuit of the oscillator circuit of Figure 1,

Figure 3 is a block diagram of another embodiment of an oscillator circuit according to the present invention,

Figure 4 illustrates the frequency temperature characteristics of a piezo-electric vibrator circuit of Figure 3,

Figure 5 illustrates the frequency load capacitance characteristics of the piezo-electric vibrator of the oscillator circuit of Figure 3,

Figure 6 is a block diagram of another embodiment of an oscillator circuit according to the present invention,

Figure 7 is a frequency temperature characteristic diagram of the oscillator circuit of Figure 6,

Figure 8 is a block diagram of a further embodiment of an oscillator circuit according to the present invention,

Figure 9 is a frequency temperature characteristic diagram of a ring oscillator of the oscillator circuit of Figure 8,

Figure 10 is a block diagram of a yet further embodiment of an oscillator circuit according to the present invention,

Figure 11 is a frequency-temperature characteristic diagram of a piezo-electric vibrator of an oscillator circuit shown in Figure 12, and

Figure 12 is a block diagram of yet another embodiment

of an oscilaltor circuit according to the present invention.

In the drawings and the following description like parts have been designated by the same reference numerals.

Referring to Figure 1, an oscillator circuit according to the present invention comprises a vibrator circuit consisting of a feed back resistor R, a C-MOS inverter V_1, load capacitors C_1, C_2 and a quartz crystal vibrator Q. A capacitor C_3 is connected in parallel with the load capacitor C_2 of the vibrator circuit and a switching circuit S is connected in series with a capacitor C_3.

The connection of the capacitor C_3 to the load capacitor C_2 is controlled by supplying pulses P to a terminal a of the switching circuit S. Thus, the effective load capacitance seen from an output terminal b of the vibrator circuit by the switching circuit S is as represented in Figure 2. The effective load capacitance varies with the duty ratio $\tau d/\tau p$ of the pulses P, and so the oscillation frequency oscillator circuit can be adjusted.

It will now be explained how the effective load capacitance C(t) seen at the terminal b, varies with the duty ratio of the pulses P. The capacitance C(t) is expanded by Fourier series analysis as follows:-

$$C(t) = a_0 + a_1 \cos \omega p \cdot t + a_2 \cos \omega p \cdot t + \cdots + b_1 \sin \omega p \cdot t + b_2 \sin \omega p \cdot t + \cdots$$

Provided that,

$$\omega p = 2\pi fp, \quad fp = 1/\tau p$$

$$a_0 = 1/\tau p \int_0^{\tau p} C(t)dt$$

$$a_n = 2/\tau p \int_0^{\tau p} C(t) \cos n\omega p \cdot t dt$$

$$b_n = 2/\tau p \int_0^{\tau p} C(t) \sin n\omega p \cdot t dt$$

Consequently, capacitance C(t) is given by:

$$C(t) = C_2 + C_3 \left\{ \tau d/\tau p + \sum_{n=1}^{\infty} 1/n\pi \cdot \sin n\omega p \tau d \cdot \cos n\omega p \cdot t + \sum_{n=1}^{\infty} 1/n\pi \, (1-\cos n\omega p \cdot \tau d) \cdot \sin n\omega p \cdot t \right\}$$

$$= C_2 + C_3 \left\{ \tau d/\tau p + \sum_{n=1}^{\infty} 1/n\pi \cdot 2(1-\cos 2n\pi \, \tau d/\tau p) \cdot \sin\left(2n\pi \, t/\tau p + \tan^{-1} \frac{\sin 2n\pi \, \tau d/\tau p}{1-\cos 2n\pi \, \tau d/\tau p}\right) \right\} \cdots\cdots (1)$$

Equation (1) includes a switching frequency n · fp(n = 1, 2, 3 ---), and so the response of the vibrator circuit of the switching circuit will now be explained. The time constant τc of the passive parts of the vibrator circuit is given by:

$$\tau c \fallingdotseq 2Q/\omega_o,$$

where Q is the Q value of the quartz crystal vibrator

$\omega_o = 2\pi f_o$, f_o is the oscillation frequency.

Accordingly, by making the frequency fp of the switching pulses P much higher than $1/\tau c$ i.e. $f_p > 1/\tau c$,

the frequency fp becomes negligible in the oscillation frequency spectrum of the vibrator circuit. Therefore, in equation (1), the terms containing n · fp can be ignored. Consequently, the effective load capacitance C(t) is given by:-

$$C(t) = C_2 + C_3 \cdot \tau d/\tau p,$$

in other words the effective load capacitance is determined only by the duty ratio of the pulses P. Thus the oscillation frequency can be controlled by the duty ratio of the pulses.

Accordingly, the oscillation frequency can be adjusted by the duty ratio of the pulses P without losing the stability of the oscillation frequency.

Figure 3 illustrates another embodiment of an oscillator circuit according to the present invention. A frequency divider D frequency divides the oscillation frequency, and output signals d_1, d_2 from the frequency divider have frequency of $1/2^n$, $1/2^m$ $(n > m)$ of the oscillation frequency, respectively. A differentiation circuit T differentiates the output signal d_1, and the output pulse signal from the differentiation circuit T is supplied to an input terminal PE of a K(K = n-m) bits presettable down counter A. A gate circuit G receives an output pulse signal E from the counter A, and the output signal d_2 from the frequency divider D passes through the gate circuit G. A predetermined desired value is set by a digital switch DS, and is memorized in a non-volatile memory circuit M.

The operation of the oscillator circuit of Figure is as follows. A pulse from the differentiation circuit T causes a predetermined desired value memorized in the memory circuit M to be preset in the counter A. Therefore, the output signal e is logic 1 so the output signal d_2 passes through the gate circuit G, and is supplied to the counter A. The output signal e becomes logic 0 when the counter A has counted the predetermined desired value. Then, the content of the memory circuit M is preset again in the counter A by the next pulse of the output signal d_1 and the above described operation is repeated.

Consequently, the pulses of the output signal d_1 have a duty ratio corresponding to the predetermined desired value set in the digital switch DS, and switch the switching circuit S. Thus the effective load capacitance and so the oscillation frequency of the oscillator circuit is adjusted.

In Figure 3 all but the digital switch DS, capacitors C_1, C_2, C_3 and the quartz crystal vibrator can be integrated. A conventional trimmer condenser is not required so the stability of the oscillation frequency is improved compared to conventional oscillation circuits.

An AT cut quartz crystal vibrator has frequency-temperature characteristics represented by a cubic curve shown in Figure 4. In Figure 4, a frequency difference Δf between the desired frequency f_0 and the actual frequency f is shown on the vertical axis, and the temperature is shown on the horizontal axis.

Frequency load capacitance characteristics are illustrated by the curve shown in Figure 5 so frequency drift with temperature can be compensated by controlling the effective load capacitance.

An oscillator circuit according to the present invention and shown in Figure 6 has temperature converted to a corresponding voltage by a thermistor Th and a resistor r, and this voltage is supplied to comparison circuits $CM_1 \ldots CM_r$. Terminals $P_1 \ldots P_r$ of the comparison circuits $CM_1 \ldots CM_r$ respectively are set to predetermined different voltages. The output signals from the comparison circuit $CM_1 \ldots CM_r$ are converted to binary coded data by an encoder E, and the data is then supplied to the counter A.

Consequently, data corresponding to the temperature is preset in the counter A to determine the duty ratio of the pulses for the switching circuit S. Therefore, the switching of the switching circuit is controlled in dependence upon temperature and consequently the effective load capacitance is controlled in dependence upon temperature and accordingly the oscillation frequency is temperature compensated. The frequency temperature characteristics of the oscillation frequency when not temperature compensated are shown by curve ℓ_1 in Figure 7 and when temperature compensated by the waveform ℓ_2 in Figure 7. Accordingly, the rate of frequency drift $\Delta f/f$ can be controlled to be under 1 part per million over a very wide temperature range.

Next, referring to Figure 8, there is shown another embodiment of an oscillator circuit according to the present invention for the temperature compensation of the oscillation frequency. A ring oscillator RG consists 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 between the output frequency of the ring oscillator RG and the frequency of an output signal d_3 from 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 9. On the vertical axis shown in Figure 9, the rate of frequency drift $\Delta f/f_{25^oC}$ (f_{25^oC} is the oscillation frequency at 25°C, $\Delta f = f_{T^oC} - f_{25^oC}$, and f_{T^oC} is the oscillation frequency T°C) is shown.

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

Consequently, the oscillation frequency of the oscillator circuit is compensated as shown in Figure 7. Except for the quartz crystal vibrator Q and the capacitors C_1, C_2, C_3 the oscillator circuit of Figure 8 can be integrated on a C-MOS IC chip.

A further embodiment of an oscillator circuit according to

the present invention is shown in Figure 10. The oscillation frequency of a CR oscillator H, which includes a thermistor, is counted by a frequency counting circuit CT, and its content is converted to binary coded data by the data converter DT. The oscillation frequency of the CR oscillator H varies with temperature so data from the data converter DT also varies with temperature. The oscillator circuit of Figure 10 operates in a similar manner to the oscillator circuit of Figure 6 and so will not be described further.

Another embodiment of an oscillator circuit according to the present invention shown in Figure 12 includes a quartz crystal vibrator whose frequency temperature characteristics are shown as a quadratic curve ℓ_3 in Figure 11. The oscillation frequency of a CR oscillator H and an output signal d_3, frequency divider D are supplied to a mixer MR, and the difference frequency is converted to binary coded data by a data converter DT. The oscillation frequency of the CR oscillator H is predetermined to be coincident with the frequency of the output signal d_3 at 25°C, namely at the centre line of the quadratic curve ℓ_3 in Figure 11. 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 frequency temperature characteristics shown by the quadratic curve ℓ_3 in Figure 11 can be compensated under $\pm$ one part per million over a very wide temperature range, as shown by waveform ℓ_4.

In the embodiments of the present invention described above, the parallel connection between a capacitor and a load capacitor of the vibrator is controlled by switching pulses which have a predetermined duty ratio. Therefore, the oscillation frequency can be adjusted by controlling the duty ratio of the switching pulses, and a conventional trimmer condenser is not needed, and the frequency stability of the oscillator circuit is improved compared to that of conventional oscillator circuits. Further, since the switching pulses are generated from a frequency divider which frequency divides the oscillation frequency, the oscillation frequency and the switching pulses are not influenced by aging. In addition, since the duty ratio of the switching pulses can be varied with change of temperature, the oscillation frequency can be temperature compensated and kept stable over a wide range of temperatures.

CLAIMS

1. An oscillator circuit comprising: a vibrator circuit comprising a load capacitor and a piezo-electric vibrator; a further capacitor connected in parallel with the load capacitor of the vibrator circuit; a switching circuit for controlling the connection of the further capacitor to the vibrator circuit; a pulse generator for generating pulses to switch the switching circuit, the pulse generator being arranged to generate pulses with a period which is shorter than the time constant τc of the vibrator circuit, where

$\tau c \doteqdot 2Q/\omega_o$,

Q is the Q value of the piezo-electric vibrator,

$\omega_o = 2\pi f_o$, and

f_o is the oscillation frequency

2. An oscillator circuit as claimed in claim 1 in which the pulse generator comprises a frequency divider for frequency dividing the oscillation frequency of the vibrator circuit, and a control circuit for controlling the pulse width of the pulses from the frequency divider.

3. An oscillator circuit as claimed in claim 1 or 2 including temperature compensating means for varying the duty ratio of the pulses in dependence upon temperature.

4. An oscillator circuit as claimed in claim 3 when dependent upon claim 2 in which the temperature compensating means includes

a ring oscillator consisting of a plurality of inverters connected in a circle, the control circuit being connected to control the pulse width of the pulses from the frequency divider in dependence upon the oscillation frequency of the ring oscillator.

5. An oscillator circuit as claimed in claim 3 in which the temperature compensating means comprises a CR oscillator including a thermistor, the control circuit being connected to control the pulse width of the pulses from the frequency divider in dependence upon the oscillation frequency of the CR oscillator.

6. An oscillator circuit substantially as herein described with reference to and as shown in the accompanying drawings.

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