

PATENT SPECIFICATION

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- (21) Application No. 56328/73 (22) Filed 5 Dec. 1973
 (31) Convention Application No. 124 665/72 (32) Filed 12 Dec. 1972 in
 (33) Japan (JA)
 (44) Complete Specification published 19 May 1976
 (51) INT. CL.³ H03B 5/36//G05C 3/00
 (52) Index at acceptance
 H3T 1G3X 2C 2P 2T3F 3J 4D 4G 5E 5S
 G3T A5X

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(54) IMPROVEMENTS IN OR RELATING TO PIEZO-ELECTRIC CRYSTAL OSCILLATING CIRCUITS EMPLOYING MOS TRANSISTORS

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese Company of 3-4, 4-chome, Ginza, Chuo-ku, Tokyo, Japan, do hereby declare the invention, for which we

5 pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to semi-conductor piezo-electric crystal oscillating circuits employing MOS transistors and more specifically to such oscillating circuits employing a quartz (i.e. piezo-electric) crystal in conjunction with complementary MOS transistors and wherein a monolithic integrated

15 circuit construction is employed. The object of the invention is to provide such oscillating circuits which shall be relatively cheap and easy to manufacture, extremely compact, and of high frequency stability and constancy. The invention is of great advantage for, and primarily intended for, the time standard oscillators of electronic timepieces.

20 According to this invention a piezo-electric crystal oscillating circuit comprises a piezo-electric crystal, complementary MOS transistors having a common gate terminal and a common drain terminal, a feedback resistor connected in a circuit across said crystal, an output resistor connected in a circuit between said common drain terminal and one terminal of said crystal and a connection between said common gate terminal and the other terminal of said crystal, said

35 output resistor and said complementary MOS transistors being incorporated on the same substrate in a monolithic integrated circuit construction.

40 Said output resistor may be constituted by doped polycrystalline silicon, or undoped polycrystalline silicon or a P-type layer, formed on an N-type substrate simultaneously with P-type diffusion for producing an N-channel transistor when the complementary MOS transistors are produced.

In a preferred embodiment the feedback resistor is connected directly across the crystal and has one end connected directly to the common gate terminal of the MOS transistors and the other end connected directly to that end of the output resistor which is remote from the common drain terminal of said MOS transistors one of the crystal terminals being connected to ground through said output resistor and the drain capacitance of the transistors and the other crystal terminal being connected to ground through the gate capacitance of the transistors, said transistors, capacitances and output resistor being all in the same substrate of the monolithic integrated circuit chip.

55 The value of the aforesaid output resistor is preferably between 10K Ω and 500K Ω .

There may be bias means providing bias through said output resistor.

60 The invention is illustrated in and further explained in connection with the accompanying drawings, in which:—

65 Figure 1, which is not in accordance with the invention but is provided for purposes of explanation, shows diagrammatically a quartz crystal oscillating circuit employing complementary MOS transistors but which does not contain an output resistor,

70 Figure 2 shows diagrammatically a quartz crystal oscillating circuit employing complementary MOS transistors and which is in accordance with this invention. In Figure 2, V is a quartz crystal vibrator; R is a feedback resistor; MT are the complementary MOS transistors; C_g represents gate capacitance; C_d represents drain capacitance; and r_D represents the output resistor provided,

75 Figure 3 shows graphically characteristics in which supply voltage (abscissae) is plotted against oscillatory frequency (ordinates). Characteristic α is that of a quartz crystal oscillating circuit (such as

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that of Figure 1) which does not contain an output resistor and characteristic *b* is that of a quartz crystal oscillating circuit in accordance with this invention wherein an output resistor is provided.

Figure 1 shows a quartz crystal oscillating circuit employing complementary MOS transistors and which is not in accordance with this invention and wherein an output resistor is not provided in the drain circuit. With such a circuit a relatively large change of frequency usually accompanies change in supply voltage, the frequency increasing in response to increase in supply voltage as typified by characteristic *a* of Figure 3. Also, even if the supply voltage of the quartz crystal oscillating circuit is not very liable to undergo change, variation in the threshold voltage of the MOS transistors will produce a condition caused by changes which is like that produced by a change in supply voltage so that again there is an undesired frequency change and a frequency different from the desired frequency is generated. These undesired frequency changes as typified by curve *a* of Figure 3 arise by reason of the fact that the output impedance of a complementary MOS transistor circuit as shown becomes lower with increase of the supply voltage.

In the embodiment of the invention shown in Figure 2, a quartz crystal oscillating circuit employing complementary MOS transistors comprises a quartz crystal vibrator *V*, and a feedback resistance *R* connected in parallel therewith. One terminal of the crystal is connected to the common gate terminal of complementary MOS transistors *MT* and the other terminal is connected to the common drain terminal thereof through an output resistor *r* which is incorporated in the monolithic integrated circuit in which the oscillating circuit is built up. The gate and drain capacitances *C_g* and *C_d* respectively are, as shown, connected to ground each on one side, each being between ground and one or other side of the crystal. The circuit of Figure 2 has a voltage-frequency characteristic as typified by curve *b* of Figure 3. It will be seen that characteristic *b* is much better than characteristic *a* there being a much smaller change in oscillating frequency and better stability. In practice the value of *r_p* should be about 10Ω— to several hundred KΩ being chosen, of course, to suit the equivalent resistance of the quartz crystal vibrator employed.

The incorporation of output resistor *r* on the same substrate in a monolithic integrated circuit with the transistors will now be described.

When the complementary MOS transistor structure is produced, a lightly doped P-type layer is diffused into an N-type sub-

strate. A heavily doped N-type layer is further diffused into this substrate to form an N-channel transistor. The lightly doped P-type layer may be used as the resistor, and a fairly high resistance can be obtained in this way. To obtain a considerably higher resistance, non-doped polycrystalline silicon may be used. To obtain a somewhat lower resistance doped polycrystalline silicon may be used. If the above-mentioned P-type layer is used as the resistor, there is the advantage that said resistor can be easily formed by the diffusion of the P-type layer which is performed to form an N-channel transistor when the complementary MOS transistor structure is produced. However, there is the disadvantage that, owing to lateral expansion of the P-type the provision of the output resistor in this way imposes some restriction in the matter of space. If, on the other hand polycrystalline silicon is used as the resistor, the only space required is that for the above-mentioned resistance, and restrictions on the space available on the same substrate for the other circuit elements seldom occur in practice.

The piezo-electric crystal oscillating circuit above described with reference to Figure 2 is high stable as regards frequency and because the output resistor is incorporated into the integrated circuit chip an extremely compact construction is obtained. Such an oscillator, so constructed, is of great advantage as the time standard of an electric timepiece, and especially of a wrist-watch, where a high degree of frequency stability and small size and weight, are extremely desirable.

WHAT WE CLAIM IS:—

1. A piezo-electric crystal oscillating circuit comprising a piezo-electric crystal, complementary MOS transistors having a common gate terminal and a common drain terminal, a feedback resistor connected in a circuit across said crystal, an output resistor connected in a circuit between said common drain terminal and one terminal of said crystal and a connection between said common gate terminal and the other terminal of said crystal, said output resistor and said complementary MOS transistors being incorporated on the same substrate in a monolithic integrated circuit construction.

2. An oscillating circuit as claimed in claim 1 wherein said output resistor is constituted by doped polycrystalline silicon, or undoped polycrystalline silicon or a P-type layer, formed on an N-type substrate simultaneously with P-type diffusion for producing an N-channel transistor when the complementary MOS transistors are produced.

3. An oscillating circuit as claimed in claim 1 or 2 wherein the feedback resistor is connected directly across the crystal and

that of Figure 1) which does not contain an output resistor and characteristic *b* is that of a quartz crystal oscillating circuit in accordance with this invention wherein an

5 output resistor is provided.

Figure 1 shows a quartz crystal oscillating circuit employing complementary MOS transistors and which is not in accordance with this invention and wherein an output resistor is not provided in the drain circuit. With such a circuit a relatively large change of frequency usually accompanies change in supply voltage, the frequency increasing in response to increase in supply voltage as typified by characteristic *a* of Figure 3. Also, even if the supply voltage of the quartz crystal oscillating circuit is not very liable to undergo change, variation in the threshold voltage of the MOS transistors will produce a condition caused by changes which is like that produced by a change in supply voltage so that again there is an undesired frequency change and a frequency different from the desired frequency is generated. These undesired frequency changes as typified by curve *a* of Figure 3 arise by reason of the fact that the output impedance of a complementary MOS transistor circuit as shown becomes lower with increase of the supply voltage.

In the embodiment of the invention shown in Figure 2, a quartz crystal oscillating circuit employing complementary MOS transistors comprises a quartz crystal vibrator *V*, and a feedback resistance *R* connected in parallel therewith. One terminal of the crystal is connected to the common gate terminal of complementary MOS transistors *MT* and the other terminal is connected to the common drain terminal thereof through an output resistor *r* which is incorporated in the monolithic integrated circuit in which the oscillating circuit is built up. The gate and drain capacitances *C_g* and *C_d* respectively are, as shown, connected to ground each on one side, each being between ground and one or other side of the crystal. The circuit of Figure 2 has a voltage-frequency characteristic as typified by curve *b* of Figure 3. It will be seen that characteristic *b* is much better than characteristic *a* there being a much smaller change in oscillating frequency and better stability. In practice the value of *r_d* should be about 10Ω— to several hundred KΩ being chosen, of course, to suit the equivalent resistance of the quartz crystal vibrator employed.

The incorporation of output resistor *r* on the same substrate in a monolithic integrated circuit with the transistors will now be described.

When the complementary MOS transistor structure is produced, a lightly doped P-type layer is diffused into an N-type sub-

strate. A heavily doped N-type layer is further diffused into this substrate to form an N-channel transistor. The lightly doped P-type layer may be used as the resistor, and a fairly high resistance can be obtained in this way. To obtain a considerably higher resistance, non-doped polycrystalline silicon may be used. To obtain a somewhat lower resistance doped polycrystalline silicon may be used. If the above-mentioned P-type layer is used as the resistor, there is the advantage that said resistor can be easily formed by the diffusion of the P-type layer which is performed to form an N-channel transistor when the complementary MOS transistor structure is produced. However, there is the disadvantage that, owing to lateral expansion of the P-type the provision of the output resistor in this way imposes some restriction in the matter of space. If, on the other hand polycrystalline silicon is used as the resistor, the only space required is that for the above-mentioned resistance, and restrictions on the space available on the same substrate for the other circuit elements seldom occur in practice.

The piezo-electric crystal oscillating circuit above described with reference to Figure 2 is high stable as regards frequency and because the output resistor is incorporated into the integrated circuit chip an extremely compact construction is obtained. Such an oscillator, so constructed, is of great advantage as the time standard of an electric timepiece, and especially of a wrist-watch, where a high degree of frequency stability and small size and weight, are extremely desirable.

WHAT WE CLAIM IS:—

1. A piezo-electric crystal oscillating circuit comprising a piezo-electric crystal, complementary MOS transistors having a common gate terminal and a common drain terminal, a feedback resistor connected in a circuit across said crystal, an output resistor connected in a circuit between said common drain terminal and one terminal of said crystal and a connection between said common gate terminal and the other terminal of said crystal, said output resistor and said complementary MOS transistors being incorporated on the same substrate in a monolithic integrated circuit construction.

2. An oscillating circuit as claimed in claim 1 wherein said output resistor is constituted by doped polycrystalline silicon, or undoped polycrystalline silicon or a P-type layer, formed on an N-type substrate simultaneously with P-type diffusion for producing an N-channel transistor when the complementary MOS transistors are produced.

3. An oscillating circuit as claimed in claim 1 or 2 wherein the feedback resistor is connected directly across the crystal and





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- has one end connected directly to the common gate terminal of the MOS transistors and the other end connected directly to that end of the output resistor which is remote from the common drain terminal of said MOS transistors one of the crystal terminals being connected to ground through said output resistor and the drain capacitance of the transistors and the other crystal terminal being connected to ground through the gate capacitance of the transistors, said transistors, capacitances and output resistor being all in the same substrate of the monolithic integrated circuit chip.
4. An oscillating circuit as claimed in any of claims 1 to 3 wherein the value of the aforesaid output resistor is between 10K Ω and 500K Ω .

5. An oscillating circuit as claimed in any of the preceding claims wherein there is provided bias means which provide bias through said output resistor.

6. A piezo-electric crystal oscillating circuit substantially as hereinbefore described and as illustrated in Figure 2 of the accompanying drawings.

7. An electronic timepiece having a time standard oscillator constituted by an oscillating circuit as claimed in any of the preceding claims.

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