

"VOLTAGE CONTROLLED OSCILLATOR CIRCUIT"

This invention relates to voltage controlled oscillator circuits.

According to the present invention there is provided a voltage controlled oscillator circuit comprising: a first
5 signal synthesising circuit for receiving two signals and producing a signal based on those signals, one of the two signals being an external signal; a first voltage controlled oscillator connected to the output of the first signal synthesising circuit; a phase-locked loop consisting of a second signal synthesising
10 circuit, a second voltage controlled oscillator and a phase comparator; an oscillator for generating a signal of a reference frequency the second signal synthesising circuit having the same characteristics as the first signal synthesising circuit, the second voltage controlled oscillator being connected to the
15 output of the second signal synthesising circuit and having the same characteristics as the first voltage controlled oscillator, one input of the comparator being connected to the output of the second voltage controlled oscillator, the other input of

the comparator being connected to the oscillator, the output of the comparator being connected to one input of the first signal synthesising circuit which does not receive the external signal and to one input of the second signal synthesising circuit; and means for supplying the reference frequency signal to the second input of the second signal synthesising circuit.

The oscillator may be a crystal oscillator.

The voltage controlled oscillator circuit, in one embodiment, includes a frequency divider or frequency converter connected between the second voltage controlled oscillator and the comparator.

The voltage controlled oscillator circuit, in another embodiment, includes a frequency divider or frequency converter connected between the comparator and the oscillator.

In a still further embodiment the voltage controlled oscillator circuit includes a frequency divider or frequency converter connected between the second voltage controlled oscillator and the comparator and a further frequency divider or frequency converter connected between the comparator and the oscillator.

In yet another embodiment of the present invention the voltage controlled oscillator circuit includes a frequency divider connected to the output of the first voltage controlled oscillator.

5 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 a voltage controlled oscillator circuit according to the present invention;

10 Figure 2 is a circuit diagram of another embodiment of a voltage controlled oscillator circuit according to the present invention;

Figure 3 is a diagram of a conventional voltage controlled oscillator circuit; and

Figure 4 is a diagram of another conventional voltage controlled oscillator circuit.

5 Conventionally, a quite large number of voltage-controlled oscillator (VCO) circuits have been suggested. As an example, a VCO circuit for use in a complementary metal-oxide integrated circuit on one chip used for a phase-locked loop is shown in Figure 3, in which the electric current flowing into a capacitor C_1 is controlled by
10 the control voltage applied to the gate of an N-channel transistor N_1 to control the frequency of oscillation. Resistors R_1 , R_2 determine the control voltage sensitivity coefficient and the free-running frequency, respectively.

Another VCO circuit as disclosed in Japanese Patent Publication
15 No. 86509/81 is shown in Figure 4, in which current flowing into ring oscillators is controlled by the gate voltage to transistors T_{41} - T_{46} connected to the sources to control the frequency of oscillation. This VCO circuit has advantages over the circuit of Figure 3 in dispensing with externally attached parts having a lower
20 current consumption and requiring less space to mount components, but it is difficult to obtain good accuracy and stability. Also, it cannot be said that the VCO circuit of Figure 3 has sufficient stability.

Generally, what must be regulated in a VCO circuit are the
25 free-running frequency and the voltage control sensitivity coefficient.

The free-running frequency is defined as the frequency of oscillation when the control voltage applied to the control terminal of a VCO circuit is at a reference voltage level, which is usually set at a central value of the controllable range of input voltage. For instance, in the case of a CMOS IC, the reference level is set to one half that of the power supply voltage. If it is assumed that the difference between the control voltage V_c and the reference voltage level V_s is ΔV_c , that

$$\Delta V_c = V_c - V_s \quad \dots (1)$$

Thus, it may also be said that the free-running frequency is the frequency of oscillation when $\Delta V_c = 0$. The voltage control sensitivity coefficient K_v is defined by

$$f_o = f_c + K_v \cdot \Delta V \quad \dots (2)$$

where f_c is the free-running frequency and f_o is the frequency of oscillation of the VCO circuit.

Drift in the free-running frequency in a phase-locked loop has an adverse effect on the loop because it introduces drift in the capture range of the system. Also, dispersion in the frequency f_c due to dispersion in constants of circuit components is so large that it cannot be neglected. Therefore, high-precision components have been conventionally used at the sacrifice of curtailment of cost, or otherwise adjustments or alignments using semi-fixed resistors or semi-fixed capacitors have been required after assembly. Also, drift in voltage in the voltage control sensitivity coefficient K_v in a phase-locked loop has an adverse effect on the loop because it results

in drift in the response velocity.

These drafts are attributed to change in the ambient temperature, fluctuation in the power supply voltage, ageing of component constants, etc. Especially, the free-running frequency f_c is affected greatly by these factors. On the other hand, variation in the coefficient K_v can be reduced by providing sufficient relative tracking characteristics employing semiconductor and integrated circuit techniques such that the value K_v depends on relative accuracy among components of the circuit, although absolute accuracy of the constants of elements is not obtained.

Referring to Figure 1, there is shown one embodiment of a voltage controlled oscillator (VCO) circuit according to the present invention. The VCO circuit includes signal synthesising circuits 701, 703 designed so as to have the same characteristics. Although voltage is treated in this circuit, other physical quantities such as current or electric charge can be similarly treated. The circuit 701 has a characteristic expressed by

$$V_{01} = f(V_{11}, V_{21}) \quad \dots (3)$$

where f is an arbitrary function when voltages V_{11} and V_{21} are applied to terminals 709, 710, respectively, and a voltage V_{01} appears at output terminal 714 of the signal synthesising circuit 701. For simplicity, the equation above is expanded as follows:

$$V_{01} = a V_{11} + b V_{21} + c \quad \dots (4)$$

where a , b and c are constants.

Similarly, when voltages V_{12} and V_{22} are applied to terminals

711, 712, respectively, and a voltage V_{O2} appears at output terminal 715 of the signal synthesising circuit 703, it is assumed that the following relation holds:

$$V_{O2} = \underline{a} V_{12} + \underline{b} V_{22} + \underline{c} \quad \dots (5)$$

5 The present circuit also includes a pair of voltage-controlled oscillators 702, 704 having the same characteristics. It is now assumed that the frequencies F_1 and F_2 of the output signals from their respective VCOs 702, 704 can be expressed by

$$F_1 = K_v \cdot V_{O1} + \underline{d} \quad \dots (6)$$

10 $F_2 = K_v \cdot V_{O2} + \underline{d} \quad \dots (7)$

where $\underline{d}$ is a constant.

Also provided are a phase comparator circuit 706 and an oscillator circuit 707, which generates a signal of a stable frequency, such as a crystal oscillator circuit. The comparator circuit 706 acts to compare the output from the VCO 704 in phase with the output signal from the oscillator circuit 707 and to deliver a signal whose frequency is proportional to the phase difference between the two signals. A low-pass filter 705 is inserted into the circuit to derive only a desired signal component from the output from the phase comparator circuit in the ordinary way. The output from the filter 705 is inversely fed back to the input terminal 712 of the signal synthesising circuit 703. That is, the VCO 704, comparator circuit 706, filter 75 and the signal synthesising circuit 703 form a phase-locked loop and the oscillation frequency of the second VCO is made equal to the oscillation frequency f_{ref}

of the oscillator circuit 707. It is possible to cause the frequency of the output from the VCO 704 to agree entirely even in phase with the frequency f_{ref} by virtue of the characteristics of the comparator circuit 706 and the filter 705. Alternatively, that frequency may be caused not to respond to a sudden change in the frequency f_{ref} . Since a circuit oscillating sufficiently stably is used for the oscillator circuit 707 in the ordinary manner, making the response of the system more rapid will introduce no problem. Also, because the output frequency of the VCO 704 can be in step with the frequency f_{ref} only in frequency and presence of error in phase is allowed, a considerable degree of freedom is given to the circuit configuration. If the oscillator circuit 707 does not operate stably and jitter, for example, takes place, the system can be so designed that it is less affected thereby.

When the free-running frequency of the VCO 704 varies due to variation in the power supply voltage, temperature characteristics, ageing or the like, the system automatically increases or decreases the voltage applied to the terminal 712 to maintain the oscillation frequency of the VCO 704 at f_{ref} . Also, in the case where an arbitrary value of voltage is applied to the terminal 711 of the signal synthesising circuit 703, the voltage applied to the terminal 712 is automatically controlled so that the oscillation frequency of the VCO 704 may be kept at f_{ref} , irrespective of the value of the applied voltage.

Thus, when a reference voltage V_s is applied to the terminal 711 of the signal synthesising circuit 703, the level of voltage applied to the terminal 712 is automatically adjusted such that the oscillation frequency of the VCO 704 is made equal to f_{ref} .

5 In a situation where the voltage applied to the terminal 712 of the second signal synthesising circuit 703 is also fed to the terminal 710 of the signal synthesising circuit 701 as shown in Figure 1, the frequency of oscillation of the VCO 702 is set to f_{ref} when the voltage applied to the terminal 709 of the signal synthesising circuit
10 701 is V_s , because the signal synthesising circuit 701 and the VCO 702 have the same characteristics as the signal synthesising circuit 703 and the VCO 704, respectively. When the voltage applied to the terminal 709 is V_s , the frequency of oscillation of the VCO 702 assumes a value f_c , if the frequency f_{ref} is set to a desired free-
15 running frequency f_c . Therefore, a voltage controlled oscillator circuit whose free-running frequency is f_c is provided by using the terminals 702, 713 as the control terminal and the output terminal respectively, of the whole circuit of Figure 1.

The VCO circuit of Figure 1 has been described thus far on the
20 assumption that the signal synthesising circuit 701 and the VCO 702 have the same characteristics as the signal synthesising circuit 703 and the VCO 704, respectively. This assumption is quite reasonable. Particularly when the VCO circuit is formed into a monolithic integrated circuit, each pair of elements can be accurately
25 symmetrically fabricated on a chip, a few millimetres in each

dimension. Since the components are fabricated at the same time, even if they experience ageing, their characteristics change in the same manner with time and so it is unlikely that the characteristics come to differ from each other widely. Further, because each pair of components is supplied with electric power from the same power supply and because they are disposed in close proximity, variation in temperature from component to component is a minimum and the possibility that their characteristics come to differ from each other widely is also small. In making designs for the integrated circuit, if the symmetry of each pair of components is considered fully so that variations in the characteristics may cancel each other, then a stable voltage controlled oscillator circuit can be obtained which is not accompanied by large drift.

Referring next to Figure 2 there is shown another embodiment of a voltage controlled oscillator (VCO) circuit according to the present invention in the form of a semiconductor integrated circuit fabricated on the concept described above. A signal synthesising circuit 801 has transistors T_1 , T_2 whose drain currents are changed by changing the gate voltages of the transistors. The drain current of the transistors T_1 , T_2 are combined into one and caused to flow into a transistor T_{13} , in which it is converted into a voltage. This voltage is applied to a first voltage-controlled oscillator (VCO) 802 consisting of a MOS transistor as its control voltage. This VCO includes an odd number of inverter stages made up of transistors T_7 , T_{10} , T_8 , T_{11} ... T_9 , T_{12} to form ring oscillators.

Other transistors $T_4, T_5, T_6, \dots T_{15}, T_{16}, T_{17}$ are connected in series with the sources of the former transistors, and the gate voltage of the latter transistors are connected to control the current supplied to the ring oscillators from the power supply for exerting control over the frequency of oscillation. In the example, as the voltages at terminals 812, 814 decrease, the drain voltage of transistor T_{13} , that is, the control voltage of the VCO 802, increases, resulting in increase in the frequency of oscillation. This is the case where $\underline{a}$ and $\underline{b}$ are negative in equation (4) and K_v is positive in equation (6). When the voltage levels at the terminals 812, 814 are high, if a high frequency of oscillation is desired, then the polarities of the transistors in the VCOs 801, 802 should all be reversed, that is, a P-channel transistor is changed to an N-channel transistor and vice versa, such that $\underline{a}$, $\underline{b}$ and K_v assume negative values. The VCO circuit of Figure 8 also includes buffer circuits 805, 806 to deliver an output.

A signal synthesising circuit 803 and a voltage controlled oscillator 804 have the same circuit configurations as the circuits 801, 802, respectively. Having the same internal construction, the construction of each of the circuits 803, 804 is not shown. The output from the VCO 804 is applied to a phase comparator circuit 808 through a buffer 807. A crystal oscillator circuit 811 generates a frequency $f_{\text{ref}} (= f_c)$ that is used as a standard for the free-running frequency. Usually, this signal is applied to the phase comparator circuit 808, in which it is compared in phase with the

VCO 804. This signal generated by the oscillator 811 is used together with timing clock signals for other circuits, the clock signal for the system or the like. If the frequency of clock signals necessary for another circuit differs from f_c , then

5 frequency divider circuits or frequency converter circuits can be connected to both or one of nodes 818, 819 to set the frequency f_c to a frequency an integer times the frequency of oscillation of the oscillator circuit 811, the frequency of oscillation divided by an integer, differences between those frequencies or the frequency of
10 oscillation multiplied by a rational fraction. Any frequency divider circuit or frequency converter circuit can be comprised of a digital circuit and no difficulty is introduced in forming it into a semiconductor integrated circuit. A low-pass filter 817 removes the high frequency components contained in the output from the phase
15 comparator circuit 808, and the output from the filter 817 is fed back to a second input terminal 815 of the signal synthesising circuit 803. Resistors R_{11} , R_{12} are connected to a first input terminal 813 to obtain a fraction of the voltage of the power supply so that an input signal level or reference level sufficient to allow
20 an oscillation at frequency f_c is provided. Although it is difficult to form resistors having accurate values in a semiconductor integrated circuit, the relative accuracy among those values can be enhanced greatly. It is also possible to connect a more accurate voltage source, such as a reference voltage source using zener diodes, to
25 this terminal. The input terminals 814, 815 of the signal

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synthesising circuits are connected to different points on opposite sides of a resistor R_{14} inside the filter 817. This resistor serves to stabilise the phase-locked loop in essentially the same manner as in the case of Figure 1.

5 The configuration of Figure 2 consists entirely of MOS transistors other than resistors $R_{11} - R_{15}$, capacitors $C_{11} - C_{13}$ and crystal oscillator C. Absolute accuracy is not required for resistors and capacitors and so resistors can be incorporated into a semiconductor integrated circuit. Further, capacitor C_{11} can be
10 often incorporated into it, although it depends on the required range of oscillation frequency. When a low frequency is needed, a frequency divider circuit is connected to an output terminal 816 to increase the frequency of oscillation of the phase-locked loop. Hence, only a small value is necessary for the capacitor C_1 with the result that
15 forming the circuit into an integrated circuit is rendered easier.

As described hereinbefore, in accordance with the present invention, a quite stable voltage controlled oscillator circuit can be fabricated without using accurately fabricated components, which makes it quite easy to fabricate the VCO circuit in the form of an
20 integrated circuit. Thus, there are great advantages in the VCO circuit from the point of view of packaging of components and manufacture.

When the VCO circuits shown in Figures 1 and 2 are compared with the VCO circuit shown in Figures 3 and 4 one might suppose
25 that they are considerably more complex. In actuality, however, when

the VCO circuit of Figure 2 is fabricated in a semiconductor integrated circuit, the area occupied by the circuit on that chip is small. On the other hand, the VCO of Figure 4 requires externally attached parts, which needs a large area occupied by bonding pads on a semiconductor integrated circuit and output transistors, for example, P_4 , P_5 , N_2 , N_3 for driving the externally attached capacitor C_1 and P_1 , N_1 for driving the externally attached resistors R_1 , R_2 . The area occupied by these parts is much greater than the area of the VCO circuit of the present invention.

The present invention necessitates a stable oscillator circuit such as a crystal oscillator, but this introduces no problem, because large-scaled integrated circuits frequently require stable reference pulse trains besides voltage-controlled oscillator circuits and these pulse trains may be also used for that purpose. In addition, in the VCO circuits according to the present invention, free-running frequency can be set at will with the same circuit by connecting frequency divider circuits or frequency converter circuits in series with the node 716 or 717 of Figure 1 or the node 818 or 819 of Figure 8 and controlling the frequency division ratio or other factor using a logic circuit.

A voltage controlled oscillator circuit according to the present invention may be readily formed into an integrated circuit such as a digital integrated circuit. This achieves a reduction in cost and packaging space, thus greatly contributing to the manufacture of devices incorporating VCO circuits.



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CLAIMS

1. A voltage controlled oscillator circuit comprising: a first signal synthesising circuit for receiving two signals and producing a signal based on those signals, one of the two signals being an external signal; a first voltage controlled oscillator
5 connected to the output of the first signal synthesising circuit; a phase-locked loop consisting of a second signal synthesising circuit, a second voltage controlled oscillator and a phase comparator; an oscillator for generating a signal of a reference frequency, the second signal synthesising circuit having the
10 same characteristics as the first signal synthesising circuit, the second voltage controlled oscillator being connected to the output of the second signal synthesising circuit and having the same characteristics as the first voltage controlled oscillator, one input of the comparator being connected to the output of the
15 second voltage controlled oscillator, the other input of the comparator being connected to the oscillator, the output of the comparator being connected to one input of the first signal synthesising circuit which does not receive the external signal and to one input of the second signal synthesising circuit; and means
20 for supplying a reference frequency signal to the second input of the second signal synthesising circuit.
2. A voltage controlled oscillator circuit as claimed in claim 1 in which the oscillator is a crystal oscillator.
3. A voltage controlled oscillator circuit as claimed in
25 claims 1 or 2 including a frequency divider or frequency converter



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connected between the second voltage controlled oscillator and the comparator.

4. A voltage controlled oscillator circuit as claimed in any preceding claims including a frequency divider or frequency converter connected between the comparator and the oscillator.
 5. A voltage controlled oscillator circuit as claimed in any preceding claim including a frequency divider or frequency converter connected between the second voltage controlled oscillator and the comparator and a further frequency divider or frequency converter connected between the comparator and the oscillator.
 - 10 6. A voltage controlled oscillator circuit as claimed in any preceding claim in which a frequency divider is connected to the output of the first voltage controlled oscillator.
 8. A voltage controlled oscillator circuit substantially
15 as herein described with reference to and as shown in Figure 1 or Figure 2 of the accompanying drawings.
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