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(54) INTEGRATED MICROWAVE OSCILLATORS

(71)We, SONY CORPORATION, a corporation organised and existing under the laws of Japan, of 7-35 Kitashinagawa-6, Shinagawa-ku, Tokyo, Japan, do hereby declare the invention, for which we 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:

This invention relates to integrated microwave oscillators.

There has been proposed a microwave oscillator which utilizes a 2-terminal negative resistance element or 3-terminal active element, for example, a gallium-arsenic field effect transistor (GaAs-FET) as an oscillating element. Such an oscillator is disclosed, for example, in IEEE MTT-23, No. 8, pages 661 to 667 "Design and property of microwave band oscillator using GaAs Schottky gate field effect transistor" which was issued in August 1975, by Maeda et al. The advantages of an oscillator using a GaAs-FET is low noise, high efficiency and low bias voltage.

In a microwave oscillator which uses a 3-terminal active element as its oscillating element there are two kinds, namely a series feedback type oscillator circuit and a parallel feedback type oscillator circuit, the equivalent circuits of which are illustrated in Figures 1 and 2 of the accompanying drawings, respectively.

The series feedback type oscillator circuit of Figure 1 includes a GaAs-FET 1, as a 3-terminal active element used as an oscillating element, having gate, drain and source terminals 2, 3 and 4, respectively. A series feedback circuit 5 forming a positive feedback circuit is formed of inductive or capacitive elements 6 and 7. If one of the elements 6 and 7 is inductive, the other is capacitive. The gate terminal 2 is connected to one end of the element 6, the source terminal 4 is similarly connected to one end of the element 7, and the drain terminal 3 is connected to one end of a load impedance element 8. The other ends of the elements 6, 7 and 8 are connected in common.

The parallel feedback type circuit of Figure 2 includes a GaAs-FET 1 as a 3-terminal active element used as an oscillating element, and a parallel feedback circuit 9 forming a positive feedback circuit. The parallel feedback circuit 9 is formed feedback circuit 9 is formed of inductive or capacitive elements 10 and 11 which are selected such that when one of them is inductive the other is capacitive. The element 10 is connected between the gate terminal 2 and the source terminal 4 of the GaAs-FET 1 and the element 11 is connected between the gate terminal 2 and the drain terminal 3. A load admittance element 12 is connected between the drain terminal 3 and the source terminal of GaAs-FET 1.

If the positive feedback circuits 5 and 9 of the oscillating circuits of Figures 1 and 2 are made using a line such as a micro-strip line, they can be made as an integrated microwave oscillator.

The practical construction of the series feedback type oscillator of Figure 1 will now be described with reference to Figure 3. A substrate 13 of a microwave integrated circuit comprises a dielectric made, for example, of alumina Al_2O_3, a conductive layer formed uniformly on the rear surface and a conductive layer of a desired pattern on the front surface of the dielectric. The GaAs-FET 1 is provided on the substrate 13 as a 3-terminal active element for oscillation. The gate terminal 2 of the GaAs-FET 1 is connected to a micro-strip line 15 the end of which is open and which forms the element 6 shown in Figure 1, and the source terminal 4 of the GaAs-FET 1 is connected to a micro-strip line 16 which forms the element 7 and the end of which is short-circuited by being connected to an earth conductor 17. The drain terminal 13 of the GaAs-FET 1 is connected to a micro-strip line 18 which is, in turn, connected through a gap capacitor 19 for choking a direct current of a high frequency output terminal 20.

On the substrate 13 there are provided high impedance lead wires 21 and 22 the ends of which are connected to the micro-strip line 15, to which the gate terminal 2 is connected, and to the micro-strip line 18 to which the drain terminal 3 is connected, respectively. Positive and negative *dc* biases are applied through the load wires 21 and 22 to the gate and the drain of the GaAs-FET 1.

The micro-strip lines 15, 16 and 18 can become capacitive elements or inductive elements in dependence on the relation of their lengths to the wavelength of the microwaves. To this end, the lengths of the micro-strip lines 15, 16 and 18 are selected suitably.

Since the equivalent circuit of the series feedback oscillator of Figure 3 can be as shown in Figure 1, the operation will be described with reference to Figure 1. If it is assumed that the output impedance seen by the active element 1 including the positive feedback circuit 5 from the ends of the load impedance element 8 is Z_{out} and the impedance of the load impedance element 8 is Z_L, the oscillation frequency f_o of the oscillator is determined by the following equation (1):

$$I_m(Z_{out})+I_m(Z_L)=O \qquad \ldots(1)$$

where $I_m(Z_{out})$ and $I_m(Z_L)$ represent the imaginary number portions of Z_{out} and Z_L, respectively.

In the case of the parallel feedback type oscillator which is not shown, but the equivalent circuit of which is shown in Figure 2, the oscillation frequency f_o is similarly determined as a frequency which will satisfy the following equation (2):

$$I_m(Y_{out})+I_m(Y_L)=O \qquad \ldots(2)$$

If the left side of equation (1) or (2) is taken as a function F, this is a function the variables of which are the function the variables of which are the angular frequency ω and all the circuit parameters of the oscillator. These circuit parameters vary in accordance with variation of the temperature T. Therefore the function F is a function of the angular frequency ω and the temperature T, that is F(ω, T). Thus, the oscillation condition is expressed by the following equation (3):

$$F(\omega, T)=O \qquad \ldots(3)$$

Accordingly, the change of angular frequency ω of the oscillation frequency due to temperature T or δω/δ T can be expressed by the following equation (4):

$$\delta\omega/\delta T=-\frac{\delta F/\delta T}{\delta F/\delta\omega} \qquad \ldots(4)$$

From equation (4) it will be understood that in order to make δω/δT small, it is sufficient to decrease δF/δT or to increase δF/δω.

As shown in Figure 3, with the previously proposed integrated microwave oscillator, the feedback circuit is formed by making the ends of the strip lines open or short-circuited. Therefore, there is not much freedom to select a large value of δF/δω in equation (4), and hence the temperature change δω/δT of the oscillation frequency cannot be made small.

According to the present invention there is provided an integrated microwave oscillator comprising:

an active element for oscillation having control, input and output terminals; micro-strip lines connected to said control, input and output terminals, respectively, and forming a feedback circuit; and a dielectric resonator coupled to one of said micro-strip lines at a predetermined position, which position is not used as an output terminal.

According to the present invention there is also provided an integrated microwave oscillator comprising:

an active element for oscillation having control, input and output terminals; micro-strip lines connected to said control and output terminals;

a micro-strip line connected between said control and output terminals to form a feedback circuit together with said first-mentioned micro-strip lines; and

a dielectric resonator coupled to one of said micro-strip lines at a predetermined position, which position is not used as an output terminal.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like numerals designate like elements, and in which:

Figure 1 is a circuit diagram showing an equivalent circuit of a previously proposed series feedback type microwave oscillator using a 3-terminal semiconductor active element;

Figure 2 is a circuit diagram showing an equivalent circuit of a previously proposed parallel feedback type microwave oscillator;

Figure 3 is a plan view showing the construction of a previously proposed integrated microwave oscillator;

Figure 4 is a plan view showing the construction of an embodiment of integrated microwave oscillator according to the invention;

Figure 5 is a circuit diagram showing an equivalent circuit of Figure 4;

Figure 6, 7, 8 and *9* are respective plan views of construction of other embodiments of the invention; and

Figure 10 is a characteristic graph showing the stability of the oscillation frequency of an integrated microwave oscillator according to the invention in comparison with one previously proposed.

Referring to Figures 4 and 5, a 3-terminal active element forming an oscillating element is a GaAs-FET 1 which has good high frequency characteristics and is coupled to micro-strip lines. A dielectric resonator 24 has a dielectric constant of, for example, 30 to 40 and is formed of a cylindrical shape. The second or source terminal 4 of the GaAs-FET 1 is connected to a micro-strip line 16 the end of which is connected to an earth conductor 17 to be short-circuited and hence to form an impedance element 27 (Figure 5). The first or gate terminal 2 of the GaAs-FET 1 is connected to the micro-strip line 23 the end portion of which is coupled to the dielectric resonator 24 and the end of which is open thereby to form an impedance element 26 (Figure 5). The third or drain terminal 3 of the GaAs-FET 1 is connected to the micro-strip line 18 to form a load element 28 (Figure 5). The micro-strip line 18 is connected through a gap capacity 19, which operates to block a *dc,* to a high frequency output terminal 20. Between the output terminal 20 and the earth conductor 17 there is connected a load resistor (not shown) having a resistance value of, for example, 50 ohms which is supplied with the high frequency output. In this case, the impedance elements 26 and 27 and the load element 28 form the series feedback circuit 5. As in the oscillator of Figure 3, on the substrate 13 there are provided high impedance lead wires 21 and 22 through which negative and positive *dc* biases are applied to the gate terminal 2 and the drain terminal 3 of the GaAs-FET 1.

Next, a description will be given of the practical positional relation between the micro-strip lines 23, 16 and 18 and the dielectric resonator 24. If it is assumed that the propagating wavelength at a designed oscillation frequency is λg, the length of the micro-strip line 23 connected to the gate terminal 2 is selected to be the same as the propagating wavelength λg. A stub 25 is provided for adjusting the frequency at a point B on the micro-strip line 23 and spaced from the end A at the gate terminal 2 by $\lambda g/4$. The micro-strip line 23 is coupled, at a point C spaced from the point B by $\lambda g/2$, to the dielectric resonator 24. The current distribution in the micro-strip line 23 becomes a maximum at this coupling point, so the coupling of the micro-strip line 23 to the dielectric resonator 24 is as large as possible. The end of the micro-strip line 23 spaced from the point C by $\lambda g/4$ is open. In the case of an integrated microwave oscillator, the propagating wavelength λg is decreased in dependence on the dielectric constant and so on.

The impedance seen to the dielectric resonator 24 from the point B is a pure resistance component R at the resonance frequency of dielectric resonator 24. The resistance R is determined by the value of a load Q for the dielectric resonator 24 and the coupling factor, and is sufficiently high compared with the characteristic impedance Z_o of the micro-strip lines which are the transmission paths of the integrated microwave circuit. An impedance seen to the feedback circuit 5 from a point A spaced from the point B by $\lambda g/4$ has a resistance component 1/R and a reactance component X_1 determined by the line length of the stub 25. Accordingly, an equivalent circuit of the oscillator of Figure 4 is as shown in Figure 5 in which the gate terminal 2 of the GaAs-FET 1 is connected to the impedance element 26 which corresponds to the impedance of the dielectric resonator 24, the source terminal 4 is connected to the impedance element 27, and the drain terminal 3 is connected to the load element 28. In this case, the other ends of the elements 26, 27 and 28 are grounded.

If the resistance component 1/R of the impedance Z_1 seen to the feedback circuit 5 form the point A is not sufficiently small, the effective factor of an output impedance Z_{out} at the designed oscillation frequency does not become negative, that is the condition $R_o(Z_{out})<O$ is not satisfied. Hence, an oscillator which will oscillate at this frequency cannot be formed. If, on the contrary, resistance component 1/R is sufficiently small, by suitably selecting the length of the stub 25, the reactance component X_1 of the impedance Z_1 can be selected to satisfy the above frequency condition at the designed frequency.

Another embodiment of the invention will be described with reference to Figure 6. The opposite end of the micro-strip line 23, to which the gate terminal 2 of the GaAs-FET 1 is not connected, is formed as a non-reflecting end 29, and the other circuit construction is substantially the same as that of Figure 4. At a frequency other than the resonance frequency of the dielectric resonator 24, and other than the resonance frequency of the stub 25, the resistance component of the impedance Z_1 seen by the feedback 5 from the point A becomes substantially the same as the characteristic impedance Z_o of the micro-strip line 23. Accordingly, the effective factor component of the load impedance Z_{out} becomes positive, that is $R_e(Z_{out})>O$ is satisfied, and hence the above oscillating condition is not completely satisfield. As a result, the microwave oscillator is prevented from oscillating parasiticly.

Turning to Figure 7, a further embodiment of the invention will be described. The micro-strip 23 is extended and then bent to be of a substantially L-shape and the dielectric resonator 24 is coupled to the micro-strip line 23 at the point C and a point D which is spaced from the point C by nλg/2 (where *n* is an integer). In this case, the end of the bent micro-strip line 23 is open. The remaining circuit construction is substantially the same as that of the embodiment of Figure 6.

With the circuit of Figure 7, the dielectric resonator 24 can be coupled to the micro-strip line 23 with a high coupling factor and hence the resistance R seen to the dielectric resonator 24 from the point B at the resonance frequency can be increased as compared with that of Figure 4. Accordingly, the resistance component 1/R of the impedance Z_1 seen to the feedback circuit 5 from the point A can be made small. As a result, even if an active element which is superior, especially in high frequency characteristic, is not used, the effective factor component of the output impedance Z_{out} seen to the active element 1 from the drain terminal 3 including the series type feedback circuit 5 becomes negative, or $Re(Z_{out})<O$ is satisfied, and consequently the power output oscillating condition can be satisfied.

Figure 8 shows a further embodiment in which the end of the bent micro-strip line 23 of Figure 7 is formed as a non-reflecting end 29. The remaining circuit construction is substantially the same as that of Figure 7. With the embodiment of Figure 8, any parasite oscillation in case of a microwave oscillator can be suppressed.

In the above embodiment, the invention is applied to a series feedback type microwave oscillator, but it can also be applied to a parallel feedback type microwave oscillator as shown in Figure 9. In the case of Figure 9, the first or gate terminal 2 of the GaAs-FET 1 or active element is connected to the micro-strip line 23 which has a length the same as the propagating length λg at the microwave oscillating frequency, and the micro-strip line 23 is coupled to the dielectric resonator 24 at point C spaced from the base point A of the gate terminal 2 by 3 λg/4. The second or source terminal 4 of the GaAs-FET 1 is connected at its base portion directly to an earth conductor 17. A micro-strip line 32 is extended at right angles from the micro-strip line 23 at the point B spaced from the base point A of the gate terminal 2 by λg/4 and is bent at right angles at a point spaced from the micro-strip line 23 by λg/2. Also, a micro-strip line 23 extends at right angles from the micro-strip line 18 at a point spaced from the base portion of the drain terminal 3 by λg/4 and is bent at right angles at a point spaced from the micro-strip line 18 to oppose the end of the bent portion of the micro-strip line 23. Between the opposing ends of the micro-strip lines 32 and 33 there is provided a gap 34. Thus, a second feedback circuit 9 is formed. In the embodiment of Figure 9, similar to the above embodiment, on the substrate 13 there are provided high impedance lead wires 21 and 22 by which negative and positive *dc* biases are applied to the gate terminal 2 and the drain terminal 3 respectively of the GaAs-FET 1.

The equivalent circuit of the embodiment of Figure 9 is similar to that shown in Figure 2. In the embodiment of Figure 9, the micro-strip line 23 and dielectric resonator 24 connected thereto form an impedance element 10, and the micro-strip lines 32 and 33 and the gap capacity 34 formed therebetween form another impedance element 11. Moreover, the micro-strip line 18 forms an impedance element 12.

Figure 10 is a graph which shows the case of the previously proposed microwave oscillator of Figure 3 having no oscillation frequency stabilizing means and the case of an embodiment of microwave oscillator according to the invention having the dielectric resonator for stabilizing the oscillation frequency. In this case, a mutual conductance gm of the GaAs-FET 1 is selected as a parameter which will change depending upon temperature, and the temperature changes of the oscillation frequencies of the above oscillators are shown when the mutual conductance gm of the GaAs-FET 1 is changed from the centre value by 10%. In the graph of Figure 10, the abscissae represent a change △gm/gmo of the mutual conductance gm and the ordinate represent a deviation △f/fo of the oscillation frequency from the designed oscillation frequency 11 GHz. In the graph of Figure 10, a solid line curve 30 represents the frequency fluctuation of the microwave oscillator of Figure 3, while a one-dot chain line curve 31 represents the frequency fluctuation of the microwave oscillator of Figure 8. From the graph of Figure 10, it will be understood that the frequency fluctuation for the temperature change of the embodiment of the invention is improved by about 5.7%.

In the embodiment of the invention shown in Figures 4, 6, 7 and 8, the stub 25 is provided for the designed oscillation frequency to satify the frequency oscillation condition. It is, however, possible that if merely the coupling of the micro-strip line 23 to the dielectric resonator 24 is selected sufficiently high, the stub 25 can be omitted by suitably adjusting the length between the points A and B. In this case, the resistance component of the impedance Z_1 seen from the point A to the feedback circuit 5 is not so great. If the stub 25 is omitted and the end of the micro-strip line 23 is formed as the non-reflecting end 29, no resonance is caused by the stub 25 and also there is no possibility that any parasite oscillation is caused at frequencies other than the resonance frequency of the dielectric resonator 24.

As described, the micro-strip lines which form the first feedback circuit are connected to the first, second and third terminals of the active element and one of the micro-strip lines which is not used as the output terminal is connected at a predetermined position to the dielectric resonator, so that by coupling a part of the micro-strip lines, which form the feedback circuit, to the dielectric resonator, which will resonate at the designed oscillator frequency, the reactance component of the feedback circuit can be changed greatly near the oscillation frequency and the oscillation frequency can be stabilized against temperature change by setting the factor $\delta F/\delta\omega$ in equation (4) to be large.

Moreover, if the dielectric resonator is formed to make the temperature coefficient zero or to compensate for the temperature characteristic of the oscillator, the oscillation frequency can be further stabilized.

Even in cases where the micro-strip lines are connected to the first and third terminals of the active element, the micro-strip line, which forms the feedback circuit together with the former micro-strip lines, is connected between the first and third terminals and one of these micro-strip lines, which is not used as the output terminal, is connected at the predetermined position to the dielectric resonator, the reactance component of the feedback circuit can be changed greatly in the vicinity of the oscillation frequency and hence the oscillation frequency can be similarly stabilized.

In the embodiments of Figures 6 and 8, the non-reflecting end 29 is formed on the substrate 13, but this is not always necessary, as it can be formed of a coaxial non-reflecting end outside the substrate 13.

The dielectric resonator 24 need not be of a cylindrical shape, but could be of a rectangular prism shape.

In the above embodiments the dielectric resonator 24 is coupled to the micro-strip line 23 which is connected to the gate terminal 2 of the GaAs-FET 1, but it is of course possible with the same result of the dielectric resonator 24 to be coupled to the micro-strip line 16 which connected to the source terminal 4 of the GaAs-FET 1.

Figures 4, 6, 7 and 8 show series feedback type oscillating circuits and Figure 9 shows a parallel feedback type oscillating circuit, but the series and parallel feedback type oscillating circuits can be used together with the same effect.

WHAT WE CLAIM IS:

1. An integrated microwave oscillator comprising:
an active element for oscillation having control, input and output terminals;
micro-strip lines connected to said control, input and output terminals, respectively, and forming a feedback circuit; and
a dielectric resonator coupled to one of said micro-strip lines at a predeterined position, which position is not used an an output terminal

2. An integrated microwave oscillator comprising:
an active element for oscillation having control, input and output terminals;
micro-strip lines connected to said control and output terminals;
a micro-strip line connected between said control and output terminals to form a feedback circuit together with said first-mentioned micro-strip lines; and
a dielectric resonator coupled to one of said micro-strip lines at a predetermined position, which position is not used as an output terminal.

3. An oscillator according to claim 1 or claim 2 wherein said active element is a GaAs field effect transistor.

4. An integrated microwave oscillator substantially as hereinbefore described with reference to Figure 4 of the accompanying drawings.

5. An integrated microwave oscillator substantially as hereinbefore described with reference to Figure 6 of the accompanying drawings.

6. An integrated microwave oscillator substantially as hereinbefore described with reference to Figure 7 of the accompanying drawings.

7. An integrated microwave oscillator substantially as hereinbefore described with reference to Figure 8 of the accompanying drawings.

8. An integrated microwave oscillator substantially as hereinbefore described with reference to Figure 9 of the accompanying drawings.

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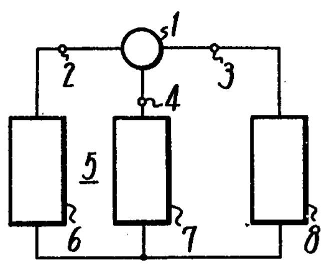
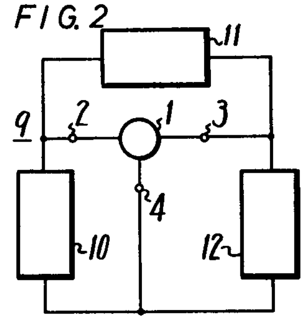
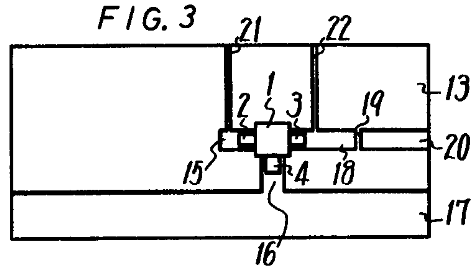
F I G. 1



F I G. 2



F I G. 3



F I G. 4

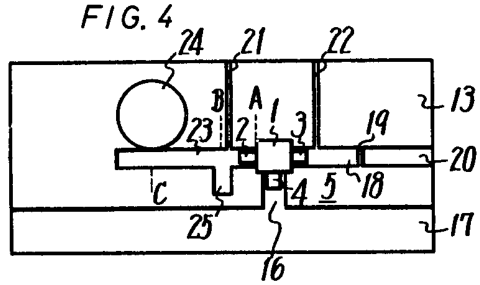


FIG. 5

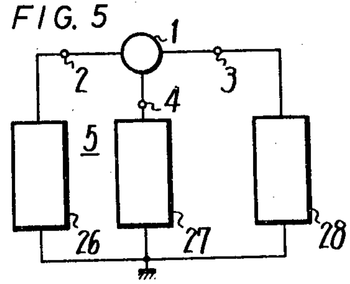


FIG. 6

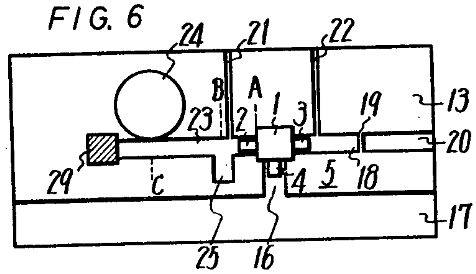


FIG. 7

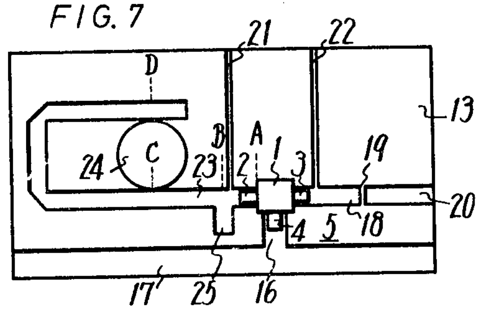


FIG. 8

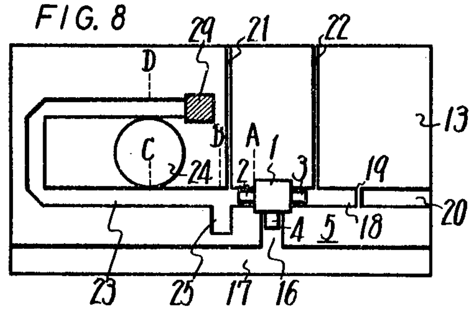


FIG. 9

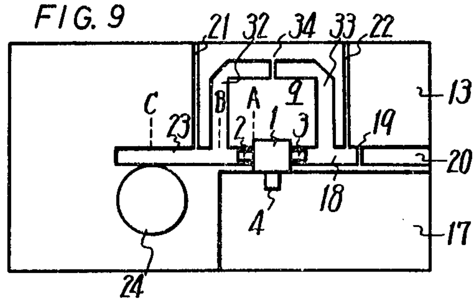


FIG. 10