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SIMULTANEOUS OSCILLATION IN GUNN OSCILLATOR

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ABSTRACT

The possibility of simultaneous oscillation in waveguide mounted Gunn oscillator has been investigated in detail theoretically and practically. The Gunn oscillator, like any other oscillator, is basically a regenerative system incorporating a limiter type non-linear element, and as such the strongest signal is captured and the weaker ones are rejected. Naturally single mode oscillation is expected but here multi-frequency oscillation is reported. No theoretical justification is available in the literature. The present paper provides an answer to this end.

Keywords: Gunn Oscillator, Negative resistance, Gunn diode, feedback oscillator.

I. INTRODUCTION

Over the years, waveguide mounted Gunn oscillators have been studied extensively [1], because it expectedly generates single spectral output. Naturally, vander Pol's model [2] of an oscillator has been adopted to analyse the Gunn oscillator behavior and as a consequence of which the device is modeled as a nonlinear negative conductance. Later it has been found that the I-V characteristics to some extend depends on frequency. Most of the papers concentrate on the fundamental mode of oscillator and in some papers [3,4] second harmonic generation of a Gunn oscillator has been emphasized. But what has not been reported is the multiple anharmonic spectral modes of oscillations around the fundamental frequency and so also the reasons for such a behavior of the oscillator.

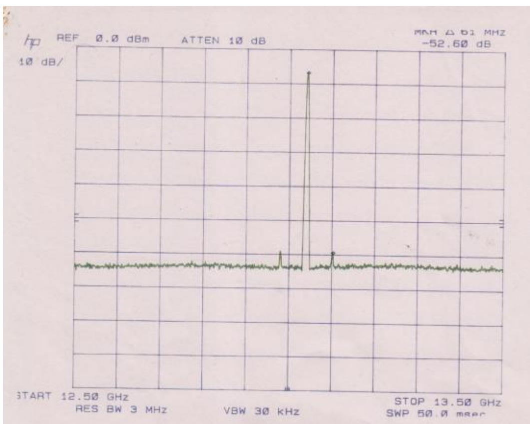

Fig. 1 Experimental Result

The question of considering simultaneous oscillations at anharmonic frequencies has never been considered because it is known that in a limiter type nonlinear regenerative circuit, the strongest signals are captured and the weaker signals are inhibited. In this paper the possibility of simultaneous oscillations at anharmonic frequencies in waveguide mounted Gunn oscillator has been investigated on the basis of the experimental observations as shown in Fig.1. The spectrum clearly indicates that there are simultaneous oscillations at three frequencies of 12.980 GHz, 13.041 GHz and 13.102 GHz.

II. WHY THE FINDING IS IMPORTANT:

1. The Gunn oscillator, like any other oscillator, is basically a regenerative system incorporating a limiter type non-linear element. In such an element the strongest signal is captured and the weaker ones are rejected. As such single mode oscillation is predicted, but not the multimode oscillations.
2. Neither experimental nor theoretical prediction is available in the literature. The present paper provides an answer to this end.

III. EXPERIMENTAL DETAILS

The schematic diagram of a waveguide mounted Gunn oscillator is shown in Fig.2a and 2b, respectively. The DC bias is adjusted to a value higher than the threshold voltage. The resonator and other loses are balanced by the negative resistance of the diode in order to generate sustained oscillations.

The Gunn diode used here is MA/COM MA49104-111, rated for minimum continuous wave (CW) power output of 25 mw. The diode package parasites were provided by the manufacturer. The typical values of the package parasites are C_p=0.27pF and L_s= 0.30nH. The value of C_g = 1.05pF is estimated from [5]. The value of R_g lies approximately in the range 6-12 Ω [5,6,7]. A value of 8 Ω is used as an approximation for the analysis of this experiment. The diode's negative resistance will decrease from -12Ω to -8Ω plus the residual resistance to a value of about -3Ω at the frequency of oscillation.

After properly mounting the Gunn diode in the waveguide cavity the required bias is applied to the Gunn

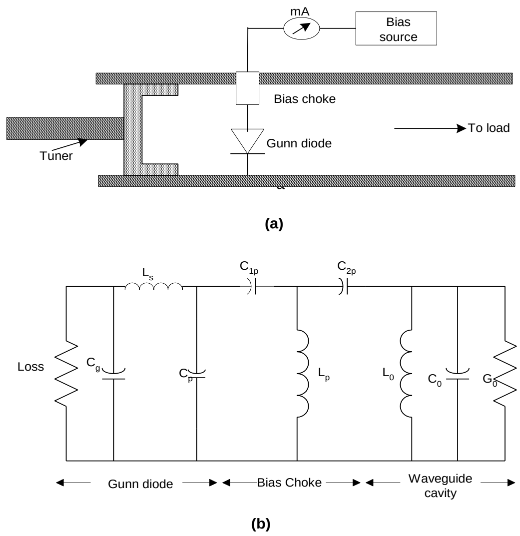

Fig.2 Schematic diagram of Waveguide mounted Gunn diode oscillator and analytical equivalent model.
a) Waveguide mounted Gunn diode oscillator at X band.
b) Simple equivalent circuit of the oscillator.

diode through a bias choke. This helps to stop bias circuit oscillation or any spurious modes of oscillation. The diode oscillates at a frequency of 10.84GHz, which can be mechanically tuned over a wide range. The bias voltage of the Gunn diode can also be used to tune the frequency of oscillation of the Gunn oscillator. The three frequencies of oscillations have been noticed experimentally at frequencies of 12.980 GHz, 13.041 GHz and 13.102 GHz after proper mechanical tuning with small variation of the bias voltage of the Gunn diode, mounted in the cavity. The details of the experimental results of the spectrum analyzer output are given in Table. I. The separation between the adjacent two peaks is 61 MHz.

Table-I details of experimental results

Bias Voltage of the Gunn diode.(V)	Position of the peak	Frequency of oscillation (GHz)	Power in dBm
9.732	Center	13.041	-6.80
	Left	12.980	-52.3
	Right	13.102	-52.6

IV. MODELING OF THE GUNN DIODE OSCILLATOR AS A FEEDBACK OSCILLATOR

A Gunn diode oscillator is modeled as a negative resistance oscillator but in this section it is shown that it can be modeled as a feedback oscillator. Referring to Figure 2a invoking a simple-minded approach to begin with, where we assume that the oscillator is operating in the fundamental mode. That is we assume the case of an ideal waveguide mounted Gunn oscillator [no package parasities and no strong circuit components]. The analytical equivalent is thus shown in Fig. 3.

The I-V relation is expressed as

$$i \equiv -\alpha v - \beta v^2 + \gamma v^3 \tag{1}$$

Where α represent the small signal conductance of the active device, β and γ are the second and third order nonlinear coefficients of the device, respectively.

Referring to Fig. 3 the governing circuit equation for the waveguide mounted Gunn diode oscillator can be written as

$$\frac{1}{L_0}\int v(t)dt + C_0\frac{dv(t)}{dt} + G_0 v(t) + \left\{-\alpha v - \beta v^2 + \gamma v^3\right\} = 0 \tag{2}$$

If operator d/dt is designed by s and

$$N(v) = \alpha v + \beta v^2 - \gamma v^3 \tag{3}$$

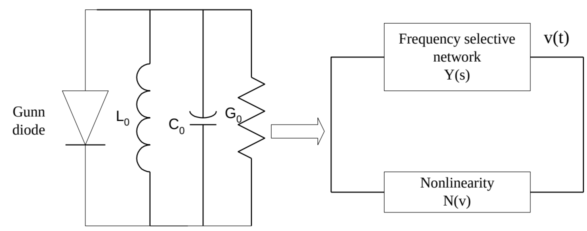

Fig. 3 The simple analytical equivalent circuit of the waveguide mounted Gunn diode oscillator. (Except the effect of package parasites of the Gunn diode and bias choke)

one can write the above equation (2) as

$$\left(\frac{1}{sL_0} + C_0 s + G_0\right)v(t) = N(v)$$
$$or,\ \frac{v(t)}{Y(s)} = N(v) \tag{4}$$

where *Y(s)* is the admittance of the parallel tuned circuit. Substituting

$$Y(s) = \left(\frac{1}{sL_0} + C_0 s + G_0\right). \tag{4a}$$

one can rewrite (4) as

$$Y(s).\ N(v) = v\ . \tag{5}$$

The above equation (5) is nothing but a loop equation of a feedback oscillator. The beauty of this model is that the device part and circuit part are separated. So one can conclude that an oscillator, be it a negative resistance or a feedback variety, can be modeled as a non-linear positive feedback network incorporating a limiter type non-linear element and a frequency selective network. Considering the circuit of Fig. 2b where the package parasites of Gunn diode and bias choke have been considered. A typical admittance variation with frequency of this circuit (excluding the negative resistance of the diode) is shown in Fig.4.

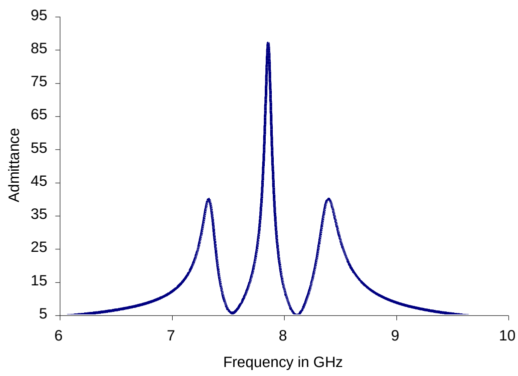

Fig.4. A typical admittance variation with frequency.

Nature of variation depends on the particular value of the package parasities. Referring to the Fig.1 the frequency response may be thought of as a sum of three single tuned admittance functions. That is

$Y(s) = Y_{-1}(s) + Y_0(s) + Y_{+1}(s)$ (6)

Where the values of the circuit parameters are appropriately chosen.

V. THEORETICAL ANALYSIS

Experimental results indicate the occurrence of simultaneous three frequencies (which are not harmonic) oscillation in case of waveguide mounted Gunn oscillator. Three frequencies oscillation is possible when the relations between the three frequencies $\omega_{-1} + \omega_{+1} = 2\,\omega_0$ is maintained. Simultaneous three-frequency oscillation in Limiter type regenerative circuit

The following method is based on the techniques of the slowly varying parameters and harmonic balance. Let us suppose that the frequency components shown in Fig.1 are anharmonically related by the following equations

$\omega_{-1} + \omega_{+1} = 2\,\omega_0$. (7)

Input output relation of the nonlinear (limiter type) element is assumed as

$y = \alpha x + \beta x^2 - \gamma x^3$. (8)

where α, β and γ are constant. The three outputs are taken as

$e_{-1} = A\cos(\omega_{-1}t + \varphi_{-1})$ (9)

$e_0 = B\cos(\omega_0 t + \varphi_0)$ (9a)

$e_{+1} = C\cos(\omega_{+1}t + \varphi_{+1})$ (9b)

where ω_{-1}, ω_0 and ω_{+1} are the center frequencies of the three tuned circuits. A, B & C are constants. Output of the oscillator can be written as

$x = e_{-1} + e_0 + e_{+1}$ (10)

So the output of the nonlinear circuit will be

$y = \alpha.\,A\cos(\omega_{-1}t + \varphi_{-1}) + \alpha.B\cos(\omega_0 t + \varphi_0) + \alpha.C\cos(\omega_{+1}t + \varphi_{+1}) - 3.\gamma/4)[\{A^3 + 2(B^2 + C^2)A + B^2C\cos\phi\}\cos(\omega_{-1}t + \varphi_{-1}) + \{B^3 + 2(A^2 + C^2)B + 2ABC\cos\phi\}\cos(\omega_0 t + \varphi_0) + \{C^3 + 2(A^2 + B^2)C + AB^2\cos\phi\}\cos(\omega_{+1}t + \varphi_{+1}) + A^2C\sin\phi\sin(\omega_{-1}t + \varphi_{-1}) + ABC\sin\phi\sin(\omega_0 t + \varphi_0) + AB^2\sin\phi\sin(\omega_{+1}t + \varphi_{+1})]$. (11)

In the above calculation we assume $\omega_{-1} + \omega_{+1} = 2\,\omega_0$ and $\varphi_{-1} + \varphi_{+1} = 2\,\varphi_0 + \phi$.

So the in phase components of y are

$y_{-1} = \alpha A - (3/4)\gamma[A^3 + 2(B^2 + C^2)A + B^2C\cos\phi]$ (12)

$y_0 = \alpha B - (3/4)\gamma[B^3 + 2(A^2 + C^2)B + 2ABC\cos\phi]$ (12a)

$y_{+1} = \alpha C - (3/4)\gamma[C^3 + 2(A^2 + B^2)C + AB^2\cos\phi]$. (12b)

Also the quardrature components are

$y_{-1})_Q = (3/4)\gamma A^2C\sin\phi$ (13)

$y_0)_Q = (3/4)\gamma ABC\sin\phi$ (13a)

$y_{+1})_Q = (3/4)\gamma AB^2\sin\phi$ (13b)

Now the three system equations of the oscillator are given by

$x_{-1} = G_{-}G_{-1}(j\omega)\,y_{-1} \Rightarrow x_{-1}Y(j\omega) = G_{-}\,y_{-1}$ (14)

$x_0 = G_0G_0(j\omega)\,y_0 \Rightarrow x_0Y(j\omega) = G_0\,y_0$ (14a)

$x_{+1} = G_{+}G_{+1}(j\omega)\,y_{+1} \Rightarrow x_{+1}Y(j\omega) = G_{+}\,y_{+1}$ (14b)

where G_{-}, G_0 and G_{+} are the gains of the amplifier. $G_{-1}(j\omega)$, $G_0(j\omega)$ and $G_{+1}(j\omega)$ are the transfer functions of the three tune circuits, ω is the instantaneous frequency. For a signal of the form $v = V(t).\exp(j\omega_1 t + \psi(t))$, we can define the instantaneous frequency as

$$j\omega = \frac{1}{v}\frac{dv}{dt} = \frac{1}{V(t)}\frac{dV}{dt} + j\omega_1 + j\frac{d\psi}{dt} \text{ with } \omega = \omega_1 + \frac{d\psi}{dt} - j\frac{1}{V(t)}\frac{dV}{dt} \quad . \tag{14c}$$

For single tune circuit we can write ($s = j\omega$):

$$Y(s) = \frac{1}{\Delta\omega}\left(s + \frac{(\omega^0)^2}{s}\right) + 1, \tag{14d}$$

ω^0 is the center frequency of tune circuit.

$$Y(j\omega) = \frac{2j(\omega - \omega^0)Q}{\omega^0} + 1 \tag{14e}$$

$Q = \omega^0/\Delta\omega$ is the quality factor of the tune circuit.

Substituting the value of ω one gets:

$$Y(j\omega) = \frac{1}{G(j\omega)} = \frac{2}{V}\frac{dV}{dt}\frac{Q}{\omega^0} + 2j\frac{Q}{\omega^0}\left(\omega_1 + \frac{d\psi}{dt} - \omega\right) + 1 \tag{15}$$

where V is the amplitude of oscillation and ω_1 is the frequency of oscillation. From equations (12 - 15) we can write the following relations:

$$\frac{2Q}{\omega_{-1}^0}\frac{dA}{dt} + A = G\_[\alpha.A - \frac{3\gamma}{4}\{A^3 + 2(C^2 + B^2)A + B^2C\cos\phi\}] \tag{16}$$

$$\frac{d\varphi_{-1}}{dt} = \frac{3}{8}\gamma.A.C.G\_\Delta\omega.\sin\phi - (\omega_{-1} - \omega_{-1}^0) \tag{16a}$$

$$\frac{2Q}{\omega^0}\frac{dB}{dt} + B = G[\alpha.B - \frac{3\gamma}{4}\{B^3 + 2(C^2 + A^2)B + 2ABC\cos\phi\}] \tag{17}$$

$$\frac{d\varphi_0}{dt} = \frac{3}{8}\gamma.A.C.G_0\Delta\omega.\sin\phi - (\omega_0 - \omega^0) \tag{17a}$$

$$\frac{2Q}{\omega_{+1}^{0}}\frac{dC}{dt}+C=G_{+}[\alpha.C-\frac{3\gamma}{4}\{C^{3}+2(A^{2}+B^{2})C+B^{2}A\cos\phi\}] \quad (18)$$

$$\frac{d\varphi_{+1}}{dt}=\frac{3}{8}\gamma.A.\frac{B^{2}}{C}.G_{+}\Delta\omega..\sin\phi-(\omega_{+1}-\omega_{+1}^{0}) \quad (18a)$$

In the steady state $\frac{dA}{dt}=0$, $\frac{dB}{dt}=0$ & $\frac{dC}{dt}=0$. Now from equations (16), (17) & (18) the following equations follow:

$$\alpha.A_{s}-\frac{3\gamma}{4}\{A_{s}^{3}+2(B_{s}^{2}+C_{s}^{2})A_{s}+B_{s}^{2}.C_{s}.\cos\phi_{s}\}=\frac{A_{s}}{G_{-}} \quad (19)$$

$$\alpha.B_{s}-\frac{3\gamma}{4}\{B_{s}^{3}+2(A_{s}^{2}+C_{s}^{2})B_{s}+2A_{s}B_{s}.C_{s}.\cos\phi_{s}\}=\frac{B_{s}}{G_{0}} \quad (20)$$

$$\alpha.C_{s}-\frac{3\gamma}{4}\{C_{s}^{3}+2(B_{s}^{2}+A_{s}^{2})C_{s}+B_{s}^{2}.A_{s}.\cos\phi_{s}\}=\frac{C_{s}}{G_{+}} \quad (21)$$

where A_S , B_S & C_S are the steady state value of the amplitudes A, B & C. The variation of amplitudes with time is shown in Fig.6. Now the phases, φ_{-1}, φ_0 and φ_{+1} of the three oscillations may or may not be steady but ϕ must be steady. So we can put [omitting the subscript of A, B, C and ϕ] $d\phi / dt = 0$.

Assuming $\varphi_{-1}+\varphi_{+1}=2\varphi_0+\phi$, $\phi=\varphi_{-1}+\varphi_{+1}-2\varphi_0$

$$\therefore\frac{d\phi}{dt}=\frac{3}{8}\gamma.A.\Delta\omega.G_{0}\sin\phi\left[\left(CG_{-}+G_{+}.\frac{B^{2}}{C}\right)-2.G_{0}C\right]+\left(\omega_{-1}+\omega_{+1}-2\omega_{0}\right) \quad (22)$$

In steady state, $\frac{d\phi}{dt}=0$

$$\sin\phi=\frac{\left(\omega_{-1}+\omega_{+1}-2\omega_{0}\right)}{\frac{3}{8}\gamma.A.\Delta\omega.G_{0}\left[\left(CG_{-}+G_{+}.\frac{B^{2}}{C}\right)-2.G_{0}C\right]} . \quad (23)$$

When the value of $\sin\phi$ is less than 1 then simultaneous three-frequency oscillation is possible. If $\sin\phi = 1$, three frequency oscillation is not possible. $\sin\phi = 0$ is the best possible situation for simultaneous oscillation. For our calculation we take $\sin\phi = 0$. The calculated steady state values of the amplitudes A,B and C are given below:-

$A_s = 0.706$ $B_s = 1.525$ $C_s = 0.733$

Substituting this values in the equations (16), (17), (18) and (23) and solving we get the values of a, b, c and $\Delta\phi$.

VI. CONCLUSIONS

On the basis of analysis and experiments it is shown that there are possibilities of simultaneous oscillations at three frequencies in a waveguide mounted Gunn oscillator.

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