STUDY OF FUNDAMENTAL WAVE INJECTION LOCKING OF MM-WAVE GUNN HARMONIC OSCILLATOR USING LARGE SIGNAL MODEL OF GUNN DEVICE

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ABSTRACT

A new large signal mathematical model of Gunn device at the state of harmonic operation is presented. The locking characteristic of fundamental wave injection locking of mm-wave Gunn harmonic oscillator is analyzed theoretically by using this model. The theoretical results have good agreement with experiment.

INTRODUCTION

The fundamental wave injection locking of the second harmonic Gunn oscillators at mm-wave band have been reported in (1),(2). It can increase the stability and reduce the phase noise of the Gunn harmonic oscillator. However, no theoretic approach so far has been done to the characteristic of this kind of injection locking and the experimental results are not complete.

The large signal characteristic of the Gunn device at the state of harmonic operation is the basis of analyzing the nonlinear circuit relating to harmonic oscillator. The model of Gunn device at the state of harmonic operation commonly used was first presented in (3). In that paper, the author gave the mathematical representation of the model and analyzed theoretically the Gunn harmonic oscillator. But his model neglects the nonlinear reactance and the effect of harmonic RF voltage on device characteristics.

In this paper, we put forward a novel large signal mathematical model of Gunn device at the state of harmonic operation. The model is obtained on the basis of device physics. Using this model, we analyze the locking characteristic of the fundamental wave injection locking of mm-wave Gunn harmonic oscillator. The formula which describes the relation between the locking bandwidth and the injection power is deduced. Experiment has also been made in V-band. The theoretical results have good agreement with experiment.

MODEL OF DEVICE

Practical Gunn devices are usually fabricated from epitaxial layers of GaAs n^+-n-n^+ sandwich configuration(see Fig.1). Since the length of the active n layer is much smaller than the device diameter, a one dimentional analytical model is considered to study the large signal characteristics of Gunn device.

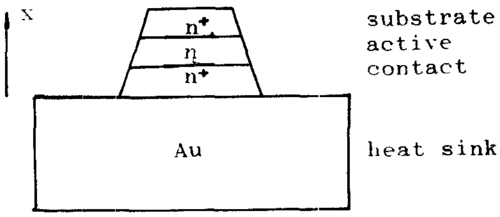

Fig.1 Configuration of Gunn Device

Unlike the fundamental Gunn oscillator, the voltage across the device not only has fundamental RF component but also harmonic RF component in the harmonic Gunn oscillator. The total voltage across the device in the harmonic Gunn oscillator can be written as

$$v(t)=V0-V1COSwt-V2COS(2wt+\phi) \quad (1)$$

where V0 is the applied DC bias voltage, V1, V2 are the fundamental and harmonic RF voltage amplitudes across the device respectively. According to the current continuity equation and Poisson's equation, the total current flowing through the device which includes drift, diffusion and displacement components is given by

$$\frac{i(t)}{S}=-\varepsilon D(E)\frac{\partial^2 E(x,t)}{\partial x^2}+\varepsilon v(E)\frac{\partial E(x,t)}{\partial x}+\varepsilon\frac{\partial E(x,t)}{\partial t}$$

$$-qD(E)\frac{\partial N_D(x)}{\partial x}+qv(E)N_D(x) \quad (2)$$

where v(E) is the electric field induced drift velocity of electrons in GaAs, D(E) is the diffusion coefficient of electrons in GaAs, E(x,t) is the electric field as a function of a space and time, ε is the dielectric constant of the GaAs, q is the electric charge and S is the cross-section area.

Eq.2 is a nonlinear partial differential equation. It can be solved by the combination of finite-difference and iterative methods(4). When i(t) is obtained, we can easily know the large signal admittance of Gunn device at the state of harmonic operation through Fourier analysis of i(t).

$$\begin{aligned} i(t)=I_0&+I_{c1}Cos(wt)+I_{s1}Sin(wt)\\ &+I_{c2}Cos(2wt)+I_{s2}Sin(2wt)\\ &+I_{c3}Cos(3wt)+I_{s3}Sin(3wt)\\ &+\cdots\cdots \end{aligned} \quad (3)$$

$$\begin{cases} G_{D1}=-I_{c1}/V1 \\ B_{D1}= I_{s1}/V1 \\ G_{D2}=-(I_{c2}Cos\phi-I_{s2}Sin\phi)/V2 \\ B_{D2}= (I_{c2}Sin\phi+I_{s2}Cos\phi)/V2 \end{cases} \quad (4)$$

For the convenience of analyzing the nonlinear circuit relating to Gunn oscillator, we put forward a novel mathematical model of Gunn device.

$$\begin{cases} i_G = \alpha_1 v + \alpha_2 v^2 + \alpha_3 v^3 \\ \dfrac{di_B}{dt} = \beta_0 + \beta_1 v + \beta_2 v^2 + \beta_3 v^3 \end{cases} \quad (5)$$

where i_G, i_B stand for the current components flowing through the conductance and susceptance. This can be clearly seen in Fig.2. The coefficients α_i and β_i can be computed by the above numerical results.

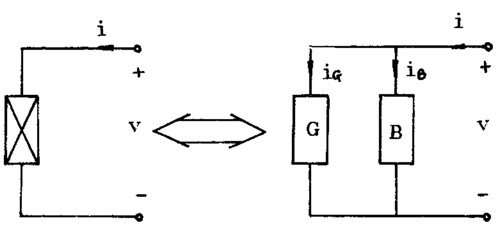

Fig.2 Equivalent Circuit of Gunn Device

INJECTION LOCKING CHARACTERISTIC

Fig.3 shows the equivalent circuit of the second harmonic Gunn oscillator which is injected by a fundamental wave signal is(t).

$$is(t)=IsCos(wt+\psi) \quad (6)$$

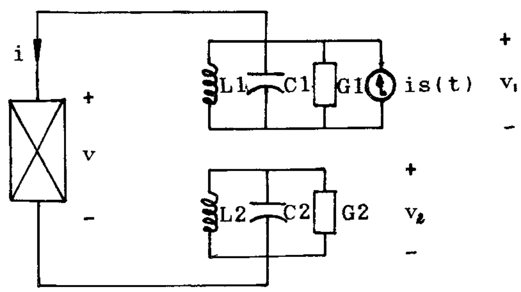

Fig.3 Equivalent Circuit of Harmonic Oscillator

The circuit equations are

$$\begin{cases} C1\dfrac{dv_1}{dt}+G1\dfrac{dv_1}{dt}+\dfrac{1}{L1}v_1+\dfrac{di}{dt}=is(t) \\ C2\dfrac{dv_2}{dt}+G2\dfrac{dv_2}{dt}+\dfrac{1}{L2}v_2+\dfrac{di}{dt}=0 \end{cases} \quad (7)$$

By using the above Gunn device mathematical model and the method of slowly changing phase and amplitude, we obtain four expressions relating to fundamental and harmonic amplitudes and phases. The formula which describes the relation between the locking bandwidth and the fundamental wave injection power can be deduced from these four expressions.

$$\frac{\Delta f}{f}=\frac{a\sqrt{Pi/P0}}{b+c\sqrt{Pi/P0}} \quad (8)$$

where f is oscillating frequency, Δf is the locking bandwidth, Pi is injected fundamental wave power, P0 is the second harmonic output power. The coefficients a,b,c are relating to coefficients of device mathematical model and the parameters of the equivalent circuit of the harmonic oscillator.

EXPERIMENTAL AND THEORETICAL RESULTS

To verify our theoretical analysis, we have measured the locking bandwidth of fundamental wave injection locking of a

V-band second harmonic Gunn oscillator. Fig.4 shows the schemetic diagram of experimental set-up. The Gunn device used in harmonic oscillator is WT-56 from Nanjing Solid State Device Research Institute, China. The computed large signal admittance and the coefficients of the mathematical model of Gunn device are shown in Fig.5 and Fig.6. The locking bandwidth experimental and computed results are shown in Fig.7. It is seen that the theoretic results have good agreement with experiment.

CONCLUSION

This paper presented a novel nonlinear mathematical model of Gunn device based on the device physics. Using this model, we analyzed the fundamental wave injection locking of harmonic Gunn oscillator. The analytic formula describing the relation between locking bandwidth and the injected power was obtained. Experiment has been made to verify the theoretic analysis. It can be concluded that with the increasing of the injected power, the locking bandwidth increases more slowly and tends to a constant.

ACKNOWLEDGEMENT

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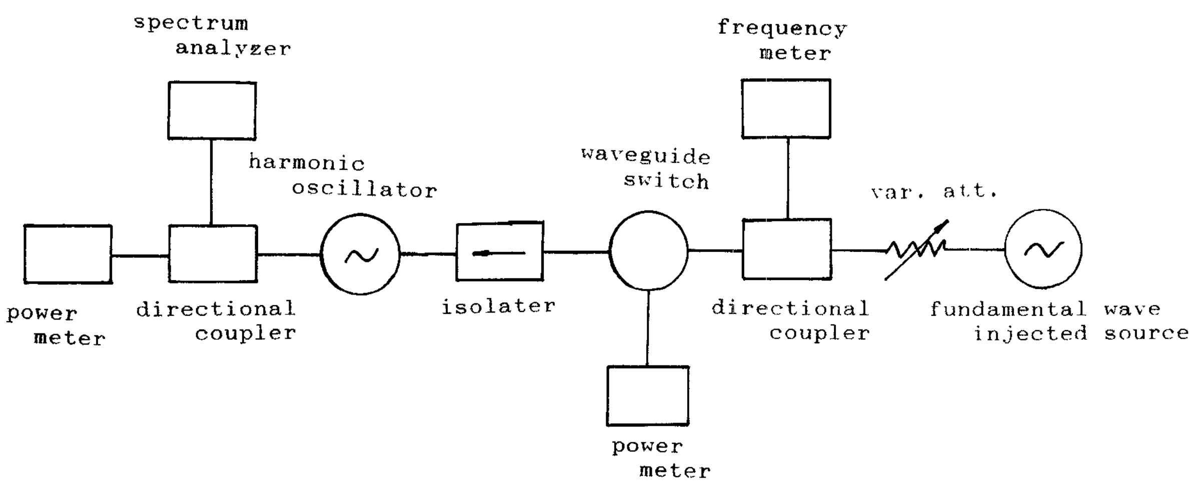

Fig.4 Measurement of Locking Bandwidth

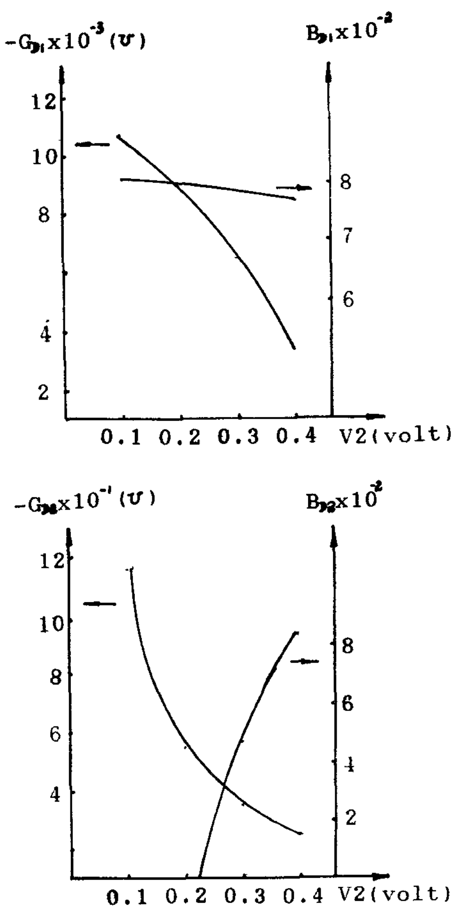

Fig.5 Large Signal Admittance of Gunn Device

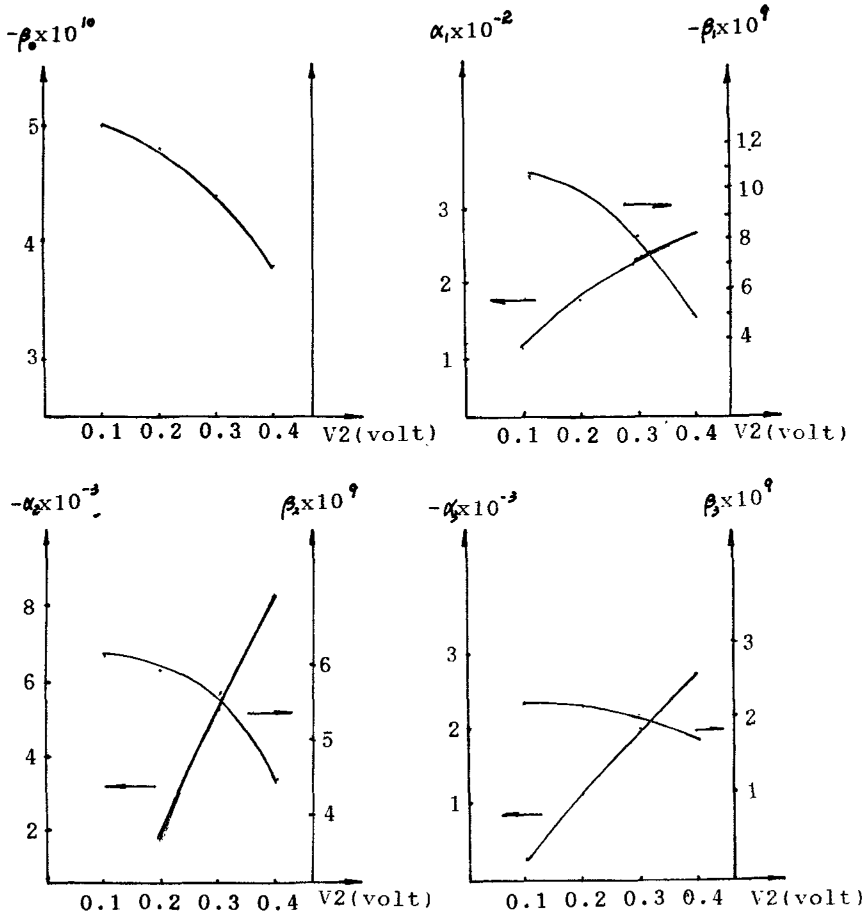

Fig.6 Coefficients of Mathematical Model of Gunn Device

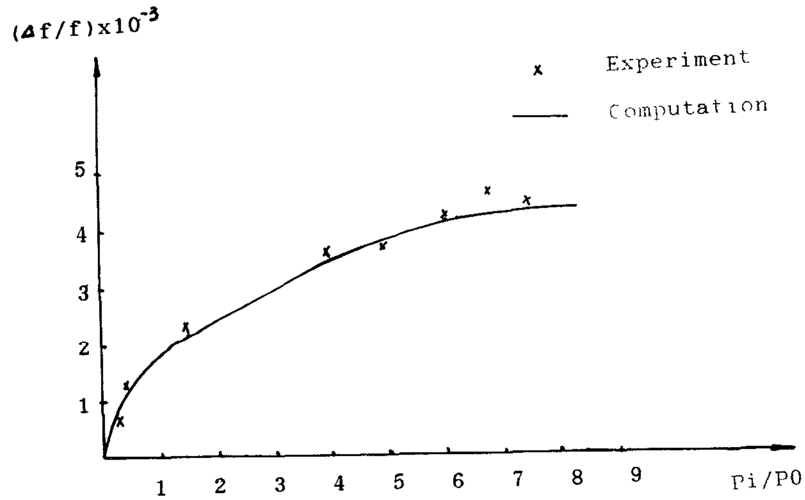

Fig.7 Theoretic and Experimental Results of Locking Bandwidth