MODELING, ANALYSIS AND OPTIMIZATION OF GUNN DIODE VCO

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ABSTRACT

In this paper, a new model of Gunn diode VCO is established on the basis of computation of coupling disc capacitance between Gunn diode and varactor using spectral-domain Hankle transformation. For the first time, the nonlinear analysis of Gunn diode VCO has been carried out by using harmonic balance technique. The experimental results are compared with the computed results.It is shown that the developed model and analysis program are available and effective. A special optimization procedure to find the doping power factor of varactor is proposed in order to get optimal tuning linearity.

I. INTRODUCTION

The millimeter-wave VCO's are important parts which have been used extensively in various millimeter-wave systems. A number of authors have developed a variety of configurations of VCO(1)(2)(3)(4)(5). Cawsy(4)(6) has pointed out that the series tuning has broader tuning bandwidth than parallel tuning. However, so far the nonlinear analysis of Gunn diode VCO is still the problem which remains to be solved. The difficulty for this is the complexity of nonlinear analysis, since VCO includes two nonlinear devices and they are coupled each other. Therefore, there exists a demand to develop a nonlinear analysis software and an optimization procedure which are necessary for CAD of VCO. In this paper, the modeling, nonlinear analysis and optimization of a Gunn diode VCO are carried out completely. A new model iseestablished on the basis of computation of coupling disc capacitance between Gunn diode and varactor using spectral-domain Hankle transformation. For the first time, the nonlinear analysis of Gunn diode VCO has been done by using harmonic balance technique. A comparison of computed and experimental results at Ka-Band has verified the availability of the developed model and analysis program. Using this program, the dependence of tuning bandwidth on coupling between Gunn diode and varactor has also been investigated. On the basis of nonlinear analysis, a specialoptimization procedure is proposed to find the doping power factor of varactor in order to get optimal tuning linearity.

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2.MODELING

The configuration of a Ka-Band Gunn diode VCO is shown in Fig.1. This is a series tuning hybrid integrated VCO. It has the advantages of easy fabrication, larger output power and broader tuning bandwidth.

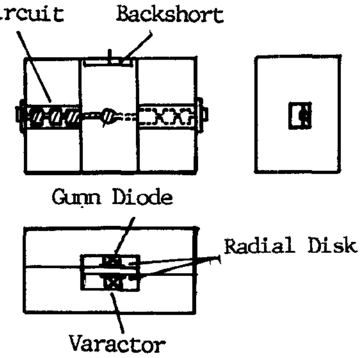

Fig.1. Configuration of hybrid integrated Gunn diode VCO.

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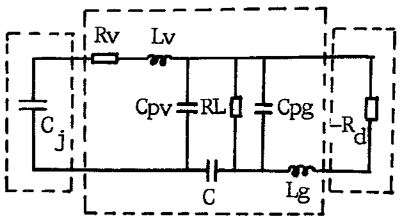

Fig.2. Equivalent circuit of Gunn diode VCO.

Fig.2 shows the equivalent circuit of VCO, where Rv, Lv,Cpv and Lg, Cpg are parasitic parameters of varactor and Gunn diode, respectively. The nonlinear junction capacitance Cj of varactor can be expressed as

$$C_j = \frac{C_j(0)}{(1 - V(t)/\phi)^{\gamma}} \tag{1}$$

where γ is the doping power factor. The intrinsic Gunn diode can be described by Van del Pol model,i.e.

$$i(t)=c_1V(t) + c_2V^2(t) + c_3V^3(t). \tag{2}$$

where typically, c_1=-0.1A/V, c_2= 0.015A/V^2, c_3= 0.01A/V^3. The remaining problem is to determine the coupling capacitance C between Gunn diode and varactor and load impedance RL.

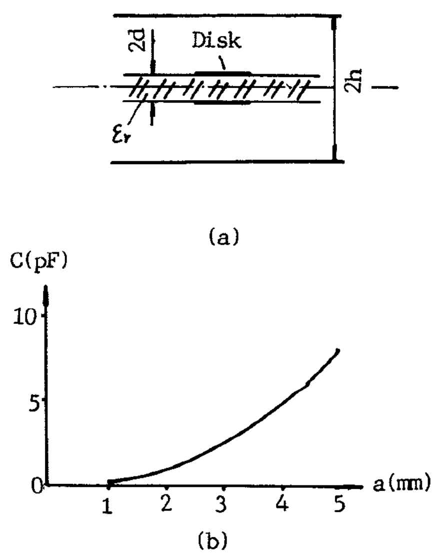

Fig.3.Computation of coupling capacitance.

Considering the model shown in Fig.3(a), we suppose that the conductive plates on the top and bottom are much greater than the metallic discs, the computation of coupling capacitance C is to solve a two-dimensional Poisson equation

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \phi}{\partial r}\right)+\frac{\partial^2\phi}{\partial z^2} = \frac{-1}{\varepsilon_0}\rho(r)\ \delta(z-d) \tag{3}$$

where $\rho(r)$ is the charge distribution on the disc, $\delta(z - d)$ is Dirac function. Applying spectral-domain Hankle transformation and Garlerkin's method, Eq.(3) is solved and the coupling capacitance C is computed. The dependence of capacitance on the radius of disc is shown in Fig.3 (b).

The load impedance RL is the transformed waveguide impedance by radial transmission line. The mode propagating in radial transmission line, which is excited by H_{10} mode in waveguide, is radial TEM mode. The field components can be expressed as

$$\begin{cases} E_z = AH_0^{(1)}(kr) + BH_0^{(2)}(kr) \\ H_\phi = \dfrac{1}{j\omega\mu}\dfrac{\partial E_z}{\partial r} = \dfrac{j}{\eta}\left[AH_1^{(1)}(kr)+BH_1^{(2)}(kr)\right] \end{cases} \tag{4}$$

The load impedance is

$$R_L = \frac{V}{I}\Big|_{r=r_i} = -\frac{E_z d}{2\pi r H_\phi}\Big|_{r=r_i} = -\frac{d}{2\pi r}\left(\frac{E_z}{H_\phi}\right)_{r=r_i}$$

where r_i is the radius of Gunn diode.

3. NONLINEAR ANALYSIS

The model of Gunn diode VCO consists of three subnetworks(divided by dashed lines), two nonlinear subnetworks and one linear embedding subnetwork. They are interconnected in cascade.

For nonlinear subnetwork including intrinsic varactor, the current through the PN junction is

$$i(t)= J[V(t)] + \frac{d}{dt}[q(V(t))] \tag{5}$$

where

$$J[V(t)] = I_s\ [\exp(\frac{eV}{nkt}) - 1]$$

$$q[V(t)]=q_T[V(t)] + q_D[V(t)]$$
$$=C_j(0)\frac{\phi^\gamma}{\gamma-1}[\phi - V(t)]^{1-\gamma} + I_s\tau[\exp(\frac{eV}{nKT})]$$

Using Fourier expansion, for kth harmonic,

$$I_{vk}= J_{vk}+ j\omega kQ_{vk}$$

For nonlinear subnetwork including intrinsic Gunn diode, $I_{gk}=G(V_{gk})$ can be determined by using Van der Pol model.

For linear embedding subnetwork, the matrix

$$[A]_k = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}_k$$

can be determined according to the circuit topology and the element parameters where C and RL are computed by using special analysis subroutine.

Obviously, the harmonic balance equation is established as follows

$$\begin{bmatrix} V_v \\ I_v \end{bmatrix}_k = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}_k \begin{bmatrix} V_g \\ I_g \end{bmatrix}_k \qquad (6)$$

choosing $[V_v]_k$, $[V_g]_k$ ($k=0,1,2,\ldots\ldots N$) and ω as optimized variables, optimization is carried out at different bias voltages of varactor to reach harmonic balance. Fig.4 shows the power and frequency versus the bias voltages of varactor. A Gunn diode VCO at Ka-Band has been fabricated and the performances has been measured. The comparison of computed and experimental results has verified the availability of the developed model and analysis program. The dependence of tuning bandwidth on the coupling capacitance has also been investigated and the computed results are listed in Table 1.

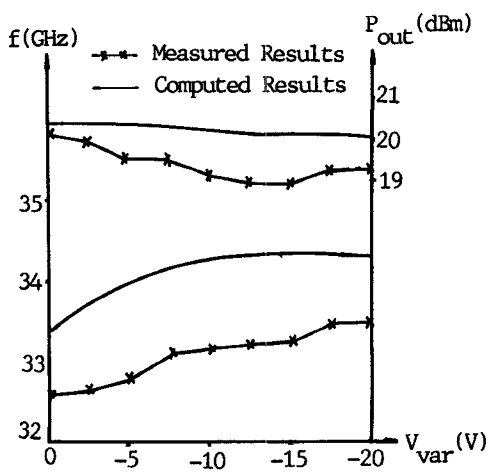

Fig.4. Comparison of computed and measured performance of the Ka-Band Gunn diode VCO. $\gamma=0.9$, C=2.1pF, $C_j(0)=1.2$pF.

a(mm)	1.3	2.0	2.5
C(pF)	1.0	2.11	3.0
f_o(GHz)	35.01	34.80	33.0
Δf(GHz)	0.82	1.2	1.4

Table 1. Dependence of tuning bandwidth on the coupling capacitance. $C_j(0)=1.0$pF, $\gamma=0.9$, a is the radius of disc and f_o is the frequency at V=0.

4. OPTIMIZATION

It is well known that the tuning linearity of VCO is very important for many applications. It closely depends on the doping power factor of varactor. It is seen from Fig.4 that the tuning linearity is not satisfactory when $\gamma=0.9$. On the basis of nonlinear analysis, a special optimization procedure is proposed to find the optimal doping power factor. At first, the tuning characteristic with respect to nine different bias voltages of varactor was computed. Then, a linear function

$$f' = a_o + b_o V$$

which approximates the tuning characteristic was found by using curve fitting technique. The approximation can be described by a error function

$$\Delta = \sum_{n=1}^{9} (f_n - f'_n)^2 \qquad (7)$$

Using Eq.(7) as objective function and γ as optimized variable, optimization was carried out to minimize the error function. The optimized tuning characteristic of VCO for different doping power factor of varactor is shown in Fig.5. It is seen that the optimal doping power factor of varactor is $\gamma=2.48$ for $C_j(0)=0.9$, C=2.11pF.

5. CONCLUSION

The modeling, analysis and optimization of a Gunn diode VCO have been carried out completely. A Ka-band Gunn diode VCO has been fabricated and the experimental results have verified the availability of new model and nonlinear analysis program. A special optimization procedure has been proposed to find the optimal doping power factor of varactor.

The nonlinear analysis and optimization procedure developed in this paper are also available for CAD of any other kind of VCO.

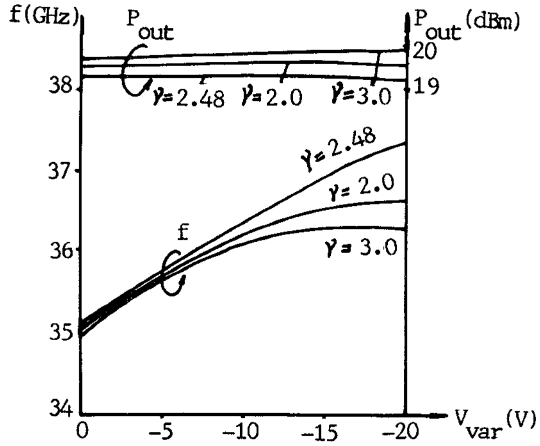

Fig.5. Optimized tuning characteristic for different doping power factor.

REFERENCES

(1) J. Ondria, "Partially Integrated Electronically Tuned Millimeter-wave (33-75GHz) Gunn Oscillator", 11th European Microwave Conference Digest, pp888-893, Sep. 1981.

(2) R.S.Tahim, G.M.Hayashibara and K. Chang, "High Performance Millimeter-wave Suspended Stripline Gunn VCO", Electronic Letters, 25th, Sep. 1986, Vol.22,No.20, pp1057--1059.

(3) E.J.Denlinger, J.Rosen, E.Mykietyn and E.C.Mc-dermott, "Microstrip Varactor-Tuned Millimeter-wave IMPATT Diode Oscillator", IEEE MTT-23, No. 12, Dec. 1976, pp953-958.

(4) C.S.Aitchison and R.V. Gelsthorpe, "A Circuit Technique for Broadbanding the Electronic Tuning Range of Gunn Oscillator", IEEE SC-12, No.1, Feb. 1977, pp21-28.

(5) J.Ondria, "Wideband Electronically Tunnable GaAs Gunn VCO's at W-band (75-110GHz)", IEEE MTT-s Digest, 1985, pp375-378.

(6) C.S.Aitchison, "Method of Improving Tuning Range Obtained From a Varactor Gunn Oscillator", Electronic Letters, 4th, Apr. 1974, Vol.10,No.7, pp94-95.