A MULTIPLE-DIODE STRUCTURE FOR HIGH POWER MICROWAVE GENERATION

Kiyoshi Fukui*
Department of Electrical & Computer Engineering
University of Wisconsin-Madison
Madison, Wisconsin 53706 U.S.A.

Shigeji Nogi
Department of Electronics
Okayama University
Okayama 700, Japan

ABSTRACT

A high power microwave oscillator with multiple-diode structure is proposed, which is merely a series connection of several waveguide sections having a pair of diode-mounts placed symmetrically with the guide-axis. The method for perfect addition of powers generated by each component diode is discussed. Experiments were carried out for double-, quadruple- and sextuple-diode case, and performances were confirmed in fairly good agreement with the theoretical results.

Introduction

Although many attempts to build a high power microwave oscillator using several diodes have been heretofore carried out,[1-5] successful ones were of a rather complicated structure in order to remove multi-mode difficulties.

In this paper, a simpler multiple-diode structure is presented which is merely a series connection of several waveguide sections having a pair of diode-mounts placed symmetrically with the guide-axis (see Fig. 1), and which permits perfect power addition without multi-mode difficulty. Results of a theoretical treatment of this structure and experimental confirmation are described below.

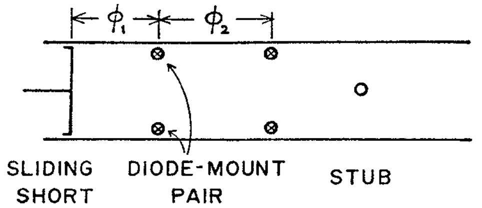

Fig. 1 Multiple-diode structure studied (quadruple-diode case).

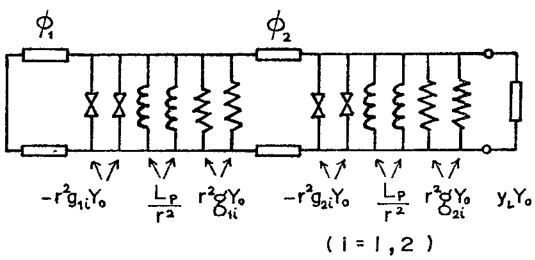

Fig. 2 Equivalent circuit for quadruple-diode structure.

Theory

Analysis is carried out based on an equivalent circuit representation of the structure such as shown in Fig. 2, where the case of quadruple-diode is shown as an example, and where a diode-mount is modeled approximately by a parallel connection of a negative conductance and a shunt inductance. The parameter r^2 (<1) represents the coefficient of coupling-reduction which arises because the diode-mounts are displaced toward the side wall of the waveguide.

*On leave from Okayama University, Okayama, Japan.

Reduced Differential Equations of the System

Assuming the voltage dependence of the negative conductance for the i^{th} diode-mount of the n^{th} pair as

$$r^2 g_{ni}(v) = r^2(g_{0,ni} - 4r^2\theta_{ni}v^2) \qquad (1)$$

$$n = 1,2,\ldots,N;\ i = 1,2$$

we can obtain a set of nonlinear circuit equations, which were solved by use of the method of harmonic balance. When we assume the solution as

$$v_n(t) = V_n(t)\cos\{\omega_0 t + \phi_n(t)\} \qquad (2)$$

the resultant reduced equations which describe the time variation of V_n's and ϕ_n's are given as follows.

First, for the simplest double-diode case, they are

$$\left.\begin{aligned} B'(\omega_0)\frac{dV}{dt} + G'(\omega_0)\,V\frac{d\phi}{dt} &= -G(\omega_0)V \\ G'(\omega_0)\frac{dV}{dt} - B'(\omega_0)\,V\frac{d\phi}{dt} &= B(\omega_0)V \end{aligned}\right\} \qquad (3)$$

where

$$\left.\begin{aligned} G(\omega) &= -r^2\{g^*_{0,11}+g^*_{0,12}-r^2(\theta_{11}+\theta_{12})V^2\}+g_L \\ B(\omega) &= -\cot\phi_1 - 2r^2/(\omega L_p Y_0)+b_L \end{aligned}\right\} \qquad (4)$$

together with $g^*_{0,ni} = g_{0,ni} - \mathscr{g}_{ni}$. In the above, the device parameters and circuit parameters should be considered as functions of frequency for precise discussion. However, neglect of the frequency dependence is permissible for treatment of the steady state. For the quadruple-diode case, only such simplified equations are given for brevity:

$$\begin{aligned} B_1'(\omega_0)\frac{dV_1}{dt} &= -G_1V_1 + V_2\operatorname{cosec}\phi_2\,\sin(\phi_2-\phi_1) \\ B_1'(\omega_0)V_1\frac{d\phi_1}{dt} &= -B_1(\omega_0)V_1 - V_2\operatorname{cosec}\phi_2\,\cos(\phi_2-\phi_1) \\ B_2'(\omega_0)\frac{dV_2}{dt} &= -G_2V_2 + V_1\operatorname{cosec}\phi_2\,\sin(\phi_1-\phi_2) \\ B_2'(\omega_0)V_2\frac{d\phi_2}{dt} &= -B_2(\omega_0)V_2 - V_1\operatorname{cosec}\phi_2\,\cos(\phi_1-\phi_2) \end{aligned} \qquad (5)$$

where

$$\begin{aligned} G_1 &= -r^2\{g^*_{0,11}+g^*_{0,12}-r^2(\theta_{11}+\theta_{12})V_1^2\} \\ G_2 &= -r^2\{g^*_{0,21}+g^*_{0,22}-r^2(\theta_{21}+\theta_{22})V_2^2\}+g_L \end{aligned}$$

CH1355-7/78/0000-0357$00.75

$$
\left.
\begin{aligned}
B_1(\omega) &= -\cot\phi_1 - 2r^2/(\omega L_p Y_0) - \cot\phi_2 \\
B_2(\omega) &= -\cot\phi_2 - 2r^2/(\omega L_p Y_0) + b_L \\
B_1'(\omega_0) &= B_2'(\omega_0) = 2r^2/(\omega_0^2 L_p Y_0)
\end{aligned}
\right\} \tag{6}
$$

Reduced equations for the case of higher N can be written in a similar way.

Maximum Output Power

The steady state solution can be obtained by setting all time derivatives equal to zero. The maximum output power, P_{max}, and the optimum load conductance seen at the last (the N^{th}) diode-mount pair, $g_{L,opt}Y_0$, can be derived from the requirement for maximizing the output power $P_{out} = \frac{1}{2} g_L Y_0 V_N^2$, and are given as

$$
P_{max} = \frac{Y_0}{8} \sum_{n=1}^{N} \frac{(g^*_{0,n1}+g^*_{0,n2})^2}{\theta_{n1}+\theta_{n2}} \tag{7}
$$

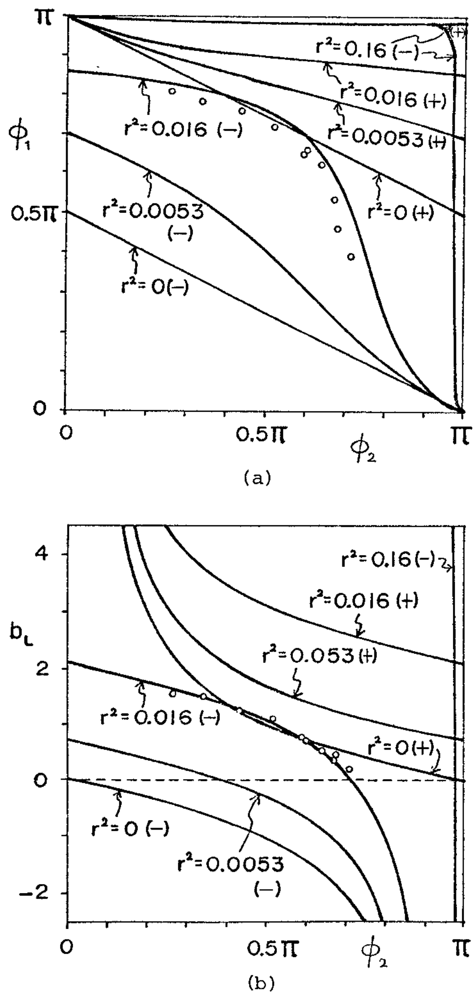

Fig. 3 Optimum values of ϕ_1 and b_L versus ϕ_2. Theoretical curves were drawn using $g_0^*=7.0$ and $1/\omega_0 L_p Y_0=66.3$.

and

$$
g_{L,opt} = \frac{r^2}{2}(g^*_{0,N1}+g^*_{0,N2}) \sum_{n=1}^{N} \frac{\dfrac{(g^*_{0,n1}+g^*_{0,n2})^2}{\theta_{n1}+\theta_{n2}}}{\dfrac{(g^*_{0,N1}+g^*_{0,N2})^2}{\theta_{N1}+\theta_{N2}}} \tag{8}
$$

respectively. Corresponding values of V_n's are

$$
V_n^2 = (g^*_{0,n1}+g^*_{0,n2})/[2r^2(\theta_{n1}+\theta_{n2})] \ . \tag{9}
$$

Since an ordinary single-diode oscillator has the maximum output power of

$$
P_{single} = \frac{Y_0}{8}\frac{g_0^{*2}}{\theta} \quad \text{for} \quad g_{L,opt} = \frac{1}{2} g_0^* \ ,
$$

Eq. (7) states that the powers generated by each diode add together perfectly as long as the parameters of pairing diodes are equal to each other.

Optimum Circuit Conditions

The optimum values of ϕ_n's (n=1,...,N), the electrical distance of the n^{th} from the $(n-1)^{th}$ diode-mount pair (from the shorting end for n=1), and $b_L Y_0$, the load susceptance seen at the N^{th} pair are also obtained by combining the steady state equations and the conditions for maximizing the output power. Here, the determining equation(s) only for the cases N=1 and N=2 are given.

For double-diode case, at a desired frequency ω_0, ϕ_1 and b_L must be chosen to satisfy

$$
-\cot\phi_1 - 2r^2/(\omega_0 L_p Y_0) + b_L = 0 \tag{10}
$$

which simply means zero total susceptance.

For quadruple-diode case, we have

$$
\cot\phi_1 + \cot\phi_2 \pm \sqrt{\operatorname{cosec}^2\phi_2 - r^4 g_0^{*2}} + \frac{2r^2}{\omega_0 L_p Y_0} = 0 \tag{11}
$$

and

$$
b_{L,opt} + \cot\phi_1 = 0 \tag{12}
$$

Here all the $g^*_{0,ni}$- and θ_{ni}-values are assumed to be equal to each other, respectively, for simplicity. We have just N such equations for the 2N diodes case. Given the value of ϕ_2 at a desired frequency ω_0, the optimum values for ϕ_1 and b_L are obtained from Eqs. (11) and (12). This is shown in Fig. 3, in which (+) and (−) correspond to the double signs in Eq. (11). Figure 3 also shows that there are two possible modes: the mode signified by (+) has a voltage minimum just at the middle of successive diode-mount pairs, while the mode (−) has a voltage maximum. For $\phi_2 > \pi$, the abscissa must be replaced by $\phi_2 - m\pi$ (m:integer) and at the same time (+) and (−) must be exchanged if m is odd. Note that the frequencies corresponding to these modes are far from each other; thus actually only one mode can appear because the working frequency range of the diode is limited.

Experimental Results

Experiments were carried out using Gunn diodes, GD511A, manufactured by Nippon Electric Company. The observed values for P_{max}, $g_{L,opt}$ and $b_{L,opt}$ in double-diode case are plotted in Fig. 4, where the theoretical curves are also drawn for comparison.

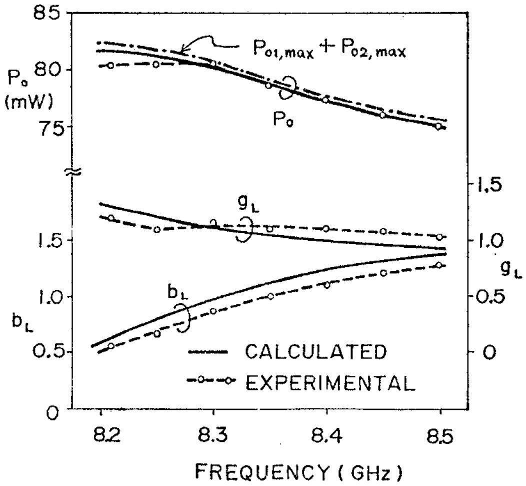

Fig. 4 Comparison of experimental results with calculated ones (double-diode case).

For the quadruple-diode case, typical measured data for P_{max} and $g_{L,opt}$ versus ϕ_2 are given in Table 1 together with calculated values, and measured values for ϕ_1 and b_L versus ϕ_2 are plotted onto Fig. 3 to give comparison with theoretical curves.

Table 1. Comparison of measured values for P_{max} and $g_{L,opt}$ with theoretical ones.

ϕ_2	Measured P_{max}	Measured $g_{L,opt}$	Theoretical*
0.262^{π}	155^{mW}	0.22	
0.332	155	.22	
0.437	159	.21	$P_{max} = 159^{mW}$
0.516	156	.25	$g_{L,opt} = 0.24$
0.594	156	.23	
0.635	158	.23	
0.713	156	.19	

$\omega_0/2\pi = 8300^{MHz}$
$r^2 = 0.0016$
$\frac{1}{\omega_0 L_p Y_0} = 66.3$
$(g_0^*)_{average} = 7.0$

*Sum of the experimental values when each diode-mount pair is operated as a double-diode oscillator.

Frequency of oscillation can be changed by about 100 MHz at X-band by moving the sliding short in the vicinity of the optimum position, maintaining the output power within 2% reduction. Furthermore, load-characteristics were measured regarding the entire portion left of the stub as an oscillator, and the operation under the condition adjusted at the optimum was not sensitive to the change of the load seen from the stub.

Conclusion

It was shown that the simple structure presented here has excellent performance. This paper presents not only useful knowledge for power addition technique, but also one of the most practical methods.

Noise characteristics and injection-locking property are further interesting problems to be discussed; they are being studied. Another important subject of future investigation must be the study of oscillator performance when some of the diodes become inactive.

References

1. C.T. Rucker, IEEE Trans. MTT-17, 1156 (1969).
2. Kimura, Nakagawa and Kaneko, IECE Japan, MW70-49 (1970).
3. K. Kurokawa & F. M. Magalhaes, Proc. IEEE 59, 102 (1971).
4. K. Kurokawa, IEEE Trans. MTT-19, 793 (1971).
5. K. Fukui, S. Nogi, et al., IECE Japan, MW75-128 (1976).