

# AXIALLY SYMMETRIC FABRY-PEROT POWER COMBINER WITH ACTIVE DEVICES MOUNTED ON BOTH THE MIRRORS

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## ABSTRACT

We investigate an axially symmetrical Fabry-Perot power combiner with many more active devices operating in axially symmetric  $TEM_{01n}$  mode, which has an excellent feature of uniform device-field coupling required for high power combining efficiency. By numerical calculation using the boundary element method, it was shown that high combining efficiency can be obtained when a circular groove of larger radius is installed on either the plane mirror or the concave mirror. In experiments at X-band, almost perfect power combining of twenty or twenty-four devices mounted on both the mirror was achieved.

## INTRODUCTION

Recently, various methods for combining output powers of solid-state active devices have been developed[1, 2]. In millimeter wave frequency range, power combining using a Fabry-Perot resonator is considered effective and several investigations using the fundamental  $TEM_{00n}$ -mode have been reported[3-5]. However, as far as the authors know, the power combining efficiency has been relatively low. One of the reasons is supposed to be insufficient device-field coupling and lack of its uniformity. Inadequate coupling of the resonator to an output line can be another reason of low combining efficiency.

In order to resolve these problems, the authors proposed an axially symmetrical Fabry-Perot multiple-device oscillator shown in Fig.1[6]. The oscillator has a plane mirror which has a circular output window and a circular groove mounted with many solid-state devices. When it operates at an axially symmetrical mode, uniform device-field coupling required for high efficiency combining can be realized. Installation of the output window on the plane mirror can give strong coupling of the resonator to the output line because of narrow beam width at the plane mirror. Then the output coupling can be optimized corresponding to the negative conductance of the active devices. In experiments at X-band, almost perfect power combining was attained for the six- and eight-device oscillators. However, for the case of twelve-device structure power combining efficiency reduced because the strength of the device-field coupling decreases[6].

In this paper, in order to increase the number of devices mounted in the oscillator and achieve high power combining efficiency, we study the structure in which a circular groove

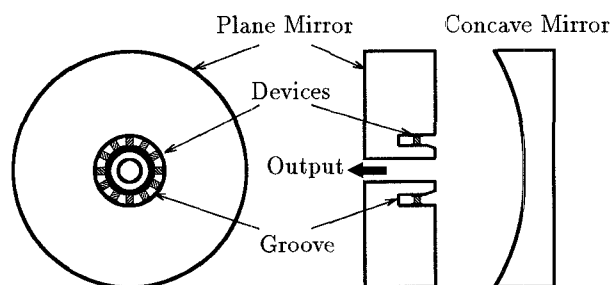


Fig.1 Axially symmetrical Fabry-Perot multiple-device oscillator.

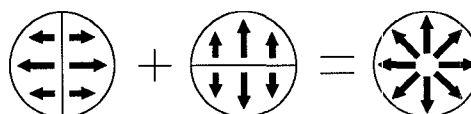


Fig.2 Axially symmetrical  $TEM_{01n}$  mode derived by sum of two linear-polarized modes.

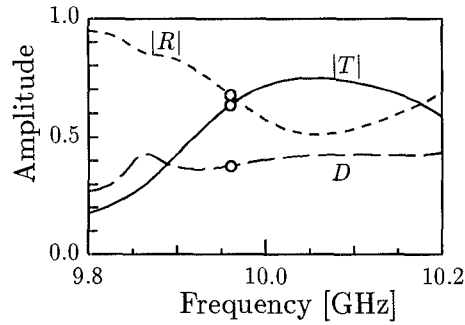
of larger radius is installed on the concave mirror or the plane mirror. In addition, we investigate the Fabry-Perot oscillator mounted with devices on both the mirrors in order to double the number of devices.

## STRUCTURE OF OSCILLATOR

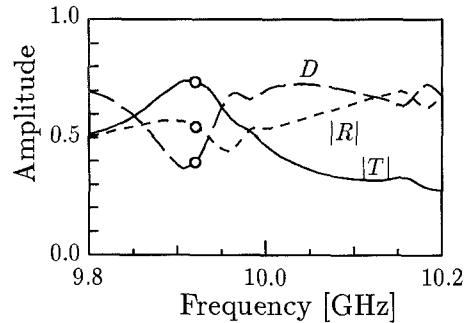
We consider the Fabry-Perot oscillator shown in Fig.1 and use an axially symmetrical  $TEM_{01n}$  mode shown in Fig.2 as a combining mode. This mode is obtained by combination of two linearly polarized  $TEM_{01n}$  mode, one in  $x$ -direction and the other in  $y$ -direction. Thus electric field of this mode has only radial component of azimuthally uniform magnitude. In order to achieve efficient power combining, every active device should generate the maximum output power cooperatively. This requires the same  $rf$  device current of the optimum magnitude through all the devices[7], which can be attained by uniform and sufficient device-field coupling. Active devices are mounted at equal spacing in the circular groove on the plane mirror or the concave mirror and are coupled to the axially symmetrical field in the groove.

The coupling of the device to electromagnetic field in the resonator consists of two steps; (A) the coupling of the devices to the groove field, and (B) the coupling of the groove field to the resonator. The uniformity of device-field cou-

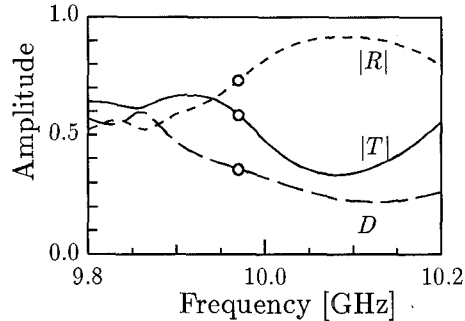




(a) case of groove on the plane mirror with  $r_{gp} = 22.5[\text{mm}]$ . (power transmission ratio  $\eta = 0.74$ .)



(b) case of groove on the concave mirror with  $r_{gc} = 34.0[\text{mm}]$ . ( $\eta = 0.78$ .)



(c) case of groove on the plane mirror with  $r_{gp} = 34.0[\text{mm}]$ . ( $\eta = 0.73$ .)

Fig.5 Frequency dependence of reflection  $|R|$ , transmission  $|T|$ , and diffraction loss  $D$  for the case of resonator length 100mm.

## EXPERIMENT

Experiments were carried out at X-band for twelve, twenty, and twenty-four Gunn diodes oscillators. Figure 6 shows the structure of the oscillator with the same structural dimensions as for the numerical analysis. Twelve diodes were mounted on the concave mirror, while eight or twelve diodes were mounted on the plane mirror. When either of the mirrors was mounted with diodes, the groove was not installed on the other mirror. The groove centers have a radius  $r_{gp}$  of 22.5mm or 34mm on the plane mirror, and a radius  $r_{gc}$  of 34mm on the concave mirror. The depth of the groove was adjusted by a short plunger for output power maximum. In order to alleviate the discontinuity in impedance at the

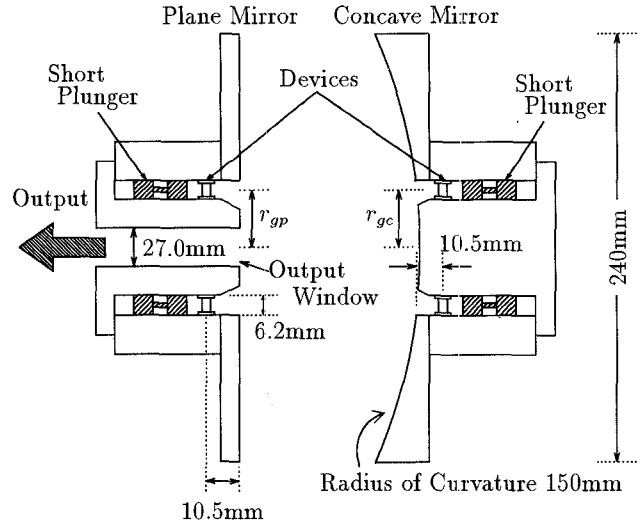


Fig.6 Oscillator structure for experiment.

groove opening, a tapered transition was provided. For the adjustment of the coupling of the resonator to the output waveguide, a circular window was prepared at the waveguide opening. The circular waveguide was converted to a rectangular waveguide.

Figure 7 shows a typical measured variation in oscillation frequency and output power with the resonator length when both of the grooves on the plane mirror ( $r_{gp} = 34[\text{mm}]$ ) and on the concave mirror ( $r_{gc} = 34[\text{mm}]$ ) were each mounted with twelve diodes. In Fig.7(a), the theoretical resonant frequency is also plotted. Compared with the theoretical frequency, it is considered that the oscillator operated at  $\text{TEM}_{01n}$  mode. High output power was obtained stably even if the resonator length increased.

The measured maximum combining efficiencies for various cases are listed up in Table 1, where the power combining efficiency is defined as the ratio of the output of a multiple-device oscillator to the sum of the maximum output powers of each device when they are measured in a usual waveguide cavity. Then combining efficiency was not sufficiently high when the groove on the plane mirror had small radius which gave the spacing between devices smaller than half of the wavelength. However, high combining efficiency was obtained<sup>1</sup> when the groove of large radius was installed on the plane mirror or on the concave mirror, because the coupling of the devices to the field in the groove is strong due to enough spacing between devices. When both the mirrors were mounted with diodes, almost perfect power combining was attained.

<sup>1</sup>In a usual waveguide cavity single-device oscillator, only less than about 80% of the power generated by the active device can be extracted to the output waveguide; this estimation can be obtained using measured external and internal  $Q$  values of the cavity. This is one of the main reasons why power combining efficiency often exceed 100% in experiments. As another important factor, multiple-device oscillators are advantageous in power combining efficiency because the resonator loss is shared by the many active devices[7].

Table 1 Measured maximum combining efficiencies. (— means that the groove is not installed on the mirror.)

radius of groove center on plain mirror $r_{gp}$ (mm)	22.5	34	—	22.5	34
number of diodes on plain mirror	12	12	—	8	12
radius of groove center on concave mirror $r_{gc}$ (mm)	—	—	34	34	34
number of diodes on concave mirror	—	—	12	12	12
resonator length $L$ (mm)	108	98	96.7	99	97
mode number	017	016	016	016	016
oscillation frequency (GHz)	10.80	10.07	10.10	10.04	10.08
maximum efficiency (%)	87.8	91.5	94.5	105.2	100.5

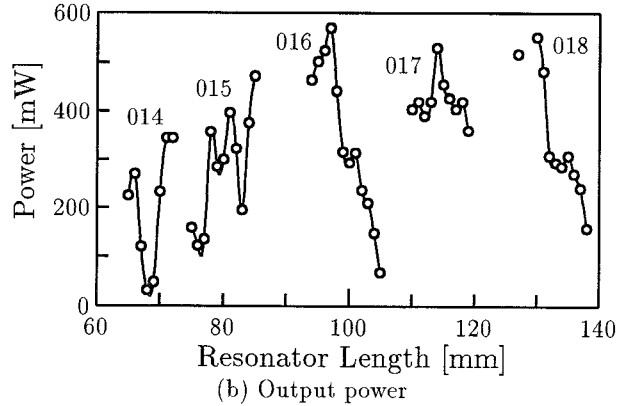
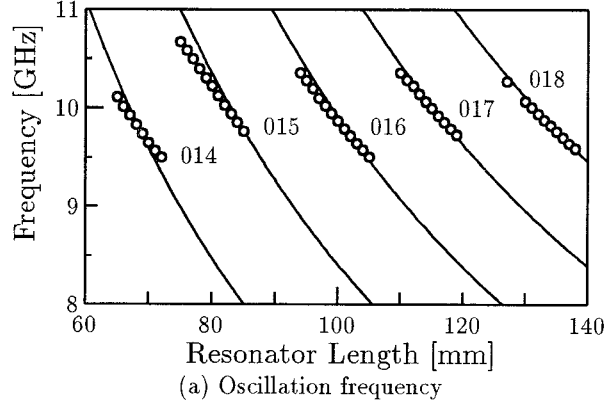


Fig.7 Experimental result when both mirrors were mounted with twelve diodes and  $r_{gp} = r_{gc} = 34$ [mm].

## CONCLUSION

We investigated axially symmetrical Fabry-Perot oscillators which have circular grooves mounted with active devices on the plane mirror or/and the concave mirror in order to combine the output powers of many more devices. The essential features of the oscillator presented in this paper are as follows. By using the axially symmetrical  $TEM_{01n}$  mode, uniform device-field coupling required for high combining efficiency can be realized. The coupling of the resonator to the output line can be strong by installing the output window on the plane mirror. Active devices can be mounted on the concave mirror due to axial symmetry of the structure. Then,

the number of the devices can be increased easily by mounting devices on both the mirrors. By numerical calculation using the boundary element method, it was shown that high combining efficiency is expected when the circular groove of larger radius is installed on either the concave mirror or the plane mirror. By experiments at X-band, power combining efficiency as high as 90% was attained for the case twelve devices on either of the mirrors and almost perfect power combining was accomplished for the case of mounting twenty or twenty-four devices on both the mirrors. Power combining in millimeter-wave frequency range is a future subject.

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