A 94-GHz OVERMODED WAVEGUIDE OSCILLATOR WITH GUNN DIODES

Jongsuck Bae, Masayuki Fujita, and Koji Mizuno

Research Institute of Electrical Communication, Tohoku University,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

Abstract **- Spatial power combining of Gunn diodes with an efficiency of more than 80 % has been demonstrated at W-band using an overmoded waveguide resonator with an array of TE_{10}-mode waveguides. This resonator makes use of selective coupling between an *mxn* TE_{10} modes in the waveguide Gunn diode array and the TE_{m0} mode in the overmoded waveguide to produce high power. An efficiency of 84 % and an output power of about 0.23 W at 94 GHz, has been achieved using three Gunn diodes. The output mode of TE_{30} in the oscillator has been converted to the fundamental TE_{10} mode with an efficiency of about 80 % using an oversized waveguide with an *H*-corner.**

I. INTRODUCTION

Spatial power combining of solid state devices is a potential technique to produce coherent and intense millimeter waves, particularly at higher frequencies above 90 GHz [1-2]. So far, various power combiners with an output power of more than 1 W have been demonstrated by many authors [3-5]. Their operation, however, still remain at frequencies below 60 GHz. In order to achieve highly efficient spatial power combining at short millimeter wavelengths, an overmoded waveguide resonator has been developed [6].

The overmoded waveguide resonator incorporates an array of fundamental-mode (TE_{10}) waveguides containing Gunn diodes, inside of an overmoded-waveguide resonator (refer to Fig. 1). The *mxn* TE_{10}-modes in the waveguide array are converted to the TE_{m0}-mode in the overmoded waveguide through the horn couplers with a theoretical efficiency of 100 %. Radiation power from the Gunn diodes thus are combined efficiently in the resonator. The waveguide-based resonator provides a large heat sink for the Gunn diodes, and allows the diodes to stably operate in CW. Those features in the overmoded waveguide oscillator were demonstrated using nine Gunn diodes at 60 GHz [6].

The overmoded-waveguide resonator structure has been applied to W-band Gunn diodes. An efficiency of more than 85 % and an output power of 0.23 W (CW) at 94 GHz with a 3x1 waveguide Gunn diode array, has been achieved. An output mode of TE_{30} in the oscillator has been converted to the fundamental mode (TE_{10}) by using waveguide techniques with an efficiency of about 80 %. In this paper, the theoretical and experimental results for the *W*-band overmoded waveguide oscillator are presented.

II. EXPERIMENTAL SETUP

Figure 2 shows the experimental configuration of an overmoded-waveguide oscillator with three Gunn diodes for operation around 94 GHz. The standard packaged Gunn diodes used are of InP-type and the rated output power is 90 mW at 94 GHz. The TE_{10}-mode rectangular waveguides with a circularly tapered height have a total length of 30 mm and a cross section of 2.7 mm x 8.1 mm. The reduced heights are 0.8 mm. The three waveguides were separated by phosphor bronze plates with a thickness of 50 µm. The cross section of the overmoded waveguide is 8.1 mm x 8.2 mm. This small waveguide decreases the numbers of both longitudinal and transverse modes in the resonator, improving oscillation stability and widening a tuning frequency range. The oscillation frequencies and output power for the oscillator were measured using a *W*-band standard horn antenna connected to a *HP* spectrum analyzer and a power meter.

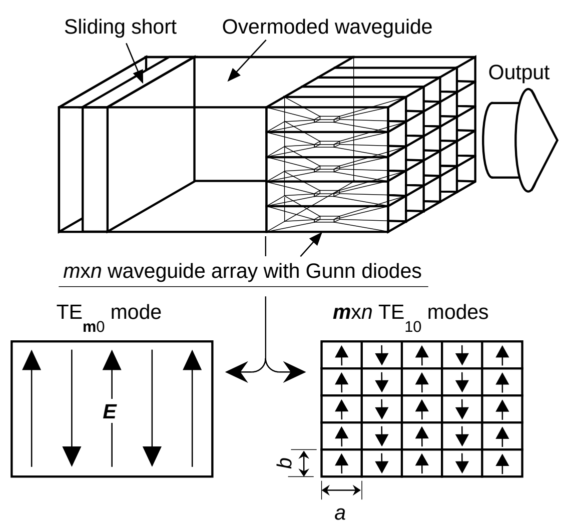

Fig. 1 Configuration of the overmoded-waveguide oscillator with Gunn diodes, and mode conversion between a mxn TE_{10} mode array and the TE_{m0} mode in the overmoded-waveguide resonator.

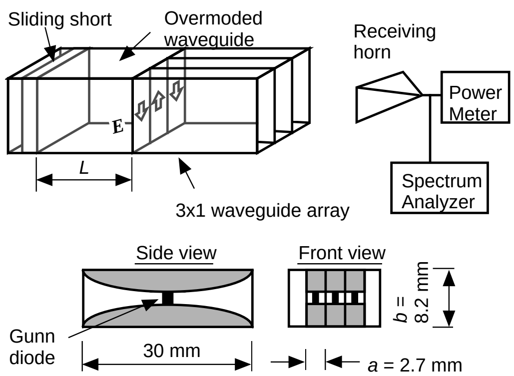

Fig. 2 Experimental setup.

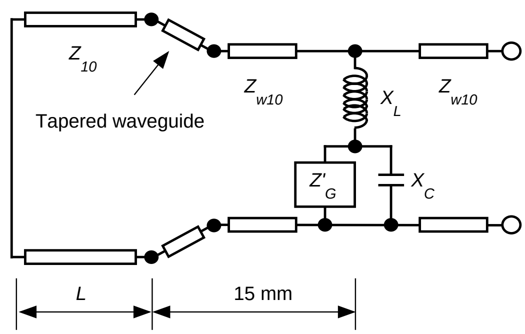

Fig. 3 Equivalent circuit for the overmoded-waveguide oscillator.

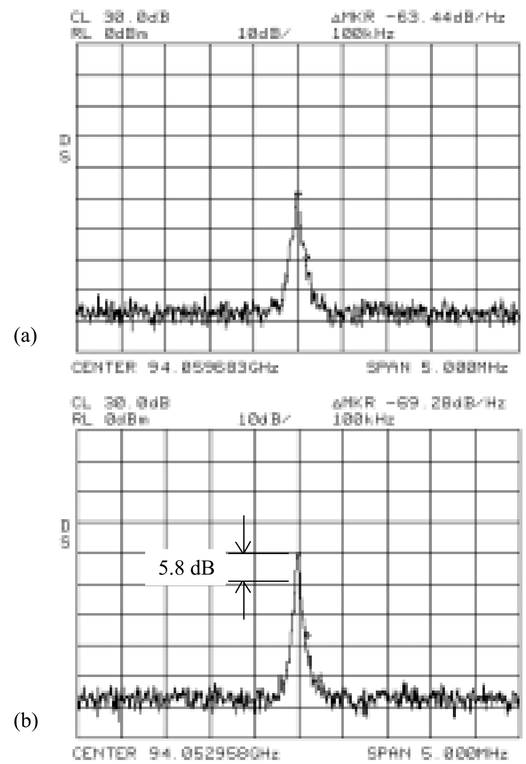

Fig. 4 Measured frequency spectrum of the overmoded-waveguide oscillators with (a) one Gunn diode and (b) three diodes at 94 GHz.

The overmoded waveguide oscillator has been designed using an equivalent circuit shown in Fig. 3. The overmoded waveguide acts as a TE_{10} mode transmission line because the propagation constant matches that of the TE_{10}-waveguides in the array. In Fig. 3, Z_{10} and Z_{w10} are the characteristic impedance of the TE_{10}-waveguides, and X_L and X_C are reactances of a bias post which are calculated using the induced EMF method [7].

III. Oscillation characteristics

A. Oscillation spectrum

Figure 4 compares the measured frequency spectra for the oscillators with (a) one and (b) three Gunn diodes at 94 GHz. The measured C/N ratio for the oscillator with three diodes is 69 dBc/Hz at a 100 kHz offset which is compared to 63 dBc/Hz measured for that with one diode. The C/N ratio reduction indicates that power from the three diodes has been successfully combined coherently in the overmoded waveguide resonator.

B. TE_{30} oscillation mode

From the operation principle of the overmoded waveguide oscillator, the oscillation mode is determined by the number, m, of the TE_{10}-waveguides in H-plane. For m=3, the oscillation mode thus is TE_{30}. This theoretical prediction has been verified comparing calculated and measured radiation patterns from the output waveguide in the oscillator at 94 GHz, and the results are shown in Fig. 5.

C. Output frequency and power

Figure 6 shows the measured frequencies (a), and corresponding total output power for the oscillator in the TE_{30} mode (b), as a function of the length, L, between the waveguide array and the sliding short. The total output power of the oscillator was estimated from the power detected by the W-band standard horn antenna and the theoretical radiation patterns for the TE_{30} mode shown in Fig. 5.

The solid lines indicate theoretical frequencies calculated using the equivalent circuit shown in Fig. 3. The measured tuning frequency range is 3.4 GHz (3.6 %) about a center frequency of 94 GHz. It should be noted that this tuning range is wider than conventional circuit combiners [8]. The maximum output power is 227 mW at 93.8 GHz, demon-

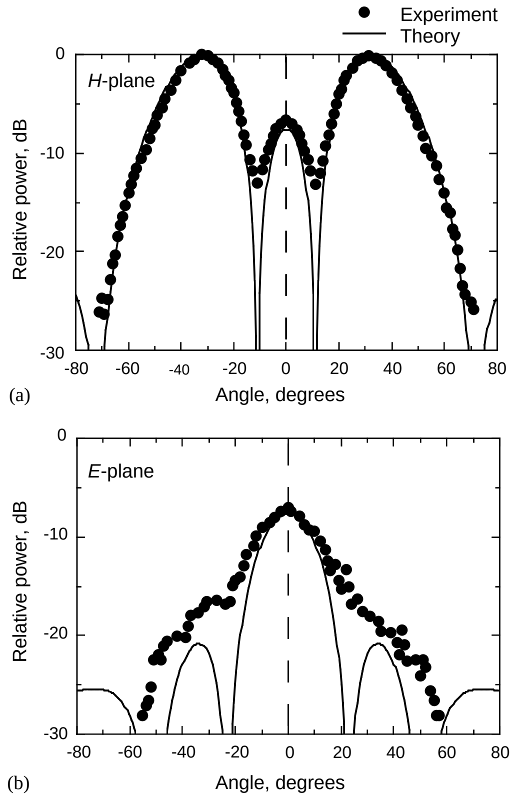

Fig. 5 Measured and theoretical (a) *H*- and (b) *E*-plane patterns of the output beam from the overmoded-waveguide oscillator in the TE_{30} mode at 94 GHz.

strating a power combining efficiency of about 84 %. Higher output power could be obtained by simply increasing the number of the diode arrays in the oscillator.

IV. Mode conversion

The output mode of TE_{30} in the oscillator has been converted to the fundamental mode using an oversized waveguide with a corner in *H*-plane (*H*-corner) [9]. In Fig. 7, the *H*-corner waveguide with an angel θ=36°, and a width, *A*=13 mm, changes the direction of wave propagation in the TE_{30}-mode, converting to a quasi-plane wave. This wave comprises the modes from TE_{10} to TE_{80} in the oversized waveguide with *A*=13 mm. The tapered waveguide extracts the TE_{10} mode from those modes.

The fractional power of the TE_{10} mode in the mode converter for various frequencies has been estimated through simulation in *HP- HFSS*™. The results are shown in Fig. 8. It has been found that the quasi-plane wave delivers about 80 % of input power in the TE_{30} mode to that in the TE_{10} mode at the frequencies between 92 GHz and 96 GHz.

The mode converter have been fabricated and tested to verify the theory. From the experiments, it has been found

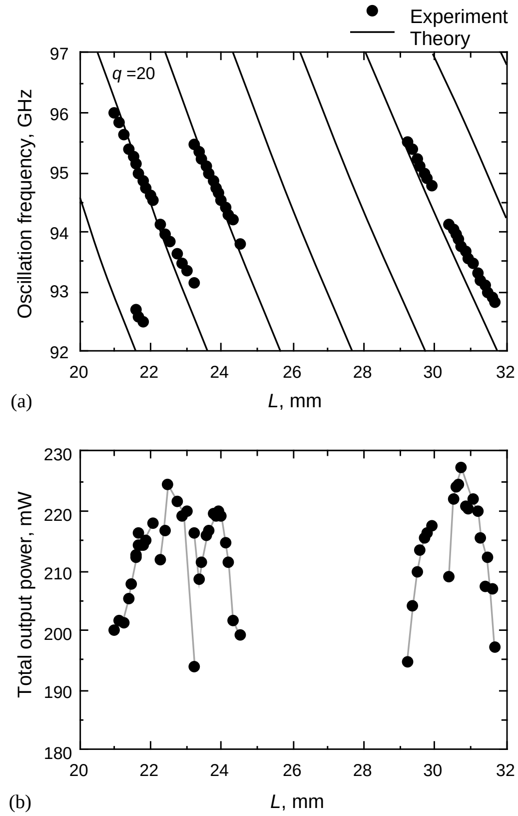

Fig. 6 Measured oscillation frequency (a), and total output power (b), in the overmoded-waveguide oscillator operating in the TE_{30} mode as a function of *L*. In the figure, *q* is the longitudinal mode number determined by the resonator length, *L*+15mm.

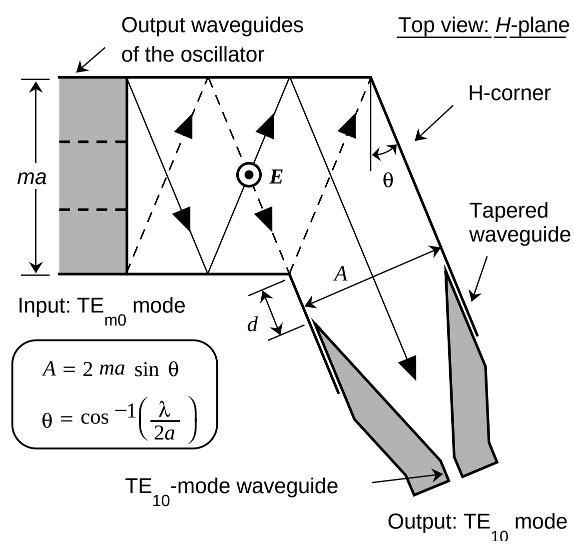

Fig. 7 Schematic drawing of the mode-converter with a corner in the *H*-plane. In the figure, *a* is the width of the output TE_{10}-waveguide in the overmoded waveguide oscillator, λ is the wavelength, *m* is the array number in the *H*-plane, and *d* is the spacing between the corner and the tapered waveguide.

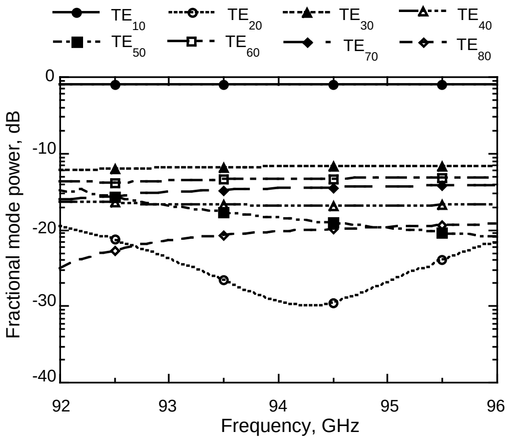

Fig. 8 Calculated fractional mode power for the TE-modes between TE_{10} and TE_{80} in the *H*-corner waveguide as a function of the frequency.

that the oscillation frequency has not been adjusted by the sliding short any longer, but been determined by the position, *d*, of the tapered waveguide in the mode converter. This could be due to the reflection of about 20 % of the input power from the tapered waveguide. In this case, the sliding short in the oscillator has acted as a tuning stub for the output power.

Figure 9 shows the measured maximum power from the output TE_{10}-mode waveguide in the mode converter as a function of the frequency. The oscillation frequencies were adjusted by changing *d* from zero to 2 mm. The average power is about 162 mW at the frequencies around 94 GHz. The maximum power is 197 mW at 93.9 GHz which corresponds to an overall power combining efficiency of 73 %. These results indicate that the *H*-corner waveguide can convert the output mode in the overmoded waveguide oscillator to the fundamental mode with a high conversion efficiency, as predicted by the theory. This type of mode converter is suitable for the overmoded waveguide oscillator because of its simple structure and high conversion efficiency in the wider frequency range.

V. Conclusion

We have demonstrated the use of a compact overmoded-waveguide resonator with a fundamental-mode waveguide array, as a coherent power combiner with Gunn diodes at *W*-band. An overmoded waveguide oscillator with three Gunn diodes was used to produce about 0.23 W of CW output power, with a combining efficiency of 84 % for operating frequencies around 94 GHz. The output mode (TE_{30}) in the overmoded waveguide oscillator has been converted to the fundamental mode (TE_{10}) using an oversized *H*-corner as an output waveguide. The overall power combining efficiency

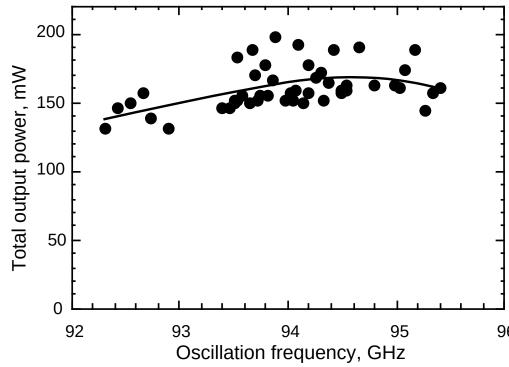

Fig. 9 Measured maximum power from the output of the mode converter connected to the overmoded waveguide oscillator as a function of the frequency.

of about 70% in the oscillator with the mode converter has been also achieved. The overmoded waveguide oscillator is quite compact and its dimensions are only 8.1 mm x 8.2 mm x 50 mm. Those results show that the overmoded waveguide oscillator is a practical high power source at short-millimeter wavelengths.

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