SPATIAL POWER COMBINING OF GUNN DIODES USING AN OVERMODED WAVEGUIDE RESONATOR AT MILLIMETER WAVELENGTHS

Jongsuck Bae[†‡], Takanori Uno[†], Tetsu Fujii[†‡], and Koji Mizuno[†‡]

[†]*Research Institute of Electrical Communication, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan.*
[‡]*Photodynamics Research Center, The Institute of Physical and Chemical Research, 19-1399 Aza-Koeji, Nagamachi, Aoba-ku, Sendai 980, Japan.*

ABSTRACT

An oscillator which incorporates an overmoded-waveguide resonator with an array of TE_{10}-mode waveguides containing Gunn diodes, has been developed as a means for achieving highly efficient spatial power combing. This oscillator makes use of mode conversion of radiation power from Gunn diodes in the waveguide array to the overmoded-waveguide resonator, to produce high power at millimeter wavelengths. An efficiency of about 83 % and an output power of 1.5 W (CW) at 61.4 GHz, has been achieved with a 3x3 waveguide Gunn diode array.

INTRODUCTION

Quasi-optical solid-state power combining has generated a great deal of interest as a means of producing a high power source at millimeter and submillimeter wavelengths [1]-[3]. Two-terminal devices such as Gunn and IMPATT diodes can be used to produce several tens of mW, even at frequencies above 100 GHz. Thus combining power from twenty of these diodes or less could produce enough rf-power for many practical applications at millimeter wavelengths.

In conventional quasi-optical resonators, a diode array with a small radiation area will produce strongly diffracted beams within the resonator, which results in a large rf loss. Closed resonators however, can maintain coherent, confined beams, and thus provide a more suitable means for combining power from small numbers of diodes. We have developed a new waveguide power combiner, which incorporates an array of fundamental-mode waveguides with Gunn diodes, inside of an overmoded-waveguide resonator, in order to avoid diffraction losses. In this paper, theoretical and experimental results obtained at millimeter wavelengths are reported to show the feasibility of the overmoded-waveguide power combiner.

RESONATOR CONFIGURATION

Figure 1 shows the configuration of an overmoded-waveguide oscillator with diode devices. The oscillator consists of an *N*x*M* array of fundamental-mode (TE_{10}) waveguides with pyramidal horn couplers at both ends, a metal overmoded waveguide with a cross section of greater than an operating wavelength, and a sliding short. The diode devices, in our case Gunn diodes, are mounted at the center of the TE_{10}-mode waveguides and are biased by a dc-power supply through a insulated metal post [4]. This resonator configuration allows the oscillator to operate in a single mode even though an overmoded-waveguide is used as a resonator. Referring

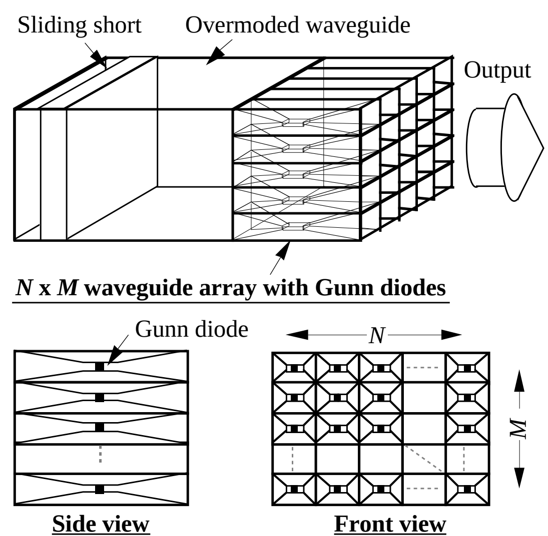

Fig. 1 Configuration of the overmoded-waveguide oscillator with Gunn diodes.

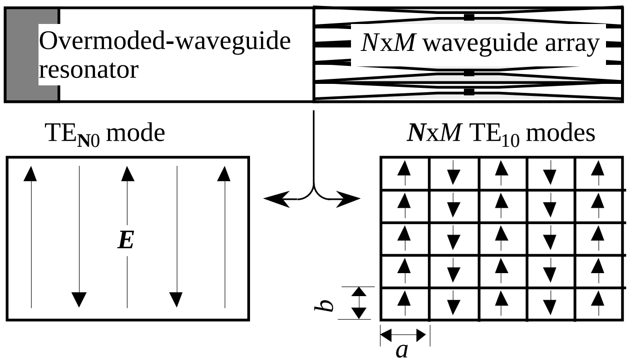

Fig. 2 Mode conversion between a *N*x*M* TE_{10} mode array and the TE_{30} mode in the overmoded-waveguide resonator.

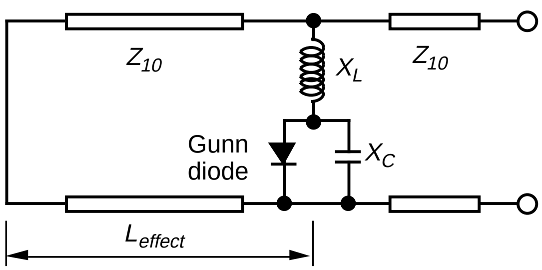

Fig. 3 The equivalent circuit for the overmoded-waveguide oscillator.

to Fig. 2, the ***N***x*M* TE_{10}-mode array transfers energy selectively to a TE_{N0}-mode in the overmoded waveguide through the horn couplers with conversion efficiency of 100 %, because their electric and magnetic fields at the boundary between the horn array and overmoded waveguide are exactly the same. The other modes in the overmoded waveguide, such as the TE_{10} mode, are strongly suppressed by the TE_{10}-waveguide array, because their mode conversion efficiencies are very low compared to that for the TE_{N0} mode.

The overmoded-waveguide resonator not only improves efficiency, but also provides a large heat sink for the Gunn diodes, which have a low dc-rf conversion efficiency of 6% or less. Therefore, the overmoded-waveguide power combiners can be used to achieve high output power with high combining efficiency at millimeter wavelengths.

EQUIVALENT CIRCUIT

Figure 3 shows the equivalent circuit developed for the overmoded-waveguide oscillator. When the oscillation mode in the resonator is TE_{N0}, the propagation constant in the overmoded waveguide

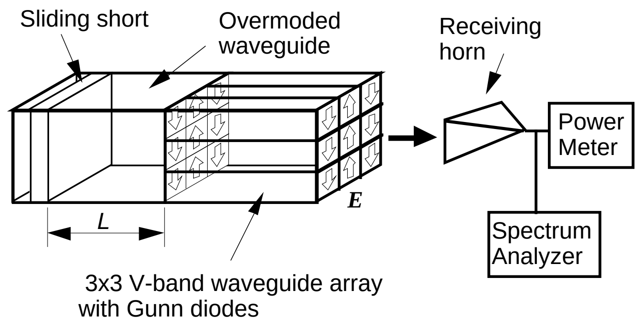

Fig. 4 Experimental setup.

matches that of the TE_{10}-waveguide formed by the horn aperture. The attenuation constants do differ: in the overmoded waveguide the attenuation constant is decreased by $1/N$ times compared to that in the TE_{10}-waveguide. The overmoded-waveguide resonator acts as a TE_{10}-waveguide with a smaller propagation loss. Consequently, we can apply the same equivalent circuit design techniques used for conventional waveguide resonators containing Gunn diodes. In Fig. 3, L_{effect} is an effective resonator length between the Gunn diode and sliding short, Z_{10} is the characteristic impedance of the TE_{10}-waveguide, and X_L and X_C are reactances of the bias post which are calculated using the induced EMF method [5].

EXPERIMENTAL SETUP

Figure 4 shows the experimental configuration of an overmoded-waveguide oscillator with a 3x3 array of Gunn diodes, for operation around 60 GHz. The Gunn diodes used are of InP-type, Japan Energy Co., NT-V140, and have a maximum rated output power of 200 mW in CW at 60 GHz. The TE_{10}-waveguides have a total length of 80 mm and inner dimensions of 3.76 mm x 1.2 mm. The pyramidal horns have square apertures with dimensions of a=b=15 mm (see Fig. 2), and the length which was chosen as 35 mm to obtain a power reflection coefficient of less than $2x10^{-3}$, for the TE_{10} mode at 60 GHz. The cross section for the overmoded-waveguide is 45 mm x 45 mm, which allows it to contain 3x3 TE_{10}-mode waveguides. The circular metal posts used to supply dc-bias to the diodes have a diameter of 1.8 mm. The oscillation frequencies and output power for the oscillator were measured using a V-band standard horn connected to a spectrum analyzer (HP-8563A) and a power meter(Anritsu Co., MP716A and ML4803A). The receiving V-band horn was placed

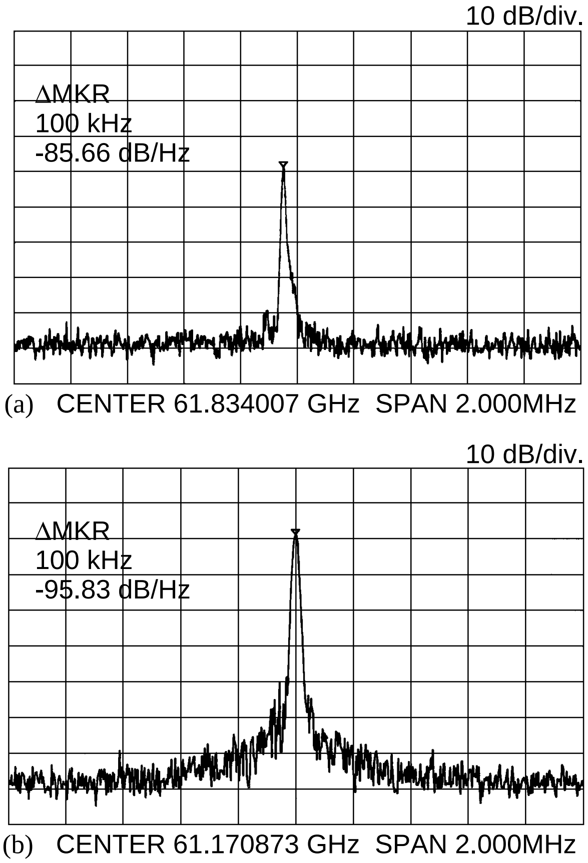

Fig. 5 Measured frequency spectra of the overmoded-waveguide oscillator with a single Gunn diode (a), and nine diodes (b).

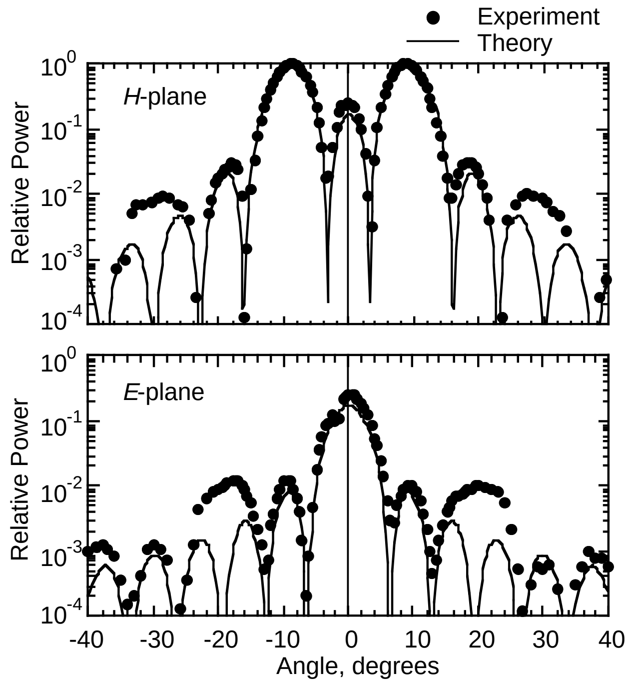

Fig. 6 Measured *E*- and *H*-plane patterns of the output beam from the overmoded-waveguide oscillator at 61 GHz. The radiation angles are measured from the center of the surface of the output horn antenna array.

at a distance of 1.3 m from the horn antenna array in the oscillator.

MEASURED RESULTS

Figure 5 compares the measured frequency spectra for the overmoded-waveguide oscillators with a single Gunn diode (a), and nine diodes (b), at operating frequencies near 61 GHz. For the oscillator with the single diode in Fig. 5 (a), a C/N ratio of -85.7 dBc/Hz at 100 kHz offset was measured at the operating frequency of 61.8 GHz. In comparison, a C/N ratio of -95.8 dBc/Hz was obtained for the oscillator containing nine Gunn diodes operating at 61.2 GHz, as shown in Fig. 5 (b). The C/N ratio reduction indicates that power from the 9 diodes was successfully combined coherently in the overmoded-waveguide resonator.

In order to confirm the TE_{30} oscillation mode, radiation patterns from the output horn array were measured. The measured radiation patterns for *H*- and *E*-planes are shown in Fig. 6. The oscillation frequency was 61 GHz. The solid curves indicate the theoretical radiation patterns for the TE_{30} oscillation mode. The measured and theoretical powers are normalized to the peak power at an angle of 9 degrees. The theoretical radiation patterns give good agreement with the measured patterns, except at powers of less than -20 dB, and at angles beyond ±30 degrees for the *H*-plane and ±20 degrees for the *E*-plane. These deviations from theory are consistent with slight differences in the actual horns from ideal TE_{10}-mode horns. The results are sufficient to show that the oscillation mode in the overmoded-waveguide oscillator is TE_{30}.

The total output power of the oscillator was estimated from the power detected by the V-band standard horn and the theoretical radiation patterns for the TE_{30} mode. For estimation of the total power, the antenna gain (23.3 dB at 61 GHz) of the receiving V-band horn was taken into account. The difference between the theoretical and measured radiation patterns in Fig. 6 was ignored, as it only accounted for a 3 % underestimation of total power. In Fig. 6, the detected power at 9 degrees was 13 mW, which was estimated to correspond to a total output power of 1.42 W.

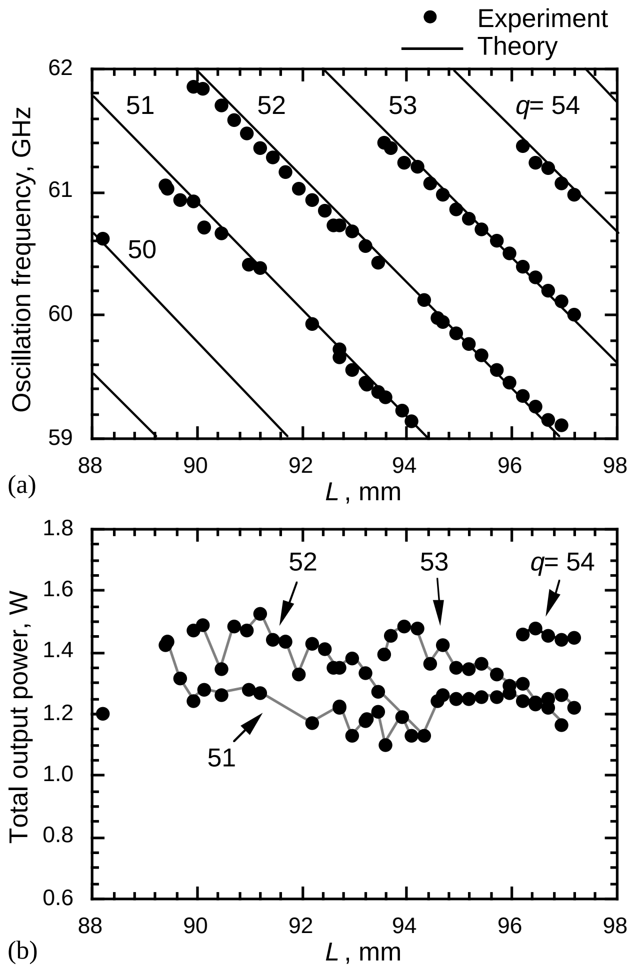

Fig. 7 Measured oscillation frequency (a), and total output power (b), in the overmoded-waveguide oscillator operating in the TE_{30} mode as a function of the length, *L*, between the horn coupler and sliding short. In the figure, *q* is the longitudinal mode number determined by L_{effect}, corresponding to *L*.

Figure 7 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 horn array and sliding short. The solid lines indicate theoretical frequencies calculated using the equivalent circuit shown in Fig. 2. In Fig. 7, *q* is the longitudinal mode number determined by the effective resonator length, L_{effect}, corresponding to *L*.

In Fig. 7 (a), the theoretical frequencies agree with measurements, within about 0.3 %. The measured tuning frequency range is about 2.8 GHz (4.6 %) about a center frequency of 60 GHz. The total output power is larger than 1 W for all frequencies measured between 59 GHz and 62 GHz. The maximum output power is 1.5 W at 61.4 GHz, demonstrating a power combining efficiency of about 83 %. It should be noted that the TE_{30} mode is the dominant oscillation mode in the oscillator. Oscillation in other modes was occasionally observed, but the power for these oscillations was quite small compared to that for the TE_{30} mode. The TE_{30} mode can be converted to TE_{10} through waveguide circuit techniques, if needed for specific applications.

CONCLUSION

We have demonstrated the use of an overmoded-waveguide resonator with a fundamental-mode waveguide array, as a coherent power combiner with millimeter wave solid state devices. An overmoded-waveguide oscillator with nine Gunn diodes was used to produce 1.5 W of CW output power, with a combining efficiency of 83 % and a C/N ratio of -95 dBc/Hz at a 100 kHz offset for operating frequencies near 60 GHz. These results show that this type of oscillator is useful as a high power millimeter wave source.

ACKNOWLEDGMENT

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