DIELECTRIC LOADED GAUSSIAN BEAM OSCILLATOR IN THE 40 GHZ BAND

Masahiro Kiyokawa , Toshiaki Matsui and Nobumitsu Hirose

Communications Research Laboratory, Ministry of Posts and Telecomm.
Koganei-shi, Tokyo 184, Japan

ABSTRACT

A 40-GHz Gaussian output-beam oscillator, using a Gaussian-beam open resonator filled with a dielectric, is described. The dielectric resonator has a highly reflective convex spherical surface and a plane mirror surface having a coupling section with an active circuit. The circuit is fabricated using a commercial HEMT chip. The phase noise of -90 dBc/Hz at 100 kHz off carrier is expected. The output power is extracted as a Gaussian beam.

INTRODUCTION

Millimeter-wave applications for sensing and communication systems have recently been important. In Japan, R&D for a wireless LAN in the 60-GHz band has become active. For such systems, a highly stable millimeter-wave source with a low phase noise is necessary. A DRO has been used for this purpose[1]. The other important factor for millimeter-wave high-speed communication systems is considered to be using a direct propagation in order to avoid influences by multipath propagation. As one promising method to satisfy these requirements simultaneously, we have developed a Gaussian output-beam oscillator (GBO) [2] using a new Fabry-Perot resonator [3], and carried out experimental validity from an X-band prototype. This features extracting highly stable output power directly as a Gaussian beam. The use of a Fabry-Perot resonator with a partially transparent spherical mirror was proposed for power combining [4], and experiments were made for a quasi-optical power combining [5], [6]. While, our oscillator features that a high reflectivity of the spherical mirror, designed within over 99%, results in a low phase noise of the oscillator with only one oscillating source. Moreover, this also features a configuration with an active circuit behind the resonator, which is powerful for constituting a transmitter. In this paper, a dielectric loaded GBO using MIC in the 40 GHz band is fabricated in order to achieve higher stability.

OSCILLATOR CONFIGURATION

The configuration of the dielectric loaded GBO (DL-GBO) is shown in Fig. 1. It uses a dielectric material with a low tan δ, which is machined so as to have a convex spherical surface and a plane surface. For stability to the ambient temperature, a material with a small thermal expansion coefficient should be selected; in this experiment fused quartz (ε_r=3.8) was used. The diameter and the radius of curvature were designed to be 30 mm and 690 mm, respectively, by considering the beam radii for 40 GHz. The distance between the surfaces, or the thickness of the dielectric at the center, is almost equal to $\lambda g/2$ to form a quasi-planar structure. Copper film was sputtered on both surfaces. To realize a highly reflective, partially transparent region, a metal stripe pattern was formed by photolithography process on a circular area, 24 mm in diameter, in the center of the spherical surface. The photo is shown in Fig. 2. Both grid parameters, d and d', were 0.25 mm. Then, the reflectivity for the

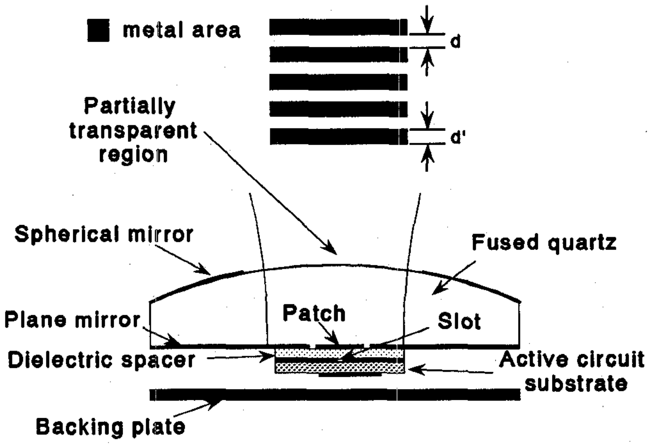

Fig. 1. Cross-section of the DL-GBO and a top view of a stripe pattern for a partially transparent region.

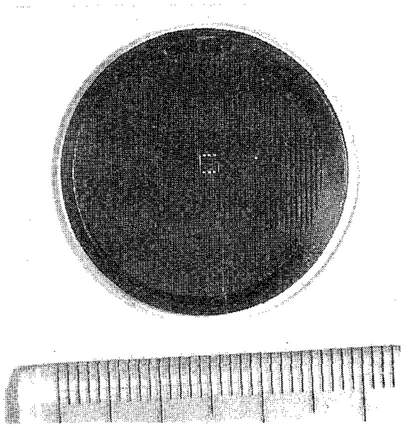

Fig. 2. Photo of the dielectric loaded Gaussian beam resonator made of fused quartz.

electromagnetic wave polarized to the stripe direction is 99.5%. The output power is extracted from this area as a TEM_{00q} mode Gaussian beam polarized to the stripe direction. In the center of the plane mirror surface, a coupling section was fabricated, and an active circuit was electromagnetically coupled to the resonator through this section. The active circuit, fabricated on the other substrate with a higher dielectric constant and a smaller size, is attached to the resonator plane surface, with a dielectric spacer sandwiched between them. A backing plate was placed $\lambda g/4$ off the circuit substrate so that the radiation from the coupling section be only the resonator side.

COUPLING SECTION AND CIRCUIT DESIGN

The structure that the active circuit is outside the resonator enables a usual oscillator design approach. For stable millimeter-wave oscillators, a tight coupling between the resonator and the circuit is necessary. While, the short condition at detuned frequencies is also necessary for the band rejection type topology which is commonly used for DRO. As a coupling section, satisfying these conditions, we used a rectangular patch overcoupled by a slot, as shown in Fig. 3 [7]. The rectangular patch was fabricated in the center of the plane surface and a slot on the rear side of the circuit substrate. The slot length, L , was designed to be almost the same as the patch size, a. For a tight coupling condition, L, and the patch length, a, should be selected to be close to $\lambda g/2$. Parameters of a, b, and L were 1.67 mm, 1.67 mm, and 1.29 mm, respectively.

The equivalent circuit of the GBO is shown in Fig. 4. The circuit topology is a negative resistance oscillator

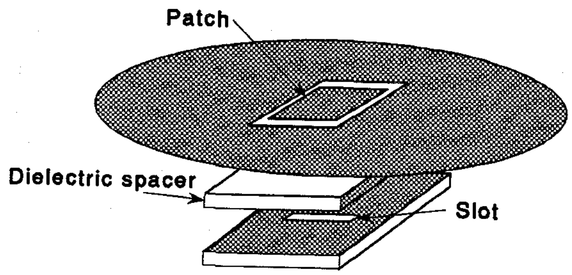

Fig. 3. A detail of the coupling section between the active circuit and the resonator.

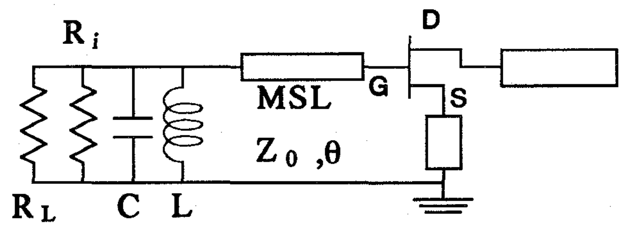

Fig. 4. Equivalent circuit of the DL-GBO.

with a band transmission type resonator. The negative resistance is obtained by common source operation and series feedback using an open-ended microstrip line (MSL) placed at the drain side. The slot with a $\lambda g/4$ open stub was fabricated at the gate side, $\lambda g/4$ apart from the gate. As a device, a HEMT chip, FHR20X, manufactured by Fujitsu was used, whose gate length and the gate width are 0.15 µm and 100 µm, respectively. The chip was mounted on a 0.3-mm Alumina substrate, and for wire bonding, a 20-µm gold wire was used. The circuit was designed by Libra from EEsof using small signal S-parameter data up to 30 GHz. For higher frequencies, extrapolated values were used.

EXPERIMENTAL RESULTS

Prior to an oscillator experiment, the characteristics of the dielectric loaded Fabry-Perot was investigated. A substrate including a slot and a MSL was used for feeding through the coupling section. Figure 5 shows a result of the impedance seen from the edge of the MSL. The characteristics are according to the design; the resonance appeares on the background due to a rectangular patch overcoupled by a slot.

The output frequency spectrum of the oscillator was measured with a horn antenna. An example of the results for the 40-GHz GBO is shown in Fig. 6, where the device was biased at V_{ds} = 1.1 V and I_{ds} = 3.5 mA. In

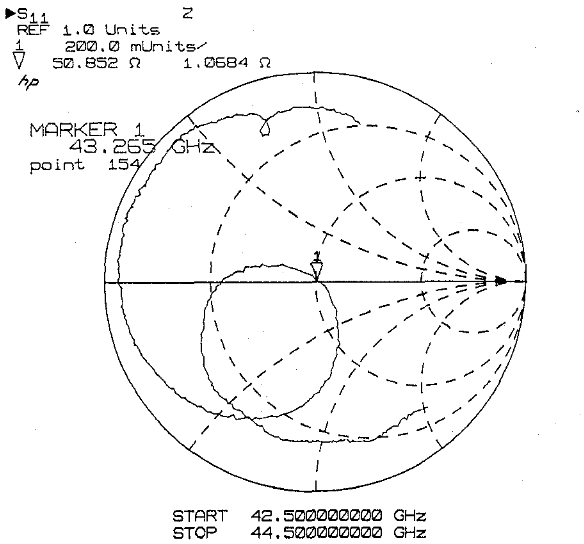

Fig. 5. Resonance characteristics of the DL-GBO.

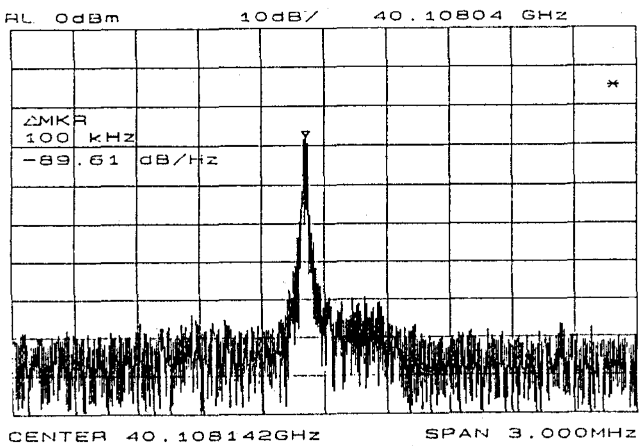

Fig. 6. Spectrum of the 40-GHz GBO for q = 1. Res. BW= 30 kHz. Hor. div. = 300 kHz. Vert. div. = 10 dB.

this case, the spherical and the plane mirrors were supported independently and the reflectivity of the spherical mirror was over 99.8%. The phase noise was measured to be -90 dBc/Hz at 100 kHz off carrier. While, the phase noise for the DL-GBO was -103 dBc/Hz at 1 MHz off carrier, which was better than that of a free running oscillator by 22 dB. Instantaneous frequency stability was improved compared to the case of the previous structure.

The unloaded Q as a radiating resonator, Q_0', which includes the loss due to the metal stripe region, was measured to be 660 by using a reflection-type method. While, the theoretical unloaded Q of an empty resonator,

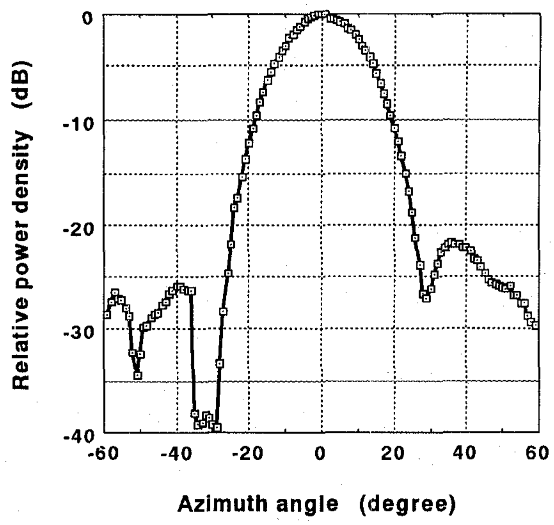

Fig. 7. Output radiation power pattern for H-plane.

Q_0, due only to the ohmic loss of the metal surface, is 5600. The rather small value of Q_0', compared with Q_0, is caused by the fact that both the loss due to the metal stripe region and the dielectric loss of the fused quartz are larger than the loss due to the ohmic loss. Therefore, the resonator characteristics seen from the coupling section side was not in an enough overcoupling condition, as shown in Fig. 5. For oscillator stability to the ambient temperature, the active circuit must be overcoupled with a high Q resonator which is stable to the temperature.

The output radiation pattern of the DL-GBO in the far-field region was measured using a precision rotating stage for optical use. As shown in Fig.7, a Gaussian-beam profile was observed.

CONCLUSION

A 40-GHz dielectric loaded Gaussian-beam oscillator was fabricated using a HEMT chip with a 0.15 μm gate length. The configuration is suitable for monolithic integration, and is applicable to a compact size transmitter. The feature as a Gaussian-beam oscillator was verified also for DL-GBO. At present, due to the insufficient reflectivity of the metal stripe region and the dielectric loss of the fused quartz, the phase noise of DL-GBO remains to be improved. However, a phase noise of -90 dBc/Hz at a frequency off carrier of 100 kHz is expected. The metal region is being altered to have a reflectivity of over 99.8%. Waterfree synthesized quartz, that is much less absorbing, is under preparation in order to achieve lower phase noise. The band rejection type circuit topology is under development.

REFERENCES

[1] U. Guttich and J. Wengler, "Design, fabrication, PM- HEMT oscillators up to 60 GHz," in 24th European Microwave Conf. Proc. pp. 361-365, 1994.

[2] M. Kiyokawa and T. Matsui, "A new quasi-optical oscillator with Gaussian output beam," *IEEE Microwave and Guided Wave Letter,* vol. 4, no. 5, pp. 129-131, May 1994.

[3] T. Matsui, K. Araki, and M. Kiyokawa, "Gaussian-beam open resonator with highly reflective circular coupling region," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-41, pp. 1710-1714, Oct. 1993.

[4] J. W. Mink, "Quasi-optical power combining of solid-state millimeter-wave sources," *IEEE Trans. Microwave Theory Tech.,* vol. MTT-34, pp. 273-279, Feb. 1986.

[5] J. C. Wiltse and J. W. Mink, "Quasi-optical power combining of solid-state sources," *Microwave J.,* vol. 35, no. 2, pp. 144-156, Feb. 1992.

[6] Z. B. Popovic, M. Kim, and D. B. Rutledge, "Grid oscillators," *Int. J. Infrared and Millimeter Waves*, vol. 9, no. 7, pp. 647-654, July 1988.

[7] M. Kiyokawa and T. Matsui, "40-GHz Gaussian beam oscillator," to be submitted to *IEEE Microwave and Guided Wave Letter,* .