A New Quasi-Optical Oscillator With Gaussian Output Beam

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Abstract— **An oscillator with a new quasi-optical resonator, called a Gaussian-beam oscillator, is described. The resonator consisits of a plane mirror substrate and a concave spherical mirror with a highly reflective, partially transparent region. A high Q factor, obtained by this spherical mirror, results in a low phase noise of the oscillator and the output power is extracted from this region as a Gaussian beam. This oscillator also features an active circuit fabricated behind the resonator. The configuration is suitable for millimeter-wave integrated circuits. Experimental validity is carried out from an X-band prototype.**

I. Introduction

Many millimeter-wave solid-state oscillators have recently been developed and used commercially. In most of these, diodes are mounted in a waveguide or a planar integrated circuit with three-terminal devices matched to a waveguide for power output. In millimeter-wave techniques, it is advantageous to extract power directly as a Gaussian beam. An analysis was made for a quasi-optical power combining using a Fabry–Perot resonator with a partially transparent spherical mirror [1]. Since then, a number of investigators have used semi-confocal Fabry–Perot resonators for power combining [2]. However, in these experiments, power is extracted using a waveguide. For beam output, a planar grid oscillator [3] and an oscillator with a Fabry–Perot coupler [4] have been reported. Both of these are based on the parallel-plane configuration and diffraction losses are unavoidable.

In this letter, a Gaussian output-beam oscillator using a new quasi-optical resonator [5] is proposed. Moreover, when integrating an oscillator with other circuits, e. g., modulation or baseband circuits, a configuration with an active circuit behind the resonator is powerful. We used slot coupling for this purpose.

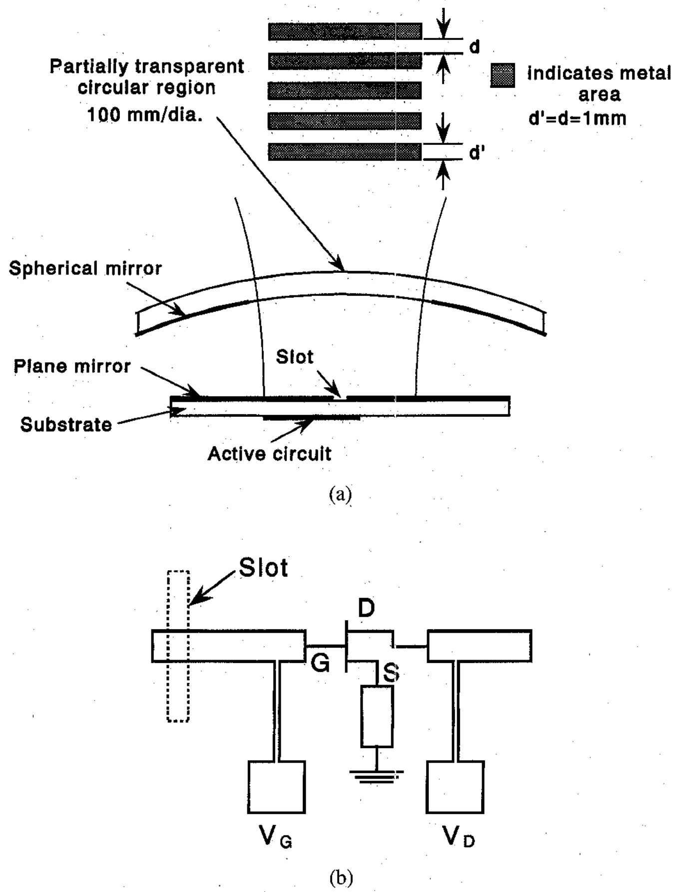

Fig. 1. Configuration of the Gaussian-beam oscillator. (a) Cross-section of the oscillator and a detailed top view of a stripe pattern for a partially transparent region. (b) Active circuit fabricated behind the plane mirror substrate.

II. Oscillator Configuration

The configuration of the Gaussian-beam oscillator is shown in Fig. 1. It uses an open resonator consisting of a plane mirror substrate and a concave spherical mirror with a highly reflective, partially transparent region [5]. To provide coupling, a metal stripe pattern was formed by a photolithography process on a circular area in the center of the spherical mirror (Fig. 1(a)). This area is large relative to the wavelength. The reflectivity of the spherical mirror can be adjusted within high values, which is necessary for the optimization of the oscillator. The output power is extracted from this area as a Gaussian beam, which is the TEM_{00q} mode excited in the resonator, and is polarized to the stripe direction. An active circuit was fabricated behind the plane substrate, and was electromagnetically coupled to the resonator by a slot. The structure is suitable for integration with other circuits. The open resonator acts both as a frequency-determining element and an RF output port. The resonator length, L, is almost equal to $(q+1)\lambda/2$, where q is the longitudinal mode number (q=0,1,2,$\cdots$) and λ is the wavelength for the oscillator frequency. By selecting small numbers of q, a quasi-planar structure can be realized in the millimeter-wave region.

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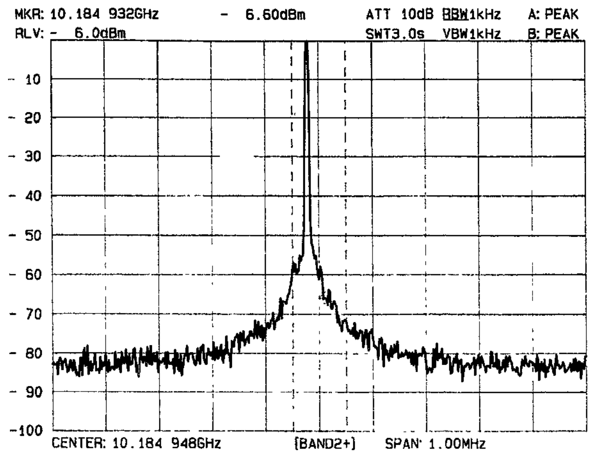

Fig. 2. Spectrum of X-band prototype oscillator (L=74.7 mm). The center frequency is 10.185 GHz. Res. BW=1kHz. Hor. div.=100 kHz. Vert. div.=10 dB. Ref. level=-6dBm.

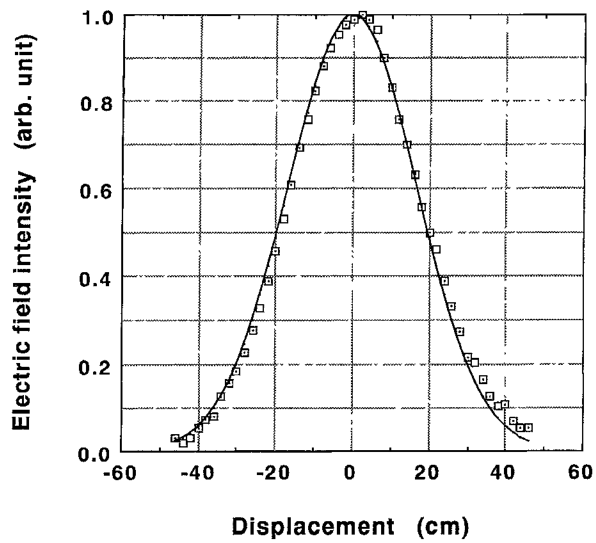

Fig. 3. Output beam pattern of the Gaussian-beam oscillator $fosc$=11.5 GHz and q=2. Squares are the measured data and the solid line is the theoretical curve. The vertical scale is normarized to the maximum value of electric field intensity.

The diameter of the spherical mirror, D_1, and the side of the square substrate, D_2, were designed by considering the beam radiuses. In our X-band prototype, D_1=250 mm and D_2=200 mm. The spherical mirror and the plane substrate were made using a DICLAD board (ϵ_r=2.17) with a thickness of 1.6 mm and 0.8 mm, respectively. The diameter of the partially transparent coupling region is 100 mm. The design of grid parameters, i. e., the metal width, d', and the gap width, d, was performed using the formulas in [6]. Both parameters were determined to be 1 mm. Then, the reflectivity for the electromagnetic wave polarized to the stripe direction is 99.7%. After fabricating the pattern, the substrate was formed into a spherical shape using a mold. An 0.8-mm-thick DICLAD board (ϵ_r=2.17) was used as a plane substrate. The active circuit is a standard reflection-type oscillator using a microstrip line. A packaged HEMT (Fujitsu FHR35LG) was used in common source operation and series feedback (Fig. 1(b)). An open stub was placed at the drain side, and a slot was fabricated at the gate side of the HEMT. The circuit was designed by Touchstone from EEsof using small signal S-parameter data. The open resonator, seen from the slot, behaves as a transmission-type resonator. However, for oscillator design, this should be considered to be a one-port resonator. A tight coupling between the resonator and the circuit should be made for providing stable oscillations [7].

III. Experimental Results

First, using a reflection-type method, we measured a Q factor of a resonator consisting of a spherical mirror and a plane mirror without a slot, which is expressed by Q_0'. The resonator was excited through the coupling region on the spherical mirror feeding from a horn antenna. Q_0' was 10900 for a resonant frequency of 10.2 GHz. The resonator length, L, and the radius of curvature of the spherical mirror, R_0, were calculated by using the frequency separation between adjacent longitudinal modes; L was 74.7 mm ($\sim 2.5\lambda; q = 4$) and R_0 was 1000 mm. The theoretical unloaded Q, Q_0, due only to the ohmic loss of the mirror surface, was 57000. Using this value, the reflectivity of the slit coupling region was calculated to be 0.997. The agreement of this value of reflectivity with the theoretical one given previously suggests that the diffraction loss is considered to be negligible to losses per reflection due to the spherical mirror and the plane mirror.

Then, the loaded Q, Q_L, of the slot-coupled open resonator was measured when excited through the slot from the microstrip line lengthened to the edge of the substrate for launching. Considering this resonator to a one-port resonator, the coupling factor, B, is defined by Q_0'/Q_{exp}, where Q_{exp} is the Q due to the slot coupling. The coupling condition depends on the slot parameters. For a slot of 4.3 mm $\times$ 1.2 mm with an open-stub length, Ls, of 4.4 mm (slot I), Q_L and B were 7300 and 0.49, respectively (undercoupling). While, when using a slot of 8.20 mm $\times$ 1.15 mm (slot II), Q_L was 1550 and β was 6.0. Thus, in this resonator, a slot length of near a half the effective wavelength was necessary for enough overcoupling.

The output frequency spectrum was measured with a horn antenna. The results for the oscillator using a resonator with slot II are shown in Fig. 2. The SSB noise power density was measured to be -104 dBc/Hz at a frequency off carrier of 100 kHz. This low value results from a high reflectivity of the spherical mirror and a negligibly small diffraction loss of the resonator. For lower longitudinal modes (q = 2, 3), almost the same spectra were obtained. By changing the length between the mirrors, the output frequency could be mechanically tuned by over 1 GHz.

The output radiation pattern of the oscillator in the far-field region was measured with a cutoff waveguide probe scanned perpendicularly to the axis of the resonator in a plane distant from the spherical mirror by 1 m. Fig. 3 shows an example of the H-plane pattern for q = 2; the output frequency was 11.5 GHz. The solid line indicates a theoretical Gaussian-beam mode curve at the same position, calculated considering the fundamental mode in the resonator. The observed distribution showed a good agreement with the theoretical results.

IV. Conclusion

A new quasi-optical oscillator was proposed. In an X-band prototype experiment, the output power was extracted as a Gaussian beam with a SSB noise power density of –104 dBc/Hz at a frequency off carrier of 100 kHz. The configuration is suitable for monolithic integration with other circuits to constitute a transmitter. The oscillator for millimeter-wave use, with a few longitudinal mode number, will be a quasi-planar structure. We are now developing this millimeter-wave version.

References

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