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Monolithic 155 GHz and 213 GHz Quasi-Optical Transistor Oscillators

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ABSTRACT

We report on the design and measurement of monolithic 155 GHz and 213 GHz quasi-optical slot antenna transistor oscillators. The oscillators were fabricated by the Hughes Malibu Research Laboratory [1]. The output signals were detected with an interferometer in front of an InSb hot electron bolometer and accurate frequency measurements were obtained by heterodyne detection using a wideband quasi-optical harmonic mixer-receiver. The circuits represent the highest frequencies achieved to date for a fundamental source using a three terminal device.

I. INTRODUCTION

Coplanar waveguide (CPW)-fed quasi-optical slot oscillators have been investigated by Kormanyos et al. [2,3] and Moyer et al. [4]. The uniplanar circuit requires no via holes and is compatible with the monolithic integration of high speed transistors. This allows oscillators to be designed to the highest frequency limit of the device. The oscillator is placed on a dielectric substrate lens for proper operation. The substrate lens simulates an infinite dielectric medium, eliminates power loss to substrate modes, and results in a unidirectional pattern [5]. The antenna impedance in this environment is accurately calculated using the space domain integral equation technique [6], a full wave method of moments approach.

II. OSCILLATOR DESIGN

The transistor used is an AlInAs-GaInAs InP based HEMT fabricated at Hughes Malibu Research Laboratory and described elsewhere [7]. The device employs a self aligned T-gate defined by an electron beam process. The gate length is 0.05μm and the gate width is 10μm. To obtain a small signal model for the 10μm transistor, a larger device with a 50μm gatewidth was built and tested to 40 GHz. A model was extracted and the results mathematically scaled for the smaller 10μm device. The scaled device model for the 10μm device is shown in Fig. 1. Since it was derived from measurements on a 50μm device, a large uncertainty exists in the 10μm device model parameters. The parasitic elements $L_g, L_d, L_s, C_{pgs}, C_{pgd}$, and C_{pds} associated with the extrinsic contact metalizations are known to about ± 5pH or fF which is greater than 100% in most cases. Values of the intrinsic elements $R_{gs}, C_{gs}, R_{gd}, C_{gd}, g_m, \tau, C_{ds}$, and g_{ds} are thought to be accurate to ± 20%. However, DC measurements of the smaller devices indicate that the transconductance is closer to 10mS than the scaled value of 16mS.

The oscillator design follows the reflection amplifier approach presented in [8]. Oscillator designs were carried out at frequencies from 150GHz to 550GHz in 50GHz increments. Due to the uncertainty existing in the device model, several designs were done at each frequency. The cases considered were with parasitics at their nominal values (low parasitics) and at twice these values (high parasitics). The transconductance was also taken to be either 16mS or 10mS. Varying the frequency and the model parameters resulted in 28 significant design cases of which 16 were selected for fabrication. The CPW layout for the oscillator circuit is shown in Fig. 2.

The transistors were integrated simultaneously with the CPW circuits. An etch was performed to remove conductive material which exists in the region of the slot antenna and in the gap between the CPW metalizations. DC biasing of the transistor is made possible by slits in the ground plane which isolate the gate, drain and source. These slits are capacitively bypassed to create an uninterrupted ground plane for the RF circuit [3].

III. MEASUREMENTS

The oscillators were positioned on a 2.54 cm diameter elliptical silicon substrate lens for testing. Operational checks and rough frequency measurements were obtained by aligning the oscillators in front of an InSb hot electron bolometer with an interferometer and mechanical chopper in the beam path. Two of the designs were found to oscillate with about 50% yield (Table 1). The 150 GHz design case assuming high parasitics and 10mS transconductance (150H10) oscillated near its design frequency generating an output signal at 155 GHz. The 500 GHz case assuming high parasitics and 16mS transconductance (500H16) generated an output at an unexpected frequency near 213 GHz. The other 14 cases generated no output. This situation is not surprising considering the large uncertainty which exists in the device model.

The oscillator frequencies were accurately measured and their spectrums were observed using a quasi-optical wideband harmonic mixer [9] setup shown in Fig. 3. The measured spectrums of a 155 GHz and a 213 GHz oscillator are shown in Fig 4. The LO frequency was varied to observe both upper and lower sidebands and different IF frequencies were used to insure that the harmonic numbers and RF frequencies are correctly determined. To be certain that the observed signal corresponds to the fundamental oscillation frequency, the LO was adjusted to search for any signals at 1/2 and 1/3 of the oscillator frequency and no signals were observed.

The oscillator output power was estimated with a quasi-optical setup using calibrated waveguide diode detectors and a lock-in amplifier. The slot-oscillator power is determined from the amplitude of the signal at the calibrated detector and the Friis transmission equation. An estimate of the directivity of the slot oscillator is made by assuming an aperture efficiency of 40% [3]. The total output power is found to be no less than 10 μW for the 155 GHz oscillator and no less than 1 μW for the 213 GHz oscillator. The corresponding (minimum) DC to RF efficiencies are 0.13% at 155 GHz and 0.014% at 215 GHz. The 155 GHz power measurements are consistent with the fact that the transistor is very small with only a 10μm gate width and the circuits are operating close to f_{max}. The circuits were optimized for high loop gain not maximum power and there is a lot of uncertainty in the device model.

IV. CONCLUSION

This paper presents the highest frequency achieved to-date for a quasi-optical oscillator using a three terminal device. A large number of these devices could be used in quasi-optical power combining designs at millimeter wave frequencies to generate milliwatt power levels. The successful development of these monolithic oscillators demonstrates the high frequency capabilities of the sub-micron gate InP based HEMT which should also find applications as a small signal millimeter-wave and submillimeter-wave amplifier.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. E. Rosenbaum et al., "Fabrication of a 213 GHz AlInAs/GaInAs/InP HEMT MMIC Oscillator," submitted to *IEEE Microwave and Guided Wave Letters*, April 1994.

[2] B. K. Kormanyos and G. M. Rebeiz, "Quasi-optical CPW-fed slot-antenna oscillators," Proceedings of the *Third Int. Conf. on Space Terahertz Technology*, Ann Arbor, Michigan, March 24-26, 1992, pp.32-36.

[3] B. K. Kormanyos, W. Harokopus Jr., L.P.B. Katehi, and G.M. Rebeiz, "CPW-Fed active slot-antennas," to appear in *IEEE Transactions on Microwave Theory Tech.*, April 1994.

[4] H. P. Moyer and R. A. York, "Active cavity backed slot antenna using MESFET's," *IEEE Microwave and Guided Wave Letters*, vol. 3, no. 4, April 1993.

[5] G. M. Rebeiz, "Millimeter-wave and terahertz integrated circuit antennas," *Proceedings of the IEEE* , vol. 80, no. 11, pp. 1748-1770, Nov. 1992.

[6] N.I. Dib and P.B. Katehi, "Modeling of shielded CPW discontinuities using the space domain integral equation method (SDIE)," *Journal of Electromagnetic Waves and Applications*, vol. 5, no. 4/5, pp. 503-523, 1991.

[7] L.D. Nguyen, A.S. Brown, M.A. Thompson, and L.M. Jelloian, "50-nm self aligned gate pseudomorphic AlInAs/GaInAs high electron mobility transistors," *IEEE Transactions on Electron Devices*, vol. 39, no. 9, Sept. 1992.

[8] G. R. Basawapatna and R. B. Stancliff, "A unified approach to the design of wide-band microwave solid-state oscillators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-27, no.5, pp. 379-385, May 1979.

[9] B. K. Kormanyos and G.M. Rebeiz, "A 26 to 220 GHz harmonic mixer-receiver," *Microwave Journal*, Vol. 36, No. 7, pp. 103-108, July 1993.

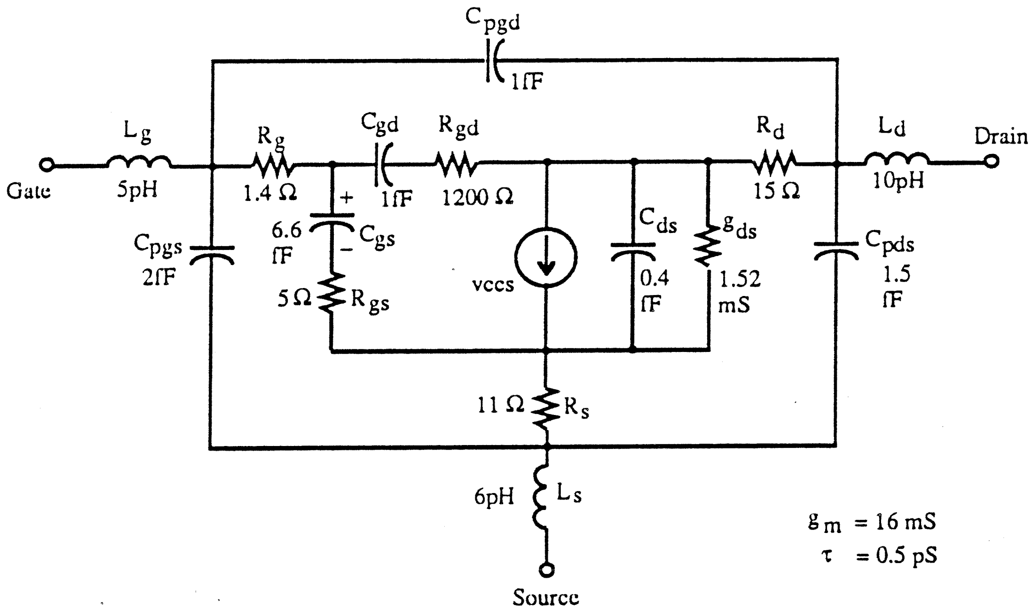

Figure 1: Small signal model for the InP based HEMT with 0.05 μm gate length and 10 μm gate width.

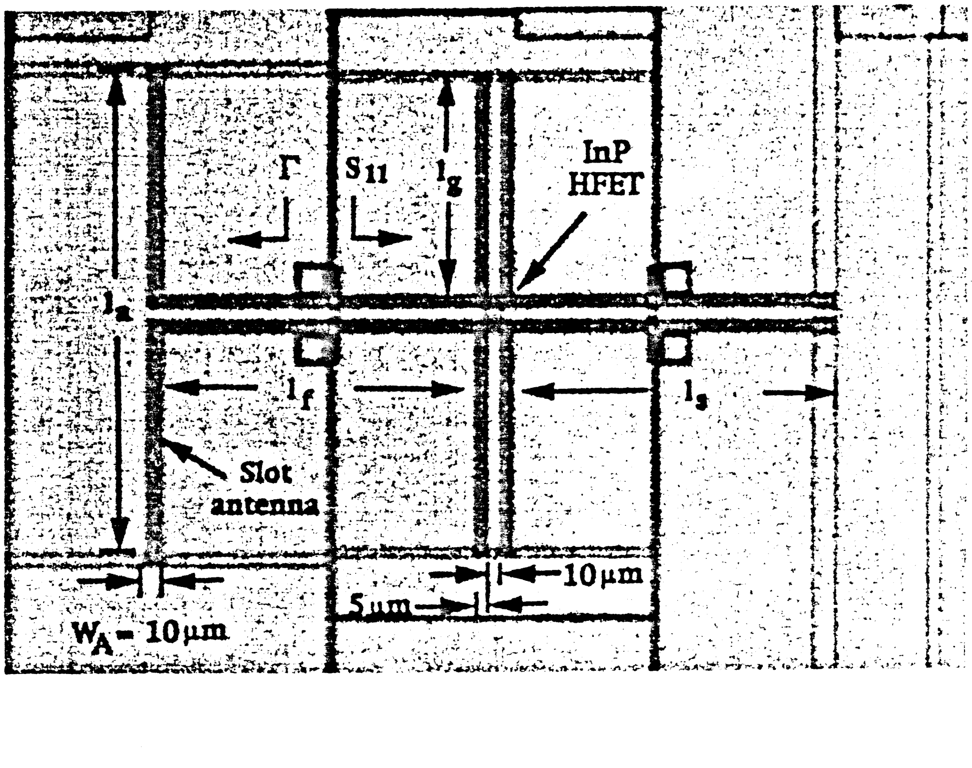

Figure 2: CPW layout for the high frequency quasi-optical slot oscillators.

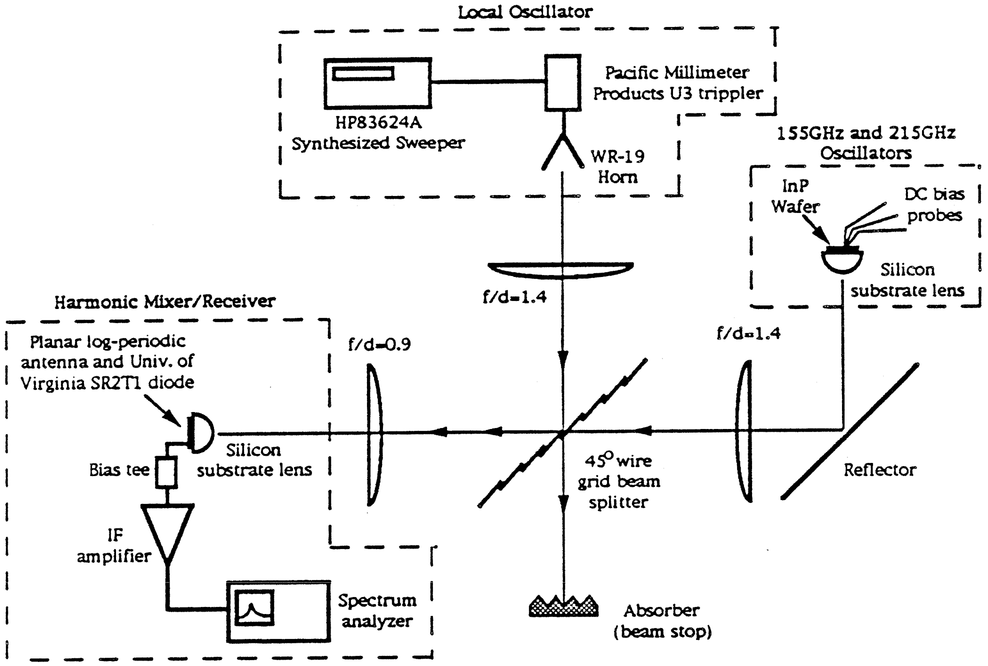

Figure 3: Wideband quasi-optical harmonic mixer setup for accurate frequency determination and spectrum measurements.

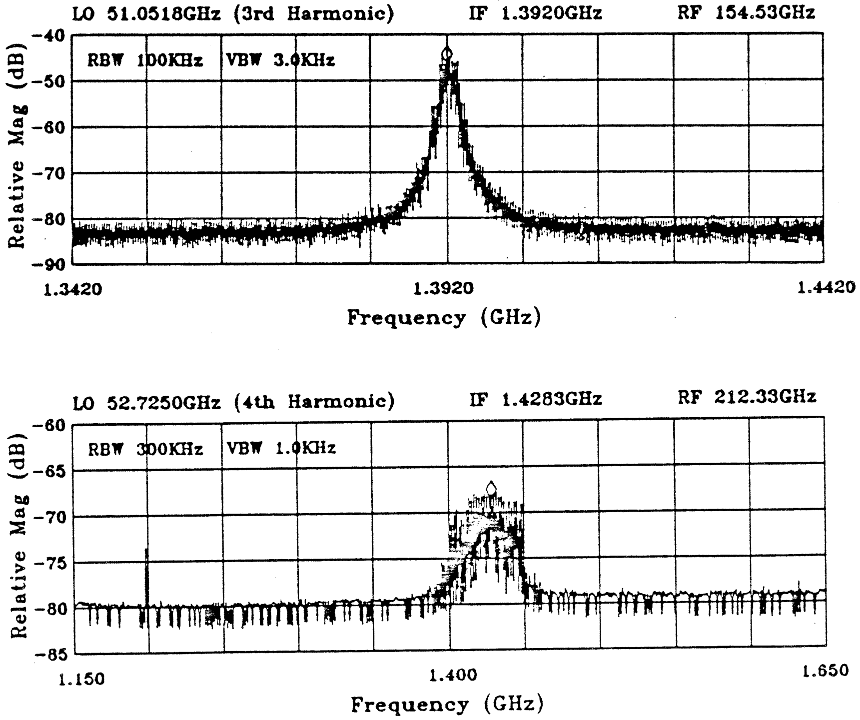

Figure 4: Measured down converted spectrums of the 155 GHz and 213 GHz oscillators.

F^* (GHz)	Lp,Cp**	g_m (mS)	l_s (μm)	l_g (μm)	l_f (μm)	l_a^{**} (μm)	$1/S_{11}$ (mag,ang)	Γ (mag,ang)
150	**High**	**10**	**239**	**164.5**	**230.5**	**360**	**0.188, 164.4**	**0.595, 164**
500	**High**	**16**	**107**	**86.5**	**71**	**70**	**0.323, -147**	**0.897, -146.5**

Table 1: Design parameters for the two successful monolithic millimeter-wave oscillators. (*F is the small signal design frequency, **Lp, Cp are the extrinsic parasitic inductors and capacitors in the device model where high parasitics corresponds to two times the nominal values shown in Fig. 1).