would also be applicable to the case of the magnetic field exposure.

Fig. 8 shows experimental results on the total power absorption in the pupa exposed to the standing waves. The ordinate shows the relative absorbed power which is obtained from (8) by normalizing the measured value of the $d\Delta T/dt$ to that in the A-oriented pupa of Fig. 7. The abscissa shows the relative distance from the pupa to the shorting plunger normalized to the guide wavelength. The solid curves show the values of the relative absorbed power calculated from (6), which approximately agree with the experimental results.

As regards the parameters for calculations, the pupa mass $m = 157$ mg and the pupa diameter $2r = 4.8$ mm were both measured. The pupa length $l = 6.5$ mm was obtained from $l = 3m/4\pi\rho r^2$ where ρ is a density of the sample pupa assumed to be 1 mg/mm³. The relative permittivity $\epsilon_r = 35 - j13$ at the experimental frequency $f = 2485$ MHz was calculated from (7).

IV. Conclusions

The microwave power absorption in the biological specimen modeled as the prolate spheroid inside the standing-wave irradiation waveguide has been examined theoretically with respect to the exposure orientation.

The absorbed power distribution and total power absorption in the spheroid with dimensions small compared to the guide wavelength were obtained in simple closed form expressions.

Numerical calculations on the Tenebrio pupa were presented, and the results on the total power absorption were confirmed experimentally.

References

[1] A R Shapiro, R. F. Lutomirski, and H T Yura, "Induced fields and heating within a cranial structure irradiated by an electromagnetic plane wave," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp 187–196, Feb. 1971.

[2] C H Durney, C C. Johnson, and H. Massoudi, "Long wavelength analysis of plane-wave irradiation of a prolate spheroid model of man," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp 246–253, Feb. 1975.

[3] H. Massoudi, C H. Durney, and C. C. Johnson, "Long wavelength analysis of plane wave irradiation of an ellipsoidal model of man," *IEEE Trans. Microwave Theory Tech.*, MTT-25, pp 41–46, Jan. 1977.

[4] T K. Wu and L. L. Tsai, "Electromagnetic fields induced inside arbitrary cylinders of biological tissue," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp 61–65, Jan. 1977.

[5] K. M. Chen and B. S. Guru, "Internal EM field and absorbed power density in human torsos induced by 1–500-MHz EM waves," *IEEE Trans Microwave Theory Tech.*, vol. MTT-25, pp 746–756, Sept. 1977

[6] L. M. Liu, F. J. Rosenbaum, and W. F. Pickard, "Electric-field distribution along finite length lossy dielectric slabs in waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 216–219, Apr. 1976

[7] R. G. Olsen, G. A. Geithan, and D. H. Schrader, "A microwave irradiation chamber for scientific studies on agricultural products," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-25, pp. 428–433, May 1977.

[8] R. L. Carpenter and E. M. Livstone, "Evidence for nonthermal effects of microwave radiation: Abnormal development of irradiated insect pupae," *IEEE Trans Microwave Theory Tech.*, vol. MTT-19, pp. 173–178, Feb. 1971.

[9] G. A. Lindauer, L M. Liu, G. W. Skewes, and F. J. Rosenbaum, "Further experiments seeking evidence of nonthermal effects of microwave radiation," *IEEE Trans. Microwave Theory Tech*, vol. MTT-22, pp. 790–793, Aug. 1974

[10] L. M Liu, F J Rosenbaum, and W. F. Pickard, "The relation of teratogenesis in Tenebrio molitor to the incidence of low-level microwaves," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 790–793, Aug. 1974

[11] R. G. Olsen, "Insect teratogenesis in a standing-wave irradiation system," *Radio Sci.*, vol. 12(6S), pp. 199–207, 1977.

[12] Y Shiau and A. R. Valentino, "ELF electric field coupling to dielectric spheroidal models of biological objects," *IEEE Trans. Bio-Med. Eng.*, vol. BME-28, pp. 429–437, June 1981

[13] S. O. Nelson and L F. Charity, "Frequency dependence of energy absorption by insects and grain in electric fields," *Trans. ASAE.*, vol 15, pp. 1099–1102, Nov. 1972.

[14] H. P. Schwan, "Interaction of microwave and radio frequency radiation with biological systems," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 146–152, Feb. 1971.

[15] C C. Johnson, C. H. Durney, and H. Massoudi, "Long-wavelength electromagnetic power absorption in prolate spheroidal models of man and animals," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp 793–747, Sept. 1975.

Comparison of AM Noise from a Klystron and an IMPATT Oscillator at around 90 GHz

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***Abstract* —This paper reports comparisons between the amplitude modulation noise performance of a Plessey IMPATT oscillator AT0273 and a Varian VRB-2113 klystron at millimeter wavelengths.**

I. Introduction

Millimeter-wave radiometers require stable sources of local-oscillator (LO) power, with low amplitude modulation (AM) noise levels at $f_{LO} \pm f_{IF}$. The frequency modulation (FM) and AM noise close to the carrier is also important, but within approximately 1 MHz of the carrier this can be greatly reduced by the use of phase lock loops (PLL) [1], but the use of a PLL will have no effect upon the oscillator noise outside this range. The presence and effect of such AM noise far from the carrier has been demonstrated by Cong and Kerr [2] who showed that the AM noise-to-carrier ratio of a doubled 57-GHz klystron was equal or better than that of three klystrons operating between 110 and 114 GHz, and by Tearle and Heath [3] who showed the effect of sideband noise of IMPATT pumps on parametric amplifier noise temperatures.

Recent advances in IMPATT diode technology to increase power capability, lifetime[1], and the use of high-Q waveguide circuits to reduce the noise of these devices (see, for example, Gokgor *et al.* [4], Berson and Kuno [5], and Bischoff and Schroth [6]) suggest that IMPATT oscillators can replace klystrons as local oscillators at frequencies up to 100 GHz.

II. The Measurements

The double sideband noise temperature of a low-noise mixer was measured using the standard hot-and-cold load technique [7]. As shown in Fig. 1, the local oscillator was coupled into the mixer through a directional coupler, and two waveguide resonant-ring filters were used to further reduce the far-from-carrier noise. The filters were successively removed and the system noise temperature was measured with room temperature and liquid nitrogen loads in front of the horn, and with a noise source

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[1]For example W. J Welch (private communication) reports more than 15000 h continuous operation of two phase-locked IMPATT local oscillators on the 86-GHz interferometer of the University of California (Berkeley)

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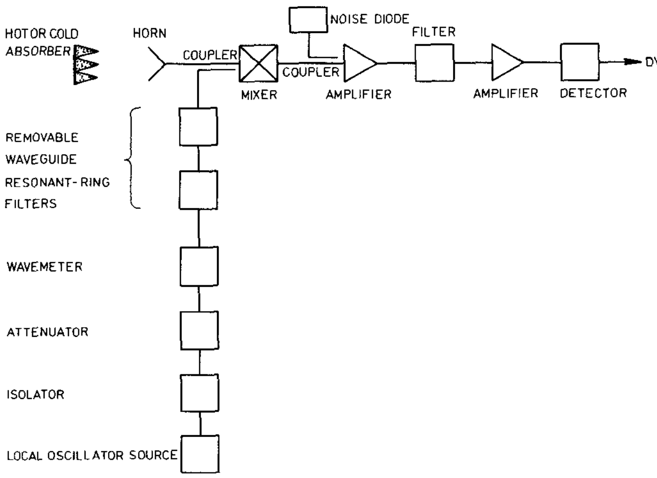

Fig. 1 IMPATT and Klystron AM noise measurement system.

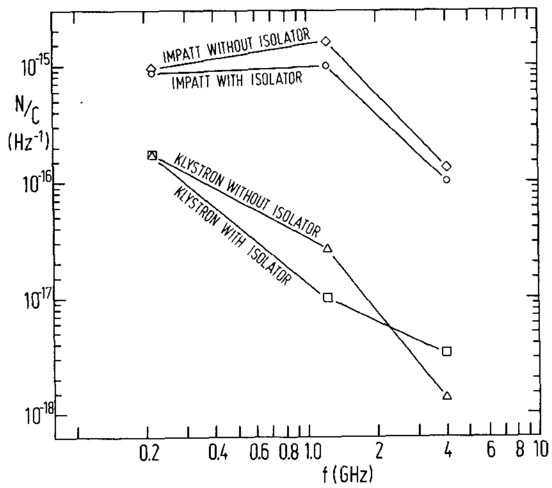

Fig. 2. Variations of double sideband AM noise-to-carrier ratio for Plessey IMPATT oscillator AT0 273 (30 mW at 94.5 GHz and 70 mA) and Varian Klystron VRB-2113 (60 mW at 89.9 GHz).

TABLE I
DOUBLE SIDEBAND AM NOISE WITHOUT AN ISOLATOR, CORRESPONDING TO RESULTS IN FIG. 2, FOR 1 mW ON MIXER

	215 MHz	1.2 GHz	4.0 GHz
IMPATT	69,000 K	122,000 K	9530 K
Klystron	13,000 K	1870 K	82 K

coupled into the IF chain in order to determine the noise contributions of the rest of the system and of the LO.

At the klystron frequency (89.9 GHz) and IMPATT frequency (94.5 GHz), insertion losses of the directional coupler and the two additional filters (which were tuned to f_{LO}) were measured at f_{LO} and $f_{LO} \pm f_{IF}$.

By operating the mixer under fixed conditions of bias, tuning, and LO power, the double sideband noise contribution of each LO was determined at three intermediate frequencies. The results are shown in Fig. 2. Table I gives the double sideband AM noise temperature corresponding to the results in Fig. 2, without an isolator, for an input power level of 1 mW on the mixer diode. The relatively poor noise performance of the IMPATT oscillator at 1.2 GHz is noteworthy but not significant; Tearle and Heath [2] also observe irregular variations of AM noise with frequency of approximately 10 dB. Chart records of radiometer output noise were similar for each LO source over periods > 90 min, with no signs of instability or excess noise.

It is noteworthy that no radical change in noise performance was observed by removing the isolator following the LO source. However, in the absence of an isolator, the IMPATT oscillator frequency was strongly dependent on load impedance.

III. CONCLUSION

These measurements indicate that the far-from-carrier AM noise of IMPATT oscillators is such that with extra filtering IMPATT's may be used as sources of local oscillator power at millimeter wavelengths without degradation of system performance.

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REFERENCES

[1] J. Baprawski, C. Smith, and F. J. Bernues, "Phase-locked solid state mm-wave sources," *Microwave J.*, vol. 19, pp. 41–44, Oct 1976.
[2] H. I. Cong and A. R. Kerr, "AM sideband noise measurements on AIL doubler and Varian VRT.2123A Klystrons at 112–114 GHz," Goddard Institute for Space Studies Internal Report, May 1979
[3] C. A. Tearle and K. R. Heath, "IMPATT sideband noise and its effect on parametric amplifier noise temperature," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 1036–1042, Dec 1975.
[4] H. S. Gokgor, I. Davies, A M. Howard, and D. M. Brookbanks, "High efficiency millimeter-wave Silicon IMPATT oscillators," *Electron. Lett.*, vol. 17 (20), pp. 744–745, Oct. 1981.
[5] B. Berson and J. Kuno, "Solid-state power improves," *Microwaves Systems News*, pp 39 *et seq*, Nov. 1978.
[6] M. Bischoff and J. Schroth, "A mm-wave receiver for 60-GHz satellite communication," *Communications Engineering International*, pp. 12 *et seq*, Aug. 1980.
[7] P. Zimmermann and R. W. Haas, "A broadband low noise mixer for 106–116 GHz," *Nachrichtentech. Z*, bd. 30, h. 9, s. 721–722, 1977.

Experimental Evaluation of a Ruby Maser at 43 GHz

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***Abstract*—The inversion ratio of pink ruby has been measured at several frequencies between 27 and 43 GHz for the push–pull pump angle of 54.7°. From these measurements a single-stage maser was designed which yielded 8 ± 1-dB net gain and a 3-dB bandwidth of 180 MHz at a center frequency**

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