Comparison of Methods for Sensitivity Determination of Point-Contact Diodes at Submillimeter Wavelength

E. SAUTER AND G. V. SCHULTZ

***Abstract*—Three independent methods were used: 1) mixing of two HCN lasers; 2) mixing of the sixth harmonic of a klystron with an HCN laser; and 3) the incremental-loss method. The results are given. The most sensitive configuration was obtained using a corner reflector. The influence of local-oscillator (LO) power on the conversion losses of the diodes are investigated.**

I. Introduction

The conversion loss L_0 of a diode is inversely proportional to its detection sensitivity, at least for small signals. Hence measuring the conversion loss one gets knowledge about the sensitivity of the detector system used. But one has to be aware that for submillimeter radiation the conversion losses are measured with point-contact diodes, which are not sufficiently pumped by the local-oscillator (LO) power, and include the losses caused by the poor coupling of signal and LO radiation into the diode.

In previous determinations of conversion losses of point-contact diodes for submillimeter radiation the incremental-loss method has been used [1]. The mixing of HCN-laser radiation with the twelfth harmonic of a 74-GHz klystron gave much different, lower values for the conversion losses. There were some doubts whether the incremental-loss method, which is a dc method, gives correct values of the conversion losses for such high frequencies as 1000 GHz.

To verify our previous results we now have used three different ways to determine the conversion losses of point-contact diodes for submillimeter-wavelength mixing: 1) heterodyne mixing with two HCN lasers; 2) dc incremental-loss method with HCN-laser radiation; and 3) heterodyne mixing with the sixth harmonic of a 148-GHz klystron.

A. The Heterodyne Method with Two HCN Lasers

Fig. 1. shows schematically the experimental setup used in the heterodyne method of loss measurements. The signal-laser beam and the LO beam, which are perpendicular to each other, are superimposed by a 15-μm-thick Mylar foil, acting as "directional coupler" (transmission 97 percent, reflection 2.5 percent for a linear polarized beam, whose plane of polarization is parallel to the incident plane).

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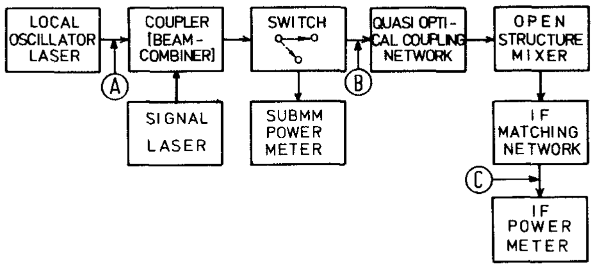

Fig. 1. Block diagram of the setup used for the heterodyne-method measurement.

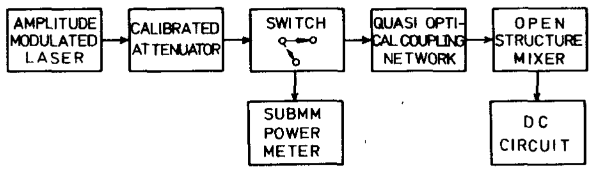

Fig. 2. Block diagram of the setup used for the dc incremental method of loss measurements.

The superimposed beams of signal and LO fall on a reflecting chopper blade at an angle of 45°. They are switched periodically between the submillimeter-power meter and mixer, and therefore allow us to monitor the power of the two lasers as well as to measure the signal power focused onto the mixer, if the LO beam is interrupted at A. The available power of the LO and the signal beams falling onto the diode are 3.8 mW and 18.7 μW, respectively. The ratio of the measured signal power P_S at B and the intermediate frequency (IF) power P_{IF} at C gives the conversion loss. With $P_S = 18.7\ \mu$W and $P_{\mathrm{IF}} = 2.52 \times 10^{-3}\ \mu$W, we obtain a conversion loss of 38.7 dB.

B. The DC Incremental Method

The dc incremental method of loss measurements [2] is simpler than the first one because only one oscillator and a simple dc circuit is needed. This method is not suitable for the investigation of the influence of matching problems, because it assumes fixed tuned conditions, i.e., the mixer is matched to signal and image frequency as well as to the LO frequency.

The laser power P falling onto the mixer (Fig. 2) creates a current I in the diode, which is terminated in its IF conductance g_b. If the laser power is increased by ΔP, the current changes by ΔI. After Torrey and Whitmer [2] the conversion loss denoted by L_0 is

$$L_0 = \frac{g_b}{2P_0(\Delta I/\Delta P)^2}$$

with $P_0 = P + 1/2\,\Delta P$. The measured values of $P = 3.01$ mW, $\Delta P = 1.76$ mW, $\Delta I = 8.7\ \mu$A, and $g_b = 1.0 \times 10^{-3}$ Ω^{-}, giving a conversion loss of 37.2 dB.

C. Heterodyne Method using HCN Laser and the Sixth Harmonic of a 148-GHz Klystron

The two results were checked with another mixing experiment: the strong HCN laser was mixed with the sixth harmonic of a 148-GHz klystron. The power at the end of the waveguide, which was placed close to the whisker for optimal coupling, was 90 mW. We assume that the higher harmonics of the 148-GHz klystron created in the diode decrease by 10 dB per harmonic up to the seventh harmonic.[1] Under this assumption the signal power in the sixth harmonic around 890 GHz amounts to 9.0×10^{-4} mW and gives a beat signal of 1.6×10^{-7} mW. Thus the conversion loss is 37.5 dB.

D. Conclusion

It is remarkable that the three different methods used to determine the conversion losses of a point-contact diode for an operating frequency of 890 GHz give values which are in good agreement with one another. In general the dc incremental method should give an upper limit for the conversion losses. In reality, the value of the dc incremental method is lower than the one obtained by the heterodyne method. This could be due to the fact that in the first experiment the IF impedance matching could not be fully optimized or that in our case ΔP is not small enough compared with P.

It must be emphasized that the given values are not the "internal conversion losses" of the diode itself, but include especially the losses caused by the poor coupling of signal and LO radiations into the diode. Further, the available LO power is not sufficient to drive the diode into saturation.

II. Increasing the Coupling Efficiency Using Different Reflectors

An improvement of the coupling efficiency using different reflectors and a better tuning have lowered the conversion losses to 29.5 dB. The LO and the signal beam were focused by means of a TPX lens ($f = 100$ mm) onto the whisker, acting as a long-wire antenna. Matarrese and Evenson [3] have shown that the experimental behavior of a whisker for submillimeter wavelengths is described in good agreement with the results given by long-wave antenna theory. The angle ϕ_0 of the main lobe with respect to the wire axis is given by the simple formula [3] $\phi_0 = \cos^{-1}(1 - 0.371\ \lambda/L)$, where λ is the wavelength and L the length of the whisker. With $L = 4\lambda_{HCN}$ ($=1350\ \mu$m), ϕ_0 becomes 24.9°. The

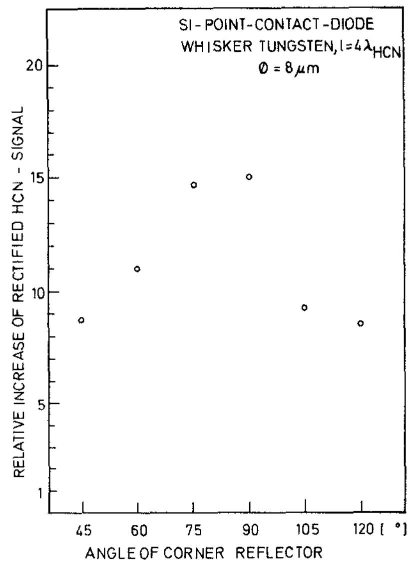

Fig. 3. Rectified HCN signal with a corner reflector compared to the signal obtained without a reflector versus the angle of the corner reflector.

antenna pattern of a long-wire antenna is symmetrical about the wire axis.

To improve the receiving performances of the point-contact diode, a plane reflector and V-shaped reflectors (corner reflectors) with the angles of 45°, 60°, 75°, 90°, 105°, and 120° were combined with the whisker antenna. In principle the influence of a reflector on antenna performances is twofold: 1) the former conical-antenna pattern is changed into a beam-antenna pattern, and hence is better adapted to the incoming laser beam; and 2) the radiation resistance is changed depending on the distance between the wire axis and corner and also depending on the corner angle [4].

It can be shown that the conversion loss L_0 is inversely proportional to the sensitivity of the diode; i.e., $L_0 \sim 1/(dU/dP)$ [2]. Fig. 3 shows the ratio of rectified HCN-laser signal with and without reflector versus angle. In the present case, the V-shaped reflectors with angles of 90° and 75° give the best results. All reflectors have the same square cross section of 4.0 × 4.0 mm. A slot with the width of 130 μm at the apex of the corner reflectors serves to pick up the loop of the S-shaped whisker when the reflector is brought close to the whisker until the reflector surface touches the crystal post. A comparison of a slotted with an unslotted reflector shows that the slot had no influence on the performance of the reflector.

III. Conversion Efficiency as Function of LO Power

The relation between conversion losses and LO power is given by McCoy [5] and Pound *et al.* [6]. The conversion efficiency of a mixer is not optimized if the LO power is insufficient to drive the diode into saturation. In the millimeter region, where typical values for coupling efficiency of diodes are 90 percent (VSWR ~ 1:2) or better, the needed LO power to drive the GaAs diodes lies between 4 and 10 mW.

We estimate that our coupling efficiency is less than 10 percent, and with an available HCN LO power of 4 mW,

[1] In order to estimate the power available in the sixth harmonic we took the values given by Horvath of Custom Microwave: the higher harmonics decrease 10 dB per harmonic and from the seventh harmonic 6 dB per harmonic.

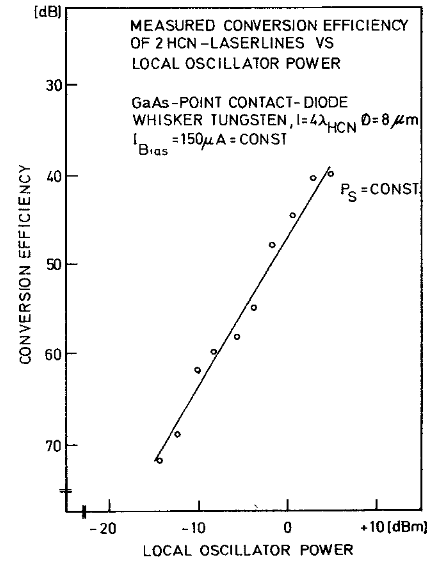

Fig. 4. Conversion efficiency versus LO power for a GaAs diode.

we are far away from the optimum driving point of our diode. It should be mentioned that with increasing frequency, the amount of LO power which is shunted by the barrier capacitance $C_j = 14 \times 10^{-15}$ F becomes more important. Fig. 4 shows a plot of the conversion efficiency versus LO power with constant signal power. It can be clearly seen that the LO power is not sufficient to drive the diode optimally. Hence the coupling efficiency has to be improved by a factor of 10, or the LO power has to be increased ten times.

To extend the heterodyning technique into the submillimeter region and to make it a successful tool for astronomical observations, certain improvements seem necessary. First, the coupling efficiency of submillimeter radiation to the mixer must be further improved. Secondly, more powerful LO generators must be developed. The second problem will likely be solved soon, since much progress had been achieved in the field of strong CO_2-pumped submillimeter lasers.

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Design of Printed Resonant Antennas for Monolithic-Diode Detectors

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***Abstract*—Model experiments at 10-GHz band have been performed to obtain optimum structures of printed resonant antennas for monolithic GaAs Schottky-diode detectors in the submillimeter-wave region. Design charts for antenna structures, which are also useful for a thin-film metal-to-metal diode structure on a dielectric substrate, are presented.**

I. Introduction

Recently, Schottky-barrier diodes have received considerable attention as submillimeter detectors [1], [2], primarily because of their strong nonlinear behavior, fast response time, and mechanical stability. A thin metallic wire (cat whisker) is usually used to obtain the coupling of applied radiation field to the diode structure. It has been shown [3] that the whisker acts as a traveling-wave long-wire antenna. The whisker collects the radiation and applies it to the Schottky contact. The cutoff frequency of the Schottky diode is determined approximately by the contact diameter. The diameter below 1.5 μm is desirable for use in the submillimeter-wave range [4]. Reasonable submillimeter response, however, has been obtained [2] using a 2.5-μm Schottky diode with a high-gain long-wire antenna. In this configuration, the mechanical stability is good enough for laboratory use, but not sufficiently practicable for general use. Moreover, cryogenically cooling the diode to reduce the noise [5] is difficult with this configuration. In order to eliminate these undesirable factors, a planar-type configuration is employed here and the design of a printed resonant antenna on a dielectric substrate is described.

The schematic configuration of the detector is shown in Fig. 1. The directivity patterns of a half-wave dipole antenna printed on a substrate has the maximum in the

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