Slot-Line Tapered Antenna with NbN Hot Electron Mixer for 300-360 GHz Operation

G.Gol'tsman*, S.Jacobsson**, H.Ekstrom**, B.Karasik*, E.Kollberg** and E.Gershenzon*.

NbN hot-electron mixers combined with slot-line tapered antennas on Si oxinitride membranes had been fabricated. Several strips of 1 μm wide and 5 μm long made from 100 Å NbN film are inserted into the slot antenna. IV-curves under local oscillator power in 300-350 GHz frequency range and conversion gain dependencies on intermediate frequency in the 0.1-1 GHz range are measured and compared with that for 100 GHz frequency band.

Our results show that pumped IV-curves and intermediate frequency bands are different for 100 GHz and 300 GHz frequency ranges. The interpretation exploits the fact that for the lowest radiation frequency the superconducting energy gap is larger than the radiation quantum energy while they are comparable at the higher frequency. Tha results show that such mixers have good perspectives for terahertz receiving technology.

For hot electron mixers based on thin superconducting films the interesting problem is to trace the transition from the condition $h\nu < 2\Delta$ to the opposit one. Here $h\nu$ is the quantum energy of the receiving radiation and 2Δ is the superconducting energy gap of the mixing element. The frequency corresponding to the energy gap of bulk NbN at $T = 0$ lies in terahertz range. For thin film mixing element under operation condition it may be much smaller due to electron heating produced by the LO power and biasing current. The study of the transition region can be carried out using wide quasioptical technique rather than wavequide technique which provides relatively narrow frequency band. In this work we study hot electron NbN film mixers matched to a slot-line tapered antenna (Fig. 1). Seven strips 1 μm wide and 5 μm long made from 100 Å thick NbN film are inserted into the antenna slot. The third (314 GHz) or the forth (360 GHz) harmonic of a 100 GHz range Gunn oscillator was used as a signal source. As a local oscillator we used a backward wave oscillator (BWO).

Figures 2,3 show IV-curves under LO radiation for frequencies 100 GHz and 314 GHz. At higher frequency (Fig. 2) the transformation of IV-curves with the increase the of LO power is quite similar to that occuring when the temperature of the mixer increases. The rise of LO power smears hysteresis and voltage steps that flattens IV-curves. The optimal operating point of the mixer belong to the relatively flat IV-curve (around point M, Fig. 2). The different behaviour of IV-curve was observed for lower frequency (100 GHz). Although the increase of LO power causes the drop of both the critical current and the reverse critical current, the former decreases faster. Thus the hysteresis becomes more pronounced. When the critical current ireaches zero IV-curve becomes flat. The optimal operating point belongs to the flat branch of IV characteristic and is located near the reverse critical current (around point M).

Intermediate frequency dependencies of the conversion gain are also different for lower and higher frequencies (Fig. 4,5). For the 100 GHz local oscillator the intermediate frequency band decreases from ≈ 2 GHz to 0.6 GHz when the operating point approaches the critical current. For the higher LO frequency the intermediate frequency band in the operating point is more than 1 GHz.

Features reported here can be qualitatively interpreted taking into account that the energy gap of the mixer film driven into the operating point is less compared to the energy gap of bulk NbN ($2\Delta = 6.5$ meV [1]). At 300 GHz the IV-curve dynamics under the LO power shows that the radiation quantum energy may be close to the energy gap value in the operating point. For 100 GHz the transformation of IV-curves is obvously non thermal, which is a consequence of the condition $h\nu < 2\Delta$. In this case electrons are heated up by RF curent in the same manner as by dc current, namely the electron heating occures only in the normal state regions of the film. In superconducting regions RF currents are transported by Cooper pairs. Contrary, for 300 GHz LO frequency the electron heating is likely more uniform.

In conclusion, it is shown that IV-curves of the hot electron NbN thin film mixer becomes more stable and the intermediate frequency band of such a mixer increases with the increase of LO frequency.

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* G. Gol'tsman, B. Karasik and E. Gershenzon are with Moscow State Pedagogical University, Moscow, Russia.
** S. Jacobson H. Ekstrom and E. Kolberg are with Chalmers University of Technology, Göteborg, Sweden.

[1] D.R.Kareski et al., Phys. Rev. B, Vol. 27, No. 9, May, 1983, pp. 5460-5466.

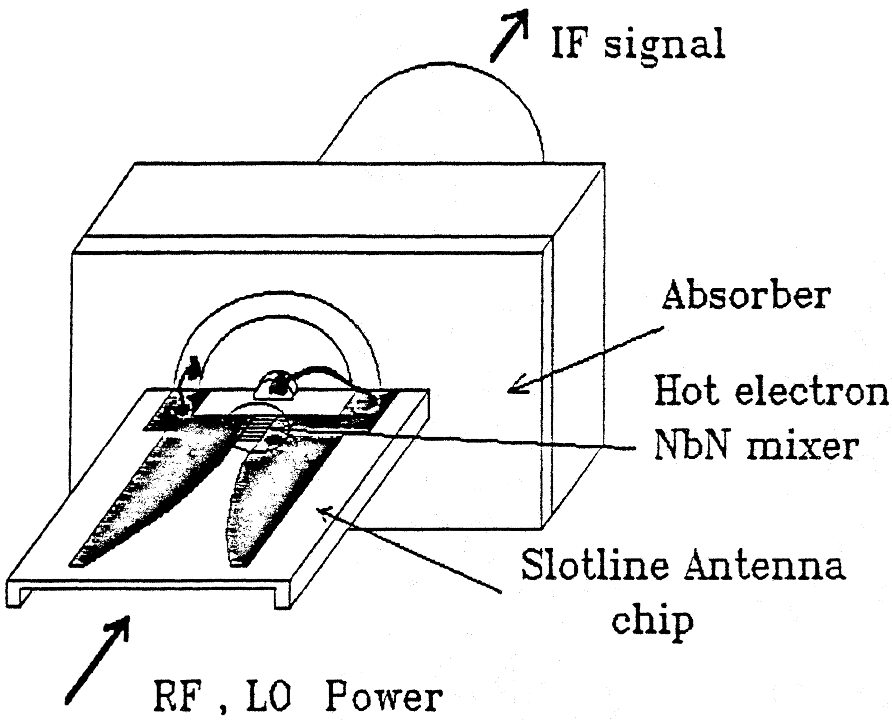

Fig. 1. Design of the antenna-coupled mixer mount.

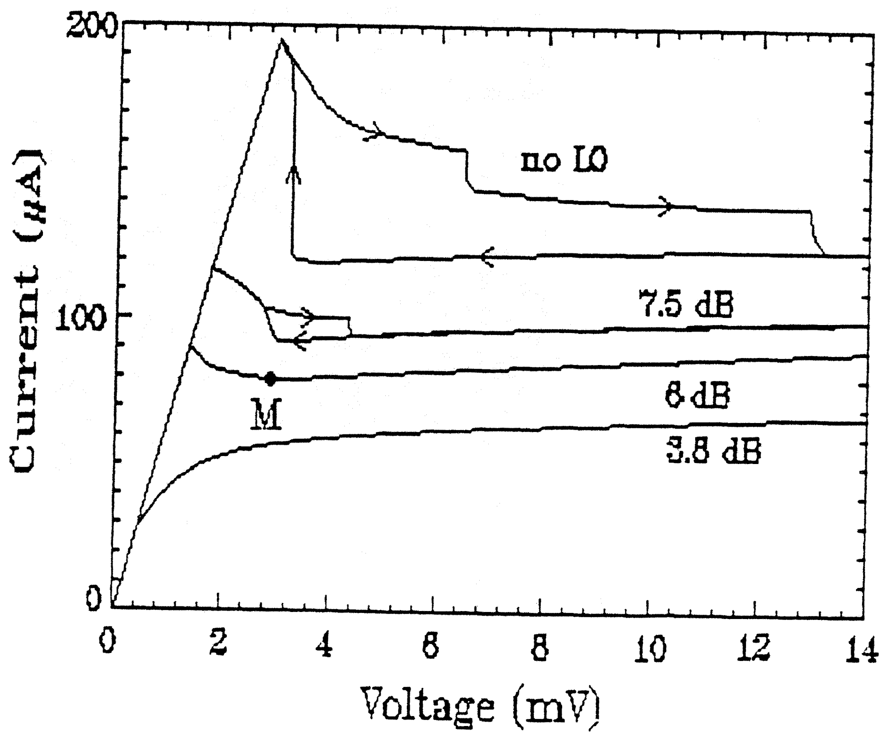

Fig. 2. IV-curves under LO power at 314 GHz.

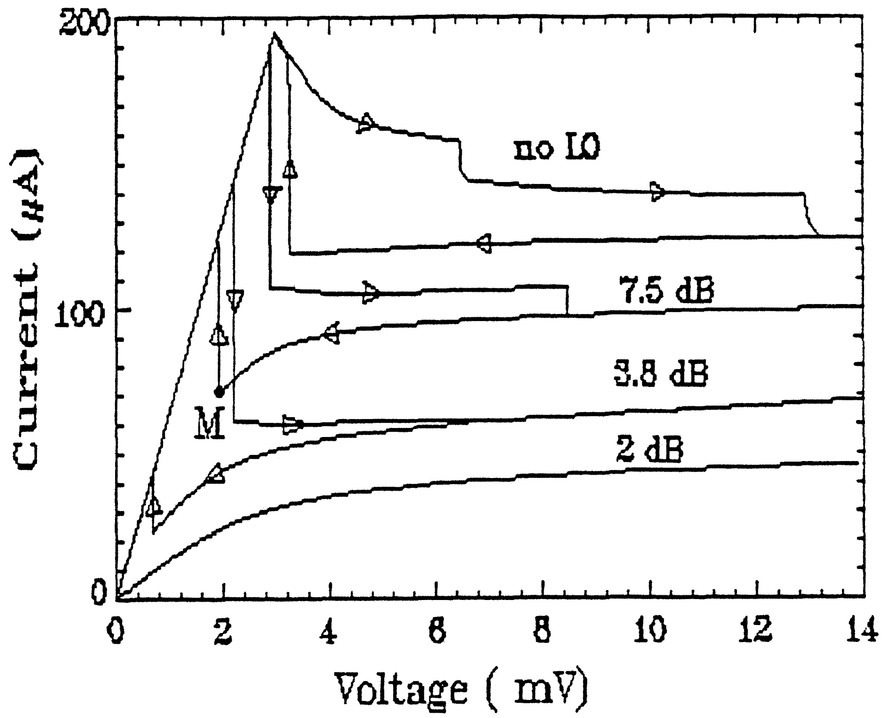

Fig. 3. IV-curves under LO power at 100 GHz.

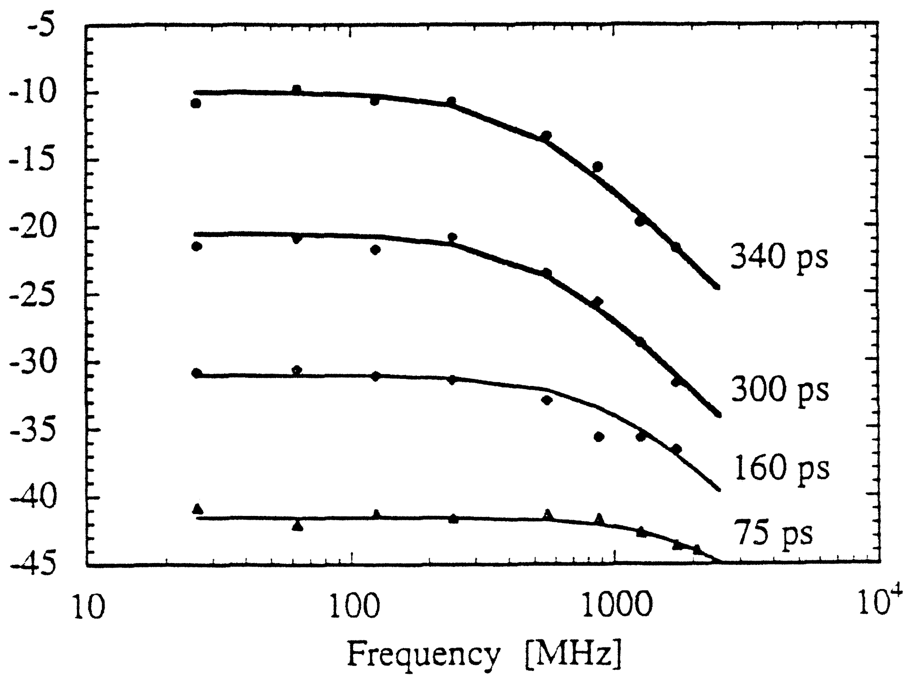

Fig. 4. Conversion gain versus intermediate frequency for 100 GHz LO frequency and three bias points.

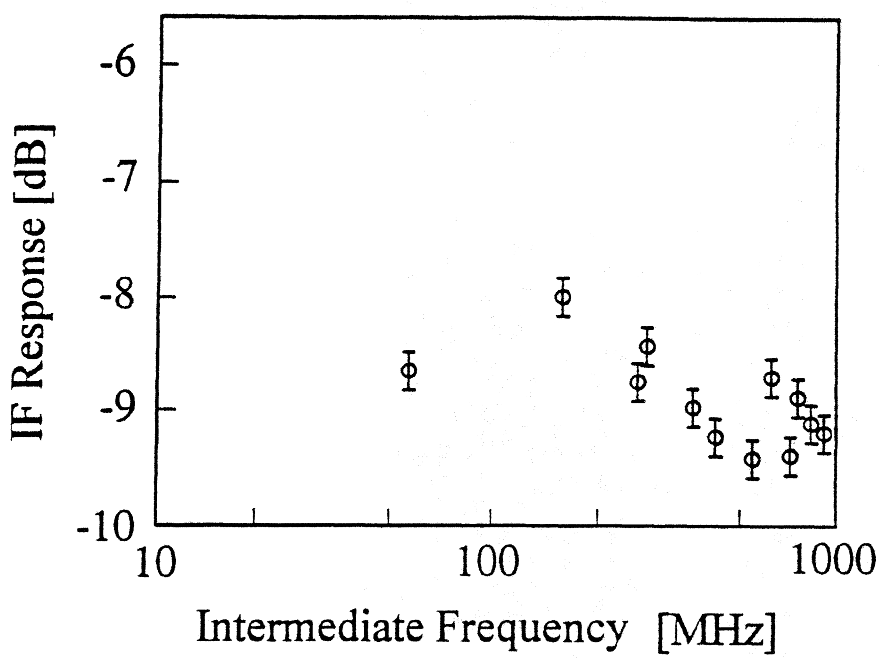

Fig. 5. Conversion gain versus intermediate frequency at 314 GHz.