Fundamental limitations of THz and Niobiumnitride SIS mixers

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The cover picture is taken the morning after the 1953 flood disaster in the province of Zeeland, the Netherlands. Clearly visible are the holes in the sea dike through which the water flows with great force. Apart from the devastating effects, the apparent huge stream of water through these holes provides an expressive analoge to the effects of pinholes in tunnel barriers as described in this thesis. (Copied with permisson from ”De watersnood in Zeeuws-Vlaanderen”, by G. Sponslee and E. Steyns, van Geyt productions, Hulst, the Netherlands).

The reading committee for this thesis consists of Prof.Dr.Ir. J.E. Mooij, Prof.Dr. M.J. Feldman, and Prof.Dr. K.H. Gundlach.

This thesis is typeset in Times Roman with LaTeX.

This work was performed at the Department of Applied Physics of the University of Groningen and the Space Research Organization of the Netherlands (SRON) as part of the research program of the *Stichting voor de Technische Wetenschappen* (STW), with financial support from the *Nederlandse Organisatie voor Wetenschappelijk Onderzoek*. This work is also supported by the *European Space Agency* (ESA) under contract no: 7898/88/NL/PB(SC) and 11653/95/NL/PB.

Rijksuniversiteit Groningen

Fundamental Limitations of THz Niobium and Niobiumnitride SIS Mixers

Proefschrift

ter verkrijging van het doctoraat in de
Wiskunde en Natuurwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus Dr. F. van der Woude
in het openbaar te verdedigen op
vrijdag 24 april 1998
des namiddags te 1.15 uur.

door

Pieter Dieleman
geboren op 24 mei 1970
te Kommerzijl.

Promotor: Prof. Dr. Ir. T.M. Klapwijk
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Preface

This thesis describes the use of superconducting niobium and niobiumnitride tunnel junctions as heterodyne mixing elements in the submillimeter frequency range from 600 to 1000 GHz. In this frequency range Nb as well as NbN layers exhibit significant absorption of submillimeter radiation, making them unsuitable as impedance matching embedding structures. This brings about the inclusion of normal metals in the design of these detectors. The frequency range obtainable with these ”hybrid” detectors as well as the attainable ultimate sensitivity are the main topics of this thesis.

Ch. 1 is an introduction to the work presented in the thesis, and describes the historical development and the basic principles of operation of heterodyne receivers based on superconducting tunnel junctions. The fabrication, materials properties and their effect on the electrical characteristics of Nb and NbN tunnel junctions are discussed in Ch. 2 as well as the fabrication related RF radiation losses in superconductors and normal metals.

The operation of the receiver as a whole and the junction in particular will be illustrated in Ch. 3 by means of a ”case study” of a Nb junction with aluminum circuitry. Measured data are compared in detail with the quantum theory of mixing.

An interesting observation when employing aluminum embedding is an improved transport of the heat generated by Joule heating of the device when operated as a detector. The cooling efficiency of aluminum *vs.* niobium embedding of the junction is investigated in Ch. 4. Using the simulation developed in Ch. 3 the effect of this enhanced heat transport is on the mixing properties is investigated.

Ch. 5 deals with the feasibility of NbN junctions in the frequency range of 600 to 1000 GHz, in which an analysis method is employed similar to that in Ch. 3. The NbN junctions exhibit a significantly enhanced shot noise which dominates the performance of the device. The physical mechanism behind this is described in Ch. 6. The same noise enhancement mechanism is found to be present in high critical current density Nb junctions as well. This observation, described in Ch. 7 answers a long-standing question on the discrepancy between the noise measured and theoretically expected.

Appendix A discusses the lay-out of the used waveguide mixers and the experimental methods used to determine the physical properties of the devices.

A summary of the work performed and the implications of the results for the feasibility of superconducting tunnel junctions in the THz regime is given in Ch. 8. The thesis ends with a summary both in English and Dutch.

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