UNIVERSIDAD DE CANTABRIA

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TESIS DOCTORAL

Cryogenic Technology in the Microwave Engineering: Application to MIC and MMIC Very Low Noise Amplifier Design

Juan Luis Cano de Diego

Santander, Mayo 2010

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Cryogenic Technology in the Microwave Engineering: Application to MIC and MMIC Very Low Noise Amplifier Design

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A mis padres
y hermano.

"The thing's hollow—it goes on forever—and—oh my God—it's full of stars!"
2001: A Space Odyssey
Arthur C. Clarke, 1968

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Abstract

Some applications such as radio astronomy, deep space communications or VLBI (Very Large Baseline Interferometry) require very sensitive receivers. When the technology limits are reached then the receiver operation under cryogenic conditions emerges as a solution to reduce the receiver noise and thus to increase its sensitivity. This dissertation deals with the cryogenic technology applied to the microwave engineering and focuses on the design of very low noise amplifiers both in hybrid (MIC) and monolithic (MMIC) technologies. The work covers a wide field of knowledge from hardware manufacture and system set up to final applications design and measurement. Starting from guidelines and advices to design cryogenic systems (cryostats) that enable to perform microwave measurements under cryogenic temperatures, this document goes into S-parameters and noise measurements in deep. Some methods are presented for measuring S-parameters in a cold environment focusing in a modified TRL (Thru-Reflect-Line) technique adapted for cryogenic measurements. The noise measurement is also covered in detail; an overview of measurement methods is given whereas this thesis makes a comprehensive study of the so-called cold-attenuator technique, providing a new attenuator design that improves the noise measurement accuracy.

The design of cryogenic circuits is initialized with the study of the effect of low temperatures on microwave transistors and components focusing in indium-phosphide (InP) devices, since they are the best solution today for very low noise applications. The knowledge gained with this study is applied to the design of very low noise amplifiers (LNA). This work presents the design of two Ka-band LNAs: one with InP transistors from HRL Laboratories in MIC technology, and the other using mHEMT (metamorphic GaAs) technology in a MMIC chip from OMMIC foundry. Finally, this thesis deals with one of the final applications of the cryogenic amplifiers such as the very sensitive receivers (radiometers) used in radio astronomy; different radiometer architectures are reviewed paying special attention to the receiver developed for characterizing the polarization of the Cosmic Microwave Background (CMB) in the QUIJOTE project, where some subsystems have been designed and measured during this work.

Resumen

Algunas aplicaciones tales como la radio astronomía, las comunicaciones con el espacio profundo y VLBI (interferometría de larga línea de base) requieren receptores muy sensibles. Cuando se alcanzan los límites tecnológicos surge como solución la operación de estos receptores bajo condiciones criogénicas para reducir su ruido y de este modo mejorar su sensibilidad. Esta tesis trata sobre la tecnología criogénica aplicada a la ingeniería de microondas y se centra en el diseño de amplificadores de muy bajo ruido tanto en tecnología híbrida (MIC) como monolítica (MMIC). El trabajo cubre un ancho campo de conocimiento desde la fabricación mecánica y la configuración de los sistemas hasta el diseño y medida de las aplicaciones finales. Comenzando con pautas y consejos para diseñar sistemas criogénicos (criostatos) que permiten realizar medidas de microondas bajo temperaturas criogénicas, este documento profundiza en la medida de parámetros-S y ruido. Se presentan algunos métodos para medir parámetros-S en un ambiente frío centrándose en una técnica TRL (Thru-Reflect-Line) modificada para la medida criogénica. La medida de ruido también se cubre en detalle; se da una visión general de los métodos de medida mientras que la tesis hace un estudio exhaustivo de la llamada técnica del atenuador frío, presentando el diseño de un nuevo atenuador que mejora la precisión en la medida de ruido.

El diseño de circuitos criogénicos se inicia con el estudio de los efectos de las bajas temperaturas sobre los transistores y componentes de microondas centrándose en los dispositivos de fosfuro de indio (InP), ya que éstos son las mejor solución hoy en día para aplicaciones de muy bajo ruido. El conocimiento adquirido en este estudio se aplica al diseño de amplificadores de muy bajo ruido (LNA). Este trabajo presenta el diseño de dos LNAs en banda Ka: uno con transistores de InP de los laboratorios HRL en tecnología MIC, y el otro usando tecnología mHEMT (metamórfica sobre AsGa) de la fundición OMMIC. Finalmente, esta tesis trata con una de las aplicaciones finales de los amplificadores criogénicos como son los receptores muy sensibles (radiómetros) utilizados en radio astronomía; se examinan diferentes arquitecturas de radiómetros poniendo especial atención en el receptor desarrollado para caracterizar el fondo cósmico de microondas (CMB) en el proyecto QUIJOTE, dentro del cual se han diseñado y medido algunos subsistemas a lo largo de este trabajo.

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