A cryogenic front end for CDMA and UMTS wireless base stations

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Abstract. The design and the laboratory performance of a cryogenic front end for CDMA and UMTS wireless base stations is described together with the results of a first field test at a CDMA base station in the region of Tangshan in China. The central elements of the cryogenic front ends are the cryocooler, the cryostat and the cryogenic platform mounted with up to 6 HTS pre-selection filters of high selectivity combined with the corresponding cryogenic low noise amplifiers of high dynamic range as well as the associated control electronics. Design and performance of the UMTS and CDMA filters are described and the characteristic parameters of the cryogenic low noise preamplifier are given. An analysis of the results of the first field test is discussed.

1. Introduction

Early exploratory measurements of the radio frequency (rf) Joule losses in polycrystalline YBCO samples¹ and the encouraging experimental results on the rf surface resistance of epitaxially grown YBCO thin films on SrTiO₃ substrates²,³ have indicated the possibility of the application of HTS materials in microwave systems. The early availability of high quality, commercially produced YBCO coated sapphire wafers⁴ have nourished this expectation. About five years after the discovery of high temperature superconductivity⁵ planar superconducting microwave bandpass filters appeared to be one of the first and challenging application of HTS technology in the fast growing area of wireless communication. HTS bandpass filters combined with cryogenic low noise amplifiers were considered to be attractive as cryogenic front ends for wireless base stations in mobile communication systems all around the world. The most successful commercial application of cryogenic front ends has been demonstrated by STI by the installation of about 5000 systems, predominantly in the United States, in the past years⁶. In the years after 2002 a collaboration between scientists of Germany, the P.R of China, Australia and New Zealand was established in order to strengthen their contribution to this promising application of high temperature superconductivity, to share technologies and to make use of global application opportunities. It is the main subject of this collaboration to investigate if high temperature rf-superconductivity proves to be an important technological contribution to future wireless communication. This report summarises in short our most recent activities.
2. UMTS and CDMA bandpass filters

In the years 1998 to 2003 UMTS bandpass filters were developed at Cryoelectra\textsuperscript{7,8} based on a patented design of Heinz Chaloupka\textsuperscript{9}. The central component of this elliptic filter design is a dual mode resonator with two poles and two transmission zeros. A filter with \(N+1\) poles and \(N\) transmission zeros is composed of \(N/2\) dual mode resonators and one H-type resonator which couples the two groups of dual mode resonators to one filter. Two characteristics of these filters are shown in figures 1 and 2.

At Tsinghua University a CDMA bandpass filter was developed\textsuperscript{10} for a series of field tests of cryogenic front ends in the P.R. of China. The filter has 16 poles and two transmission zeros. The frequency dependence of gain noise figure of the CDMA-Filter-LNA-Combination (CDMA-FLNA) is shown in figures 3.

3. A low noise amplifier with improved dynamic range

High quality low noise preamplifiers are of decisive importance for the quality of a cryogenic front end. At Cryoelectra a low noise cryogenic amplifier was developed based on the ATF-54143 transistor for the UMTS band. The rf input signal to the amplifier is split by a 3 dB hybrid, amplified in two parallel ATF-54143 transistor amplifiers and combined again (for details see ref. 8). The IP1 point of this amplifier is 6.4 dBm (see figure 5) and surpasses the IP3 point of commercial cryogenic amplifiers, which are available to us (MITEQ LNA AFS1-01900200-02-CR-2) by 9.4 dB. The LNA used in the filter–LNA Combination of the Tsinghua cryogenic front end follows the same design as the UMTS-LNA modified for CDMA frequencies. The electronic design of the LNA is shown in the photograph of figure 6.
4. Front end support systems

Several cryogenic UMTS and CDMA front end support systems have been developed at Cryoelectra and at Tsinghua University. A cryogenic front end support system consists primarily of the cryocooler, the vacuum tank, the vacuum system, the cryogenic platform to which the bandpass filter LNA combinations are mounted and the cryogenic rf cables connecting the room temperature rf components with the cryogenic assembly of the FLNAs. An electronic control system takes care of the temperature control of the FLNAs, delivers the different bias voltages, the control of the bypass relays and other electronic features considered necessary to the specific application environment of the cryogenic front end. The first Cryoelectra front end used for exploratory UMTS field tests is shown in figure 7. The FLNAs are mounted on a flat cryogenic platform mounted to the cold head of a Leybold cryocooler using a flexible cryogenic coupling. The cryogenic stainless steel rf cables with silver plated inner conductors of low rf loss and high thermal resistance are seen together with the 17 pole bandpass filters each of them followed by a MITEQ low noise cryogenic amplifier.

**Figure 5** Dynamic range of the LNA (Linearity of $P_{\text{out}}$ versus $P_{\text{in}}$)

**Figure 6** Equipped PCB of the LNA. The two hybrids and the two branches of the LNA are shown.

**Figure 7** View into the vacuum chamber of the Cryoelectra cryogenic front end used in a first UMTS field test

**Figure 8** Experimental cryogenic front end used in the Wunongchang field test.
5. The Wunongchang field test

A first field test was carried out by Tsinghua University in the Wunongchang base station of China Unicom using the cryogenic front end shown in figure 8. The design of this front end is determined by a maximum of convenience for preparatory experiments in the laboratory. It can be assembled and disassembled conveniently and its vacuum is supplied by a 2l/s ion getter pump. Three FLNAs are mounted on a vertical obelisk with an hexagonal cross section mounted to the cold head of a Leybold cooler in vertical position. The rf cable connections are similar to the ones shown in the design of figure 7.

In the field test two of the three FLNAs are used to pre-select and to pre-amplify the receive signals of one main antenna and the corresponding diversity antenna. The pre-amplified signals are then transferred to the commercial base station electronics. By a microwave switch the HTS filter LNA combination can be bypassed and the antennas are then connected to the base station electronics in the standard way. The prime motivation for the Wunongchang base station field test was to gain experience with all of the related procedures and to demonstrate the reliability of the cryogenic front end under standard operating conditions. The cryogenic front end was first operated in the base station in April 2004. The system has been working reliably up to the time that this report is written. A drive test was carried out in April of 2004. During this drive test a vehicle equipped with a mobile phone and appropriate equipment was monitoring the transmission power of the mobile phone, which in turn was controlled by the Wunongchang base station. By switching the bypass this power was registered for the case with and without pre-amplification and pre-selection by the cryogenic front end. A significant reduction of the mobile phone power by in the average 3 dB was observed. This large reduction came as a surprise to us. It was not expected on the basis of a coverage and capacity model11 developed in order to analyse this and similar experiments. The reason for this significant improvement has to be investigated in more detail in future experiments. For this purpose a new test using 5 base stations equipped with cryogenic front ends for all of the relevant antennas is being prepared by Tsinghua University.

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