Superconducting Technology for Wireless Communication: Development of a CDMA Base Station Cryogenic Front End Receiver

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***Abstract-* Cryogenic Front End (CRFE) receivers consisting of a High Temperature Superconducting filter and a cooled Low Noise Amplifier placed between a Base Station antenna and a receiver electronics can significantly increase coverage and capacity in the presence of interference. In this paper the development of a family of CDMA CRFEs (D 6-9 and M1) by Cryoelectra GmbH and their performance are presented.**

I. INTRODUCTION

The discovery of the phenomenon of superconductivity in 1911 and of High Temperature Superconductors in 1987 resulted in availability of materials with zero resistance to dc current and very small surface resistance (R_S) at lower microwave frequencies below a certain critical temperature T_C (Fig. 1).

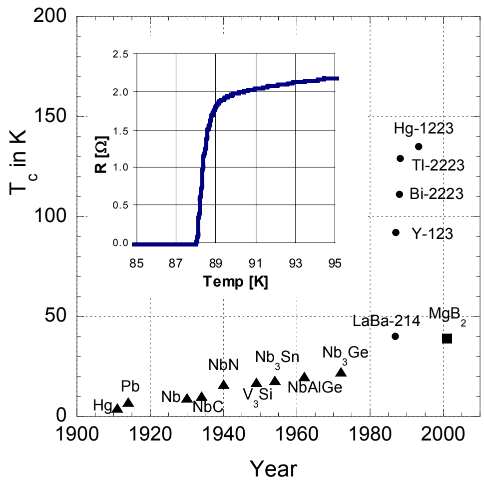

Fig. 1 History of development of superconducting materials and resistance vs temperature (insert)

The low loss (330 times smaller than copper at 1.85GHz for $YBa_2Cu_3O_7$ (Fig. 2) and lack of dispersion of HTS films allow for microwave superconducting planar circuits with a very high Q-factors. Hence HTS microwave filters [1, 2] were the first application envisaged for HTS materials as early as 1987 [3].

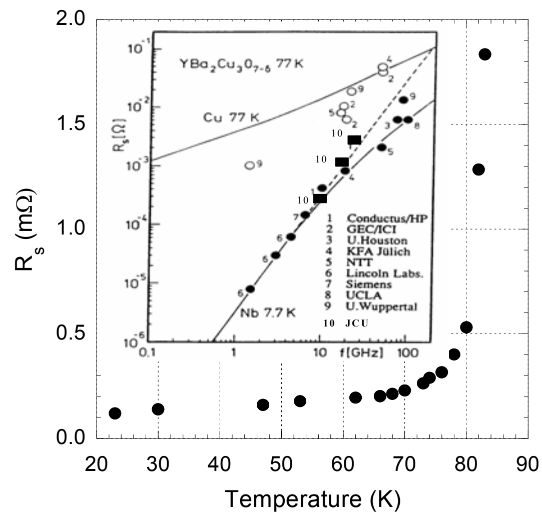

Fig. 2 Surface resistance of YBCO vs temp and frequency (insert [4])

As conventional planar designs did not take full advantage of HTS exquisite properties, several types of single and dual mode resonators for HTS filters have been developed in the last twenty years, some of which are shown in Fig. 3.

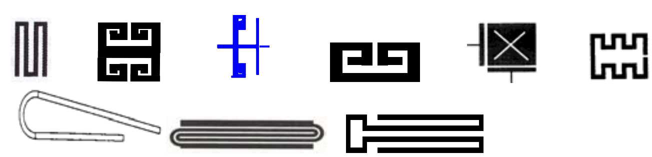

Fig. 3. Examples of resonators layouts used for HTS filters [5]

HTS planar filters combined with Low Noise Amplifiers form very selective and low noise receivers of very low Insertion Loss. Such a system, (typically refereed to as Cryogenic Receiver Front End CRFE), when installed between a receiving antenna and a base station electronics provide interference protection, increased coverage or capacity, higher data throughput and reduction in dropped and blocked calls [6].

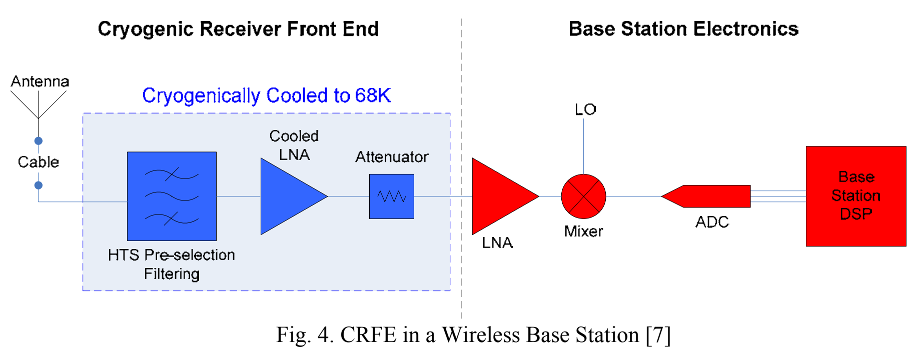

Fig. 4. CRFE in a Wireless Base Station [7]

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Various front-end HTS receivers: omni and three-sectored, CDMA, GSM and TDMA, 2G, 2.5G and 3G systems have been commercially developed [8] since 1997 by Superconducting Technologies Inc. and (but not any more) by SCT, Conductus, and ISCO Int. Several noncommercial HTS filters or/and CRFEs had been developed by large consortia: SCENET, Denso, Toshiba, Fujitsu, NEC, DuPont and LG; however most of these projects have now been closed down. A UMTS 3G CRFE with 20MHz bandwidth [9] was developed by Cryoelectra, (a small company formed by scientists from University of Wuppertal) in 2003. This was followed by development of a modular Front End for CDMA operation in collaboration with Tsinghua University, as well as Massey and JCU. Stages of this project (D6-D8, M1 and D9) and improvements made in particular models are described below.

II. DEVELOPMENT OF CDMA CRFE

A first model ready for field trials, "**Demonstrator 6" (D6**), was a 3 RF channel ground based system consisting of RF components, supporting vacuum and cryogenic equipment, and control systems as shown in 5.

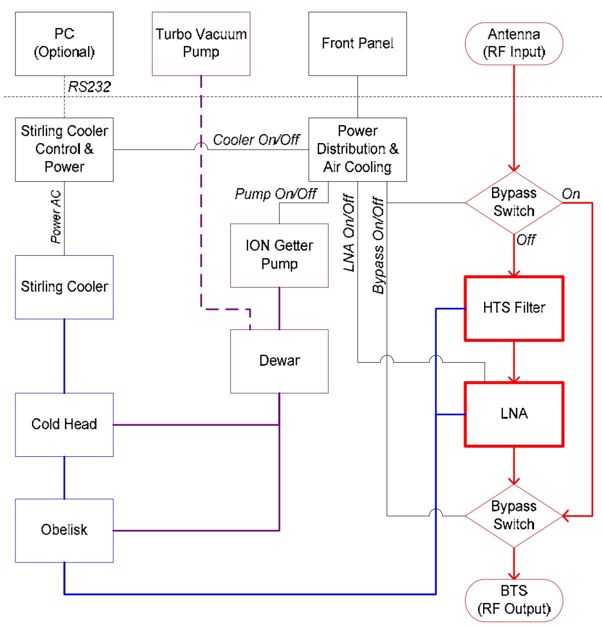

Fig. 5. Block Diagram of D6 CRFE

The RF part is the most fundamental part of the CRFE as it deals with the RF signals received by the base station. All the other components are used to support the operation. The Vacuum and Cryogenic equipment maintains a suitable operating temperature for the HTS filter and LNA, and the front panel and the power distribution board are used to control operation of the CRFE. A PC was used for the setup and monitoring of operational parameters of the cooler, but is not required for operation.

The two most fundamental components of the CRFE are an ultra low noise amplifier, developed by Cryoelectra for this application, and a HTS filter. The LNA exhibits excellent parameters [ref]; a gain of 15.2dB, a noise figure of 0.8dB at ambient temperature with a supply voltage of 5V and a very wide dynamic range (IP1 = 6.4dBm, OP1 = 20.4dBm, and OIP3= +35 dBm). The LNA for D6 was enclosed in brass housing.

A HTS filter for D6 based on a meander line resonator (Fig. 6) was designed at Tsinghua University. The filter characteristic has 16 poles and two transmission zeros, and a measured frequency dependence of the S parameters of the filter-LNA combination is shown in Fig. *7*. The insertion loss of this filter is less than 0.5dB and the steepness is approximately 50dB/MHz. Three sets of the filter-LNA combinations were mounted on an obelisk installed vertically.

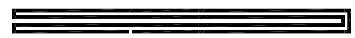

Fig. 6. HTS Resonator used in filters for D6 and D7

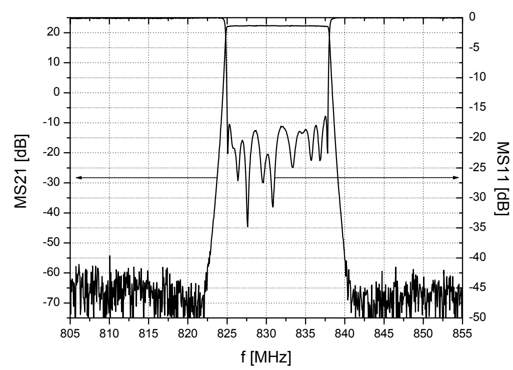

Fig. 7. Characteristic of HTS and LNA configuration [9]

To remove gases expelled from the surface of objects within the vacuum such as the obelisk, filters, LNA and the walls of the Dewar a constant pumping mechanism is required in CRFE. While heat treating the walls of the Dewar before sealing removes much of the water and hence reduces the amount of gases expelled after the Dewar is sealed, the need for vacuum maintenance still exists. The CRFE D6 used an external ION Getter pump in order to maintain the vacuum inside the Dewar. The drawback of the ION Getter Pump was the requirement for a high voltage power supply, and its size made it sit outside the Dewar. The cooling of the D6 system was provided by a Leybold Stirling cooler.

Fig. 8 CRFE D6 with Devar mounted vertically

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Field tests of CRFE D6 conducted in Wunongchang showed a 3dB decrease on power of handhold sets with D6 operating. In the course of investigating performance of D6, analysis of field tests in China [10] and simulation results obtained using a developed CDMA Uplink Model [7], a series of engineering innovations and improvements were made in an effort to optimize the performance cost ratio and bring the technology closer to the market. The goal of the new systems was to achieve the best possible technical performance while also improving its install flexibility, operator usability and minimizing the cost of production.

The system D7, an immediate successor to D6, used a six channel hexagonal obelisk in order to work with typical 6 channels base stations (a main and a diversity antenna for each of the three sectors). A less expensive and easier to tune 12 pole version of the HTS filter of D6 was used in this CRFE.

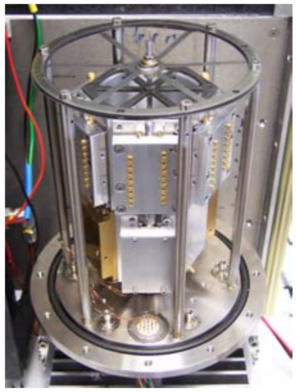

Fig. 10 A Six Channel Obelisk with 6 Filter LNA combinations

The LNA brass housing of D6 was replaced with a lighter aluminium housing in D7 in order to reduce the weight on the cold head in the rack mountable systems D8 and D9.

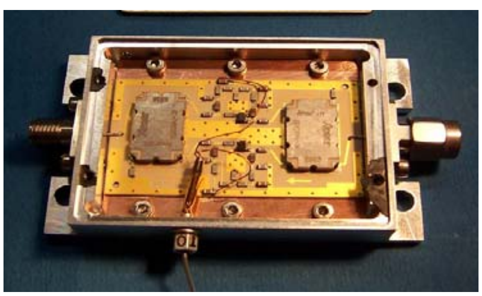

Fig. 9. Cryoelectra LNA in Aluminum Housing

D7 had also a radiation shield added, to minimize the heat introduced to the system via hot body infrared radiation. This reduced the required cooler power and improved the cost of operating the system. The radiation shield itself was a uniformly smooth, shiny (ideally gold, but in this case aluminum) surface, and was wrapped in several layers with fiberglass inserted between the layers to isolate them from one another. This simple radiation shield reduced the power consumption by approximately 42%. The system D7 was tested in Beijing, China and showed a similar decrease (2.73dB) in required handset transmit power as the D6 tests did, but also showed a 16% reduction in lost calls and a 41% reduction in access failure rate.

The system D8 was developed to fit completely into a 19 inch rack (i.e. no Dewar protruding from the top as in D6 and D7).

This required placing the cold head and Dewar horizontally rather than vertically and supporting the weight of each effectively. For CRFE D8 a new 12 pole filter was designed.

Fig. 11 CRFE D8 with Dewar mounted horizontally

The individual resonators of the D8 filter have a shape of a meandered line, but in contrast to well known designs, the coupling arms of the resonators start and finish close to the centre, not at edges of the resonator structure. This enabled a very small separation between the adjacent resonators and produced a filter characteristic with a symmetric pair of transmission zeros close to the passband. Using this approach it was possible to place the same number of resonators on the same sized substrate as for D7, but with double the line width. The wider lines resulted in the resonators having a higher unloaded Q-factor and nonlinearity threshold. Consequently the losses of the newly designed filter were reduced.

For vacuum maintenance in D8 a Non-Evaporable Getter (NEG) Pump, was employed, offering a more elegant solution as compared to the ION Getter pump employed in D7. The major drawbacks of the Getter pump employed in D7 was its size and the requirement for a high voltage power supply. In NEG pumps a variable DC source (up to 3A) instead of a high voltage power supply is sufficient.

The first mast mountable CRFE by Cryolectra was **M1** (Fig. 12, designed to eliminate the noise introduced by the length of cable between the antenna and the front end. After amplification of the signals at the top of the tower this noise was no longer an issue, therefore mast mounting the CRFE was a logical evolutionary step.

Fig. 12. M1 with an open Dewar

In CRFE M1 a 20 pole HTS filter (of design shown in Fig. 13) was employed with the same coupling arrangement between the resonators as for D8. The full wave simulated characteristic of this filter is shown in Fig. 14; Insertion Loss is below 0.6dB and the skirts are 70dB at 1MHz from the edge of the passband.

D9, the newest ground system was developed with Ricor Stirling cooler (when Laybold stopped production of the Stirling coolers). The new cooler meant once again redesigning the placement of components in the new system, which was also to be horizontally mounted. All previous improvements of D8 were also implemented in this model.

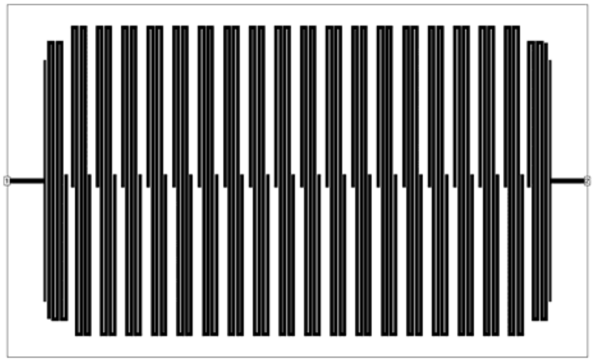

Fig. 13. Schematic of a 20 Pole CDMA Filter for M1 and D9

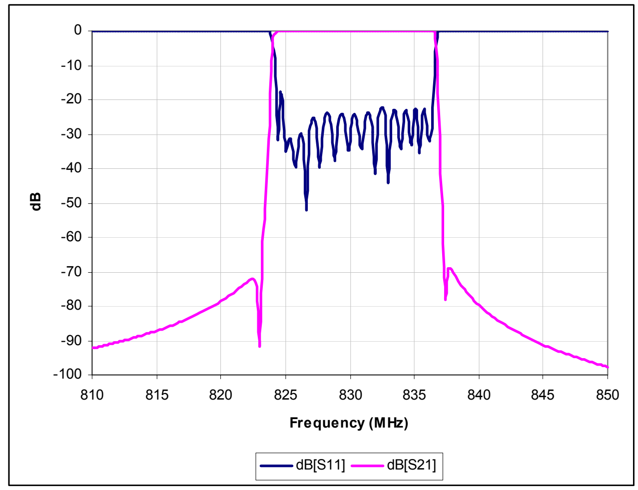

Fig. 14. Simulated Response of CDMA Filter for M1 and D9

III. CONCLUSIONS

The Table below gives a summary of the changes introduced each of the developed CRFE systems. Field trials and in house tests have shown that developed Cryogenic Front End Receivers reduce the required handset transmission power by about half, thereby increasing coverage and/or capacity, and decrease loss call and access failure rates.

Although a fairly mature technology now, HTS filters (and the CRFE they are a part of) have not been widely accepted by the marketplace despite their technical superiority. While development and manufacturing costs play a large role in this non-acceptance such hindrances are overcome with time, solutions such as those presented in this paper and mass manufacturing.

The problem the HTS filters face currently is that while they provide some benefits for current wireless systems their full potential is not realized. The Communication Industry still uses older but less expensive filtering with wide guard bands to prevent interference. In the future when bandwidth will be more expensive and les available it is distinctly possible that the base station receivers based on the HTS filter technology will become a part of everyday life.

ACKNOWLEDGMENT

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	D6	D7	D8	M1	D9
Stirling Cooler	Leybold	Leybold	Leybold	Leybold	Ricor
RF Channels	3	6	6	6	6
LNA	Brass Housing	Aluminum Housing	Aluminum Housing	Aluminum Housing	Aluminum Housing
HTS Filter	Tsignhua Design	Tsignhua Design	Cryoelectra Design	Cryoelectra Design	Cryoelectra Design
Mast Mountable	No	No	No	Yes	No
19" Rack Mountable	2 Bays	2 Bays	Yes	No	Yes
Vacuum	ION Getter	ION Getter	NEG	NEG	NEG
Heat Shielding	No	No (Optional)	Yes (Optional)	Yes (Optional)	Yes (Optional)
Control System	Leybold Polar	Leybold Polar	Leybold Polar	Leybold Polar	Cryoelectra Controller