

An HTS Transceiver For Third Generation Mobile Communications

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Abstract—Future Third-Generation Mobile Communication Systems will require improved sensitivity and selectivity to support the growth in multi-media services, increased coverage, longer talk time and larger numbers of subscribers.

The paper describes a transceiver for use in mobile and personal communications Base Transceiver Stations (BTS). Key components of the transceiver are fabricated using thin film High Temperature Superconductor technologies to achieve, in the receiver chain, enhanced sensitivity and selectivity and, in the transmitter chain, reduced combiner losses and increased selectivity.

Cryo-packaging techniques, which provide a long between-service interval are described. The cryogenic r.f. module encapsulation design features novel r.f. and thermal interconnects which obviates the need for long lossy input cables. In-situ tuning methods allow the HTS filters to be optimised at the operating temperature, 60K, and in vacuum.

The transceiver incorporates an integrated miniature Stirling-cycle cooling engine designed for a 5-watt heat lift at 60 K, over an ambient temperature range of -40°C to $+65^{\circ}\text{C}$. The control electronics are driven directly from the BTS d.c. supplies. The input power requirement to the cryo-cooler and drive electronics is <250 watts. The design of the cooler is arranged to provide an inherent balance, virtually eliminating vibration.

Multiple r.f. transceivers are integrated with a single cryo-cooler, and together with bypass switching, alarms and lightning protection, are contained within a single mast-head mounted weatherproof housing.

I. INTRODUCTION

With the projected proliferation of mobile communications, and specifically of the lower power Personal Communications Systems (PCS), research is being vigorously pursued in 'conventional' and cooled electronics, such as [1], to enhance overall system performance to increase capacity and

coverage and to achieve reduced infrastructure costs. High Temperature Superconductors (HTS) technology has been shown as one viable option to achieve the desired goal.

Described here is the work being carried out as part of the European Community's Advanced Communication Technologies and Services (ACTS) programme on Third-Generation Mobile Communications Systems or otherwise known as Universal Mobile Telecommunications Systems (UMTS). The work reported on is the ACTS project, Superconducting Systems for Communications (SUCOMS), researching the application of HTS to communications.

Key aims of the project are to enhance the r.f. performance of both the transmitter and the receiver chains of a Base Transceiver Station (BTS) by the application of HTS to the critical components. Performance improvements will be quantified through a series of technology demonstrators of increasing complexity in conjunction with 'live' operator trials. Each of the demonstrators are designed to operate with a three-sector BTS with diversity antennas. The location of the trials has been chosen to cover the different operational scenarios; high-density urban and low-density rural.

The capacity and coverage of a BTS receiver is determined primarily by the mobile transmitter power and the receiver selectivity and sensitivity on the up-link and in part by the BTS transmitter power of the down-link. Selectivity can be significantly increased by the use of high-order elliptic function filters. Conventional filters would exhibit very high pass-band insertion loss, resulting in a reduced signal to noise ratio and hence a loss of receiver sensitivity. In another system [1] a conventional dielectric filter is cooled with some improvement in performance. However, a single receiver filter and amplifier unit of this system is too large for mast-head mounting. Miniature filters fabricated from HTS materials have been shown in this work and elsewhere [2], [4] to provide high selectivity and very low loss. Sensitivity is increased two fold by the application of HTS; through the reduced insertion loss of the passive HTS elements and through

Manuscript submitted September 15 1998.

The work is part funded by the European Commission under an Advanced Communication Technologies and Services (ACTS) initiative and in part by the industrial partners GEC-Marconi, Thomson-CSF, Leybold Vakuum and contributing operator Telecomunicacoes Movel Nacionais.

a reduced noise figure of the HTS and other cooled components such as the LNA.

By innovative circuit design, thin film HTS which is generally associated with low power systems can be applied to high power components. In this respect the aim of this work is to reduce the losses and increase the selectivity of the transmitter chain components. High-power filter applications have been addressed by a number of groups [5], [6]. By utilising two or three dimensional structures which exhibit low current densities and hence low magnetic surface fields, filters suitable for application to a BTS transmitter chain can be produced.

Small low loss HTS filters can replace the large conventional cavity-type transmitter filters currently used. These filters can be used to improve selectivity and reduce spill over into adjacent channels. The filters are also configurable to form the channel combining. The reduced size enables these filters to be integrated with the receive components in a single mast-head unit. Thus the normal large, lossy r.f. mast cable feeds (typically, 27m long) can be eliminated which in turn reduces the power amplifier requirements. It is anticipated that the power amplifier output can be reduced from the current 40watts to 2watts, with a similar significant reduction in the primary d.c. supply, for the same radiated power.

Where size, mass and primary power consumption are a particular issue, e.g. for micro-BTS applications, the superconducting BTS can provide a viable solution. The overall size and mass of multiple HTS transceiver chains, including the associated cryo-cooler, are considerably less than an equivalent conventional head amplifier and receiver filter.

II. TECHNOLOGY DEMONSTRATORS:

The *SUCOMS* project is developing a series of technology demonstrators with increasing functionality. Each demonstrator includes an integrated miniature closed-cycle Stirling engine cryo-cooler and is capable of being mast-head mounted. The development models are fitted with fail-safe switching and alarm electronics to allow direct connection into operators' equipment.

A. An HTS Transceiver

Design of the r.f. components, the vacuum encapsulation, the r.f. modules and the cryo-cooler are inseparably linked. The emerging design has been accomplished by successful close collaboration of the contributing industrial and academic project partners. This has in many aspects of the design required some rethinking of established design practice.

The overall design philosophy of the miniature HTS multi-channel transceiver with an integrated Stirling engine cryo-cooler for mast-head mounting is described below.

B. R.F. Module

The r.f. components are housed in common modules. This

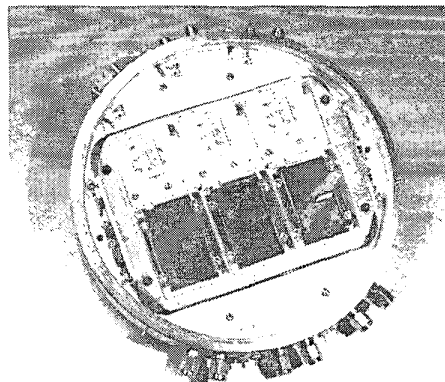


Fig.1. Dual Sided Six Channel Filter/LNA Module.

approach allows the transmitter and receiver functions to be developed in parallel. It further allows the complete system to be progressively developed and field-trialed. The first demonstrator comprises six channels. Three channels include an eight-pole HTS filter and a low noise amplifier. The other channels include a nine-pole filter of a different design. A receive filter/LNA module assembled into a connector ring is shown in Fig.1. The ring forms part of the vacuum encapsulation which was welded to the cryo-cooler. The design of the filters are fully described in [7], [8]. Fig 2 shows the performance an eight-pole filter.

Additional modules contain three high power HTS duplexers, transmitter filters and combiners, local oscillator, and a local oscillator splitting network with mixers.

Each high power duplexer comprises a pair of hybrid coupled stop-band filters in a conventional configuration. The coupled-line hybrids cover the full receiver - transmitter band, 1710 - 1880 MHz. In the transmit mode the filter resonators are non-resonant and absorb little power. Each stop-band filter is tuned to the required 15 MHz receive-channel frequency. The complete duplexer is fabricated from HTS on lanthanum aluminate (LAO) substrates. Ohmic contacts are made using sputtered silver pads. Bridging contacts on each hybrid are made via a pair of gold bond wires.

The duplexers show very low insertion loss at the receive

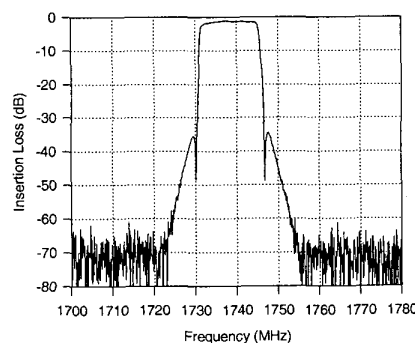


Fig. 2. Eight Pole Elliptic Function Filter.

power levels. As expected, the insertion loss increased slightly at high power levels. Tests conducted at the highest power available to us at present, 8 watts, shows an increase in the insertion loss to 0.45dB.

The significant performance figures for the HTS duplexer design are given in Table I.

TABLE I
MEASURED PERFORMANCE OF THE HTS DUPLEXER

Receiver Frequency	1770-1785MHz
Antenna Port Return Loss	>25dB
Receiver Port Return Loss	>26dB
Antenna - Receiver Port Loss	0.25dB
Transmitter Frequency	1865-1880MHz
Antenna Port Return Loss	>27dB
Transmitter Port Return Loss	>28dB
Transmitter - Antenna Loss At 8watt Input Power	0.45dB
Transmitter - Receiver Port Isolation	>36dB
Receiver - Transmitter Port Isolation	>36dB

The performance of the low noise amplifier was also evaluated. The noise figure was reduced from a room temperature figure of <0.8dB to <0.2dB at 77K. The amplifier exhibited a small increase in gain and slight reduction in the 1-dB gain compression at the low temperature. These parameter values are only slightly effected as the d.c. bias is reduced. This ability to reduce the bias power without loss of performance significantly benefits the demands placed on the cooler heat lift requirement.

A low-noise local oscillator design comprising a single FET and incorporating an HTS linear resonator in the feed back loop is currently being evaluated. The complete circuit was fabricated from HTS on a LAO substrate. To minimise the heat dissipation the regulator circuit was mounted on the warm side of the dewar. The bias was fed to the device via a high thermal resistance link as described in the following section. As a further means to minimise dissipation into the cold finger the output signal from this low power LO was amplified externally to the dewar. The LO was returned and split to six cooled mixers. The splitter and mixers are currently fabricated from conventional metals.

C. Encapsulation

A number of novel features were incorporated into the encapsulation or dewar design. Conventionally the cryogenic/r.f. interconnection across the encapsulation vacuum space is made using high thermal resistance and hence r.f. lossy co-axial cables. For this design a microstrip feed network and a novel high performance r.f./thermal link was used to perform this function. The link has been tested to 17watts

CW without failure. Vacuum sealed co-axial connectors interface to the BTS. The resulting design was compact with a low conduction heat load and low r.f. losses [9]. The modular approach adopted enabled complex systems to be configured simply by adding additional sub-assembly modules. Each self contained, double sided assembly comprised a connector ring with microstrip interconnect circuits, low thermal conduction links and a r.f. module. The connector ring included an extended reweldable flange which allowed the internal components to be reworked at least twice prior to site installation. Special design features enabled the filters to be tuned in-situ; at the system operating temperature of 60 K and in vacuum.

Input alumina microstrip circuits included interconnections to temperature sensors mounted on the cold finger and the r.f. module. These sensors formed part of the closed loop control of the cooler. The output circuits included provision for the hybrid circuit voltage regulators for the LNAs. Low thermal conductivity wire bonds bridged the thermal break between the ambient temperature dewar component and the cooled r.f. module. A schematic of the assembly is shown in Fig 3.

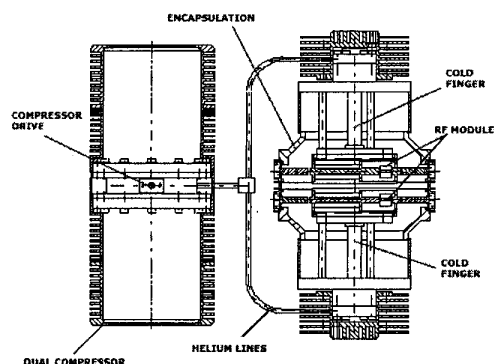


Fig. 3. Stirling Cooler and Compressor with Two Integrated r.f. Modules.

D. Cryo-Cooler

In designing a mast-head mounted transceiver based on HTS, implicitly required cryo-cooling. A major design challenge was to make the cooler "invisible" to the BTS operator. This dictated a "fit and forget" design philosophy. The design had to meet the following criteria;

- self contained, requiring minimal service utilities,
- compact and low mass, offering low mast head load and low wind resistance,
- highly reliable, provide a 40000 hour maintenance free cycle,
- capable of mast-head mounting, operating in all weathers and ambient temperatures from a -40°C to +65°C,
- highly efficient, requiring low input power, typically <250watts, and be capable of battery operation,
- operated from BTS site d.c. or a.c. supplies.

Crucial to achieving these goals was the design of the cooler. It had to provide;

- acceptable operational cool down time, <2 hours,
- continuous >40000 hour operation,
- very stable cryogenic temperature, typically <0.5K,
- medium capacity heat lift, typically 5 watts at 60K into a +65°C reject temperature,
- 'vibrationless' cold head, to eliminate induced microphonic effects in the r.f. components.

These requirements were met using, a closed cycle Stirling engine cooler with a regenerative cold head which is widely regarded as the obvious choice. A miniature Stirling engine was developed for the demonstrators and incorporates design features which specifically addressed the vibration and high reliability issues. A balanced compressor and cold head reduced the vibration levels to a minimum and gas bearings reduced the wear. The prototype cooler provided a heat lift of >4 watts at 60K which easily met the requirements of the receiver/LNA components. Fig 4 shows a demonstrator comprising r.f. modules, encapsulation and Stirling engine compressor/cooler.

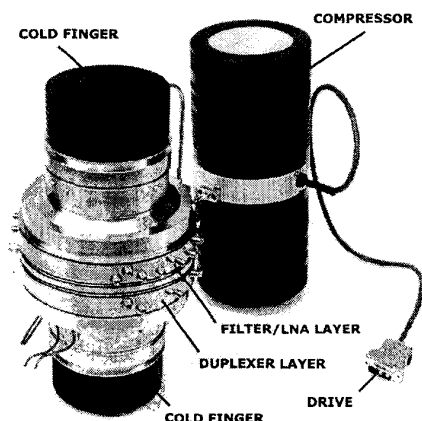


Fig. 4 Stirling Cooler with Dual Cold Finger and Dual Compressor and Vacuum Encapsulation.

E. Mast-Head Mount

To maximise the benefits from an HTS transceiver a mast head configuration was essential. The unit described met all the criteria required for this option. In practice the required low voltage supply can be drawn from the mast down-link cables. However, it has been reported that high levels of d.c. on the r.f. feeders may lead to increased intermodulation products. For future proposed designs the r.f. will be fed to and from the transceiver on optical fibre; a separate d.c. line will be required thus avoiding the problem.

All equipment, comprising cooler and temperature control loop, r.f. modules and encapsulation, and power supplies are contained within a weather proof enclosure. Lightning protection, alarms and bypass relays are included in the proto-

type. The transceiver enclosure is 650 mm x 550 mm x 300 mm with an associated mass of 37 Kg.

III. CONCLUSION

HTS technology provides one of several solutions currently being pursued to enhance the performance of a BTS. The technology is equally applicable to macro-, micro- and pico-BTSs. Enhanced performance from r.f. components has been reliably demonstrated in the current ACTS project for future the UMTS. However, the technology is sufficiently well matured to allow promulgation to second generation commercial mobile and PCS communications systems. Current production cryo-coolers for the second generation equipment, though reliable, are large, requiring high supply power, in some cases water cooling, exhibit high vibration at the cold head and have low mean time between maintenance (MTBM) periods. For future third generation communication systems, the cryo-cooler must be an "invisible" to the operator. This will be achieved by the successful design of miniature, highly reliable and efficient Stirling engine, leading to long MTBM periods. Such a design has been developed and a commercial product is today nearing the market place. Reliability and longevity is still an issue to be proven for the new design of cooler. However, similar existing designs of a Stirling engine are undergoing life testing and have already demonstrated life times in excess of 25000 hours without failure.

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