Current CSIRO Investigations into the Potential Applications of High Temperature Superconductor Filters within Radio Astronomy and Telecommunications

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Abstract

In the past few years, CSIRO has been engaged in research and development of high-T_c superconducting microwave devices and circuits. This paper describes the fabrication capability and current activities in HTS microwave technology within CTIP. For applications in telecommunications and radio astronomy, two types of HTS filters were successfully fabricated and tested in a collaborative effort between CTIP, ATNF and MOSAIC. The first was a ~1.8 GHz HTS band-pass filter for telecommunication mobile phone networks and the second was a 1.6 GHz HTS high-Q notch filter for removing Iridium satellite interference signals. The fabrication details and measurement results are presented in this paper. Future directions within CTIP, including a combined HTS/GaAs receiver front-end are outlined.

Introduction

High T_c superconductors (HTS) are new materials for microwave engineering. The HTS thin films have surface resistance values of 10 to 1000 times lower than that of conventional metallic films (copper or gold) at microwave frequencies [1]. Microwave components and circuits made of HTS materials have many distinct advantages over their metallic counterparts, such as low insertion loss, high Q factor, low noise, low power consumption and the potential for compact structure (due to high dielectric constant substrates). Successful examples of HTS resonators, filters, mixers, and hybrid HTS oscillators and amplifiers have been reported in the current literature [2-8].

The first and most important application of HTS microwave technology is in high-Q resonators and filters. At present, multi-channel communication networks demand filters with narrow bandwidths and sharp skirts to allow available RF frequency spectrums to be partitioned into small bands. HTS materials can be used to make high performance multipole filters with very narrow bandwidths, sharp skirts and very low in-band insertion losses, which can not be achieved with normal metallic designs without suffering excessive losses. These super filters are gaining increasing acceptance in both terrestrial and satellite communication systems. As a demonstration of CTIP and ATNF's capabilities, a 9-pole, band-pass HTS filter targeted at the telecommunications mobile phone networks was successfully fabricated and tested for MOSAIC.

Satellite based communication systems can cause difficulties for the international radio astronomy community. For example, the ill-fated, Iridium satellite based global communications system, which operates at 1.616 GHz and 1.626 GHz, interferes with radio astronomy signals in the 18cm band. The ATNF and CTIP have developed a 3-pole, high-Q, HTS notch filter for removing this interference, which could be of considerable interest to the international radio astronomy community. Another cause of concern for the local radio astronomy community is a microwave distribution system (MDS) operating within line of sight of the Australia telescope compact array at Narrabri, N.S.W. This MDS system operates between 2.3 and 2.4 GHz and interferes with the 13 cm band observations. A low insertion loss, HTS, band-stop filter is currently under development within CTIP and ATNF to remove these MDS interference signals.

CTIP HTS microwave device fabrication capability

CSIRO TIP has been involved in the research and development of HTS materials, devices and applications since its discovery 13 years ago. It has established a leading position in some HTS technology areas both within Australia and worldwide. In 1997, the combining of the former CSIRO Division of Radio Physics and the Division of Applied Physics produced a unique combination of expertise in HTS technology, microwave engineering and GaAs device fabrication, which places CTIP in a favourable position for developing HTS microwave technology.

CTIP has a well established Clean Room on the Lindfield site for routine fabrication of HTS devices. It contains mask aligners, ion milling machines, chemicals for wet etching, metal film deposition systems, and deposition systems for producing HTS $YBa_2Cu_3O_{7-x}$ (YBCO) thin films. The scanning electron microscopy (SEM), atomic force microscopy (AFM) and x-ray diffraction (XRD) systems can be used to characterise HTS thin films, substrates and devices. Some of our HTS research and development for the superconducting quantum interference devices (SQUIDs) is readily applied to microwave device fabrication. For example, Josephson Junction technology developed for our SQUIDs can be used for making other microwave active devices such as flux flow transistors, mixers, detectors and oscillators. Metallisation and interconnection are important steps for packaging HTS microwave devices and circuits. Techniques of making reliable low resistance and bondable HTS-metal contacts have been developed. Our passivation techniques can also be used to protect HTS microwave devices from the environmental degradation. The GaAs HEMT and flip-chip technology developed by GaAs Facility at CTIP is being used for fabricating hybrid HTS/GaAs microwave devices.

In the past three years, a number of HTS microwave devices have been fabricated within CTIP. These include 26 GHz HTS bowtie mixers with IF bandwidth of 8 GHz, microstrip line and coplanar resonators and transmission lines in the 10-20 GHz band, various microstrip line band-pass and band-stop filters of differing designs and centre frequencies (1.6 GHz, 1.8 GHz, 10-13 GHz). HTS/GaAs hybrid low phase noise oscillators and amplifiers are also under investigation. Superconducting thin films YBCO produced in house, as well as purchased from commercial sources, were used. Low loss dielectric materials MgO ($\varepsilon_r = 10$) and $LaAlO_3$ ($\varepsilon_r = 24$) were used as substrates. The fabrication and measurement of the two HTS filters for applications in telecommunication and radio astronomy are described in more details in next section.

HTS filter results

Two HTS filter designs will be described: a 9-pole, band-pass filter and a 3-pole, band-stop filter. The masks used to pattern these HTS filters are shown in Figs. 1 and 2 respectively. The band-pass filter is a compact design which uses nine, coupled, microstrip resonators to define a highly selective filter with a narrow pass-band and high attenuation of signals outside the pass-band. The band-stop filter uses three, half-wavelength, microstrip resonators coupled, at quarter-wavelength intervals, to a microstrip line through the filter.

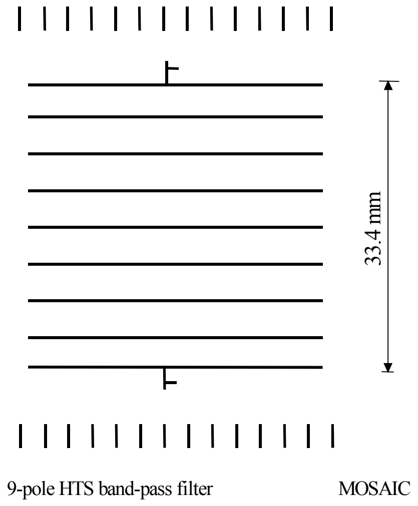

Fig.1 Design of the 9-pole band-pass filter

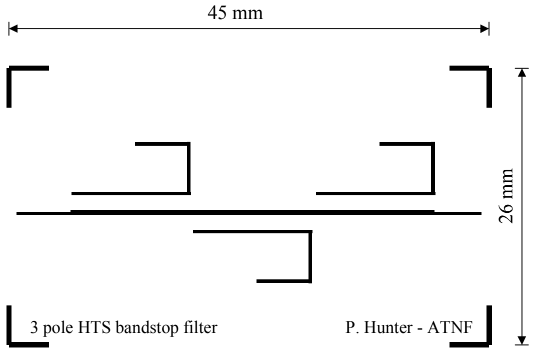

Fig.2 Design of the 3-pole notch filter

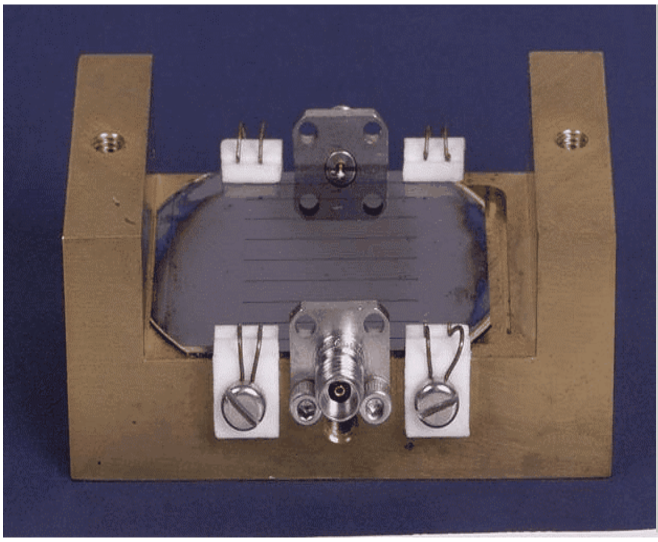

Fig.3 Photo of the packaged band-pass filter

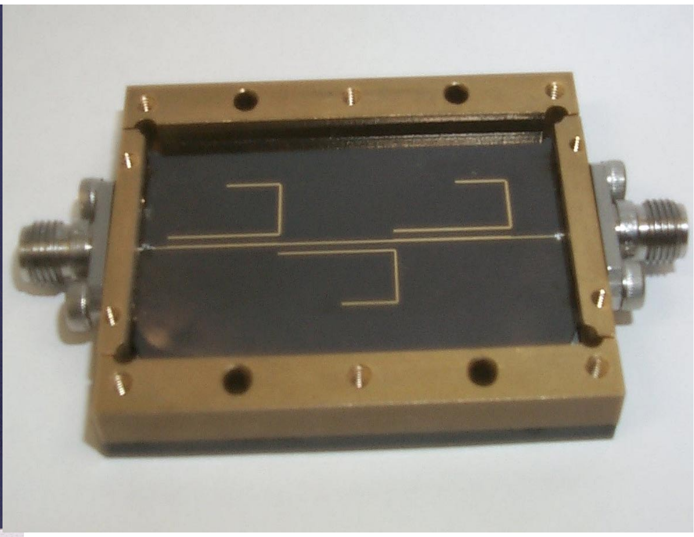

Fig.4 Photo of the packaged 3-pole notch filter

The filters were fabricated on superconducting YBCO films deposited on the 50 mm diameter, 0.5 mm thick, $LaAlO_3$ substrates[1]. The films, deposited on both sides of the $LaAlO_3$ substrate, were approximately 250 nm thick. 1000 Å thick layer of gold was deposited over the YBCO film on both sides of the substrate to provide good electrical contact between the filter and the input and output RF connections. The gold also acted as a passivating layer to protect the YBCO film. The filters were patterned by standard photolithographic methods. The film on the top was patterned to form the filter structure,

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[1] The films and substrates supplied by TU, Munich and TRW

while the film on the bottom was used as a ground plane. A combination of wet chemical etch and ion-milling techniques were used to remove the gold and YBCO materials.

The completed filters were cut to size and packaged. A variety of techniques have been used to package the filters. The band-pass filter, clamped into a gold-plated brass package with silver epoxy applied at the contacts, is shown in Fig. 3. Fig. 4 shows the band-stop filter, mounted on an AlSiC base using silver paste[2]; the remainder of the band-stop filter package was gold-plated brass.

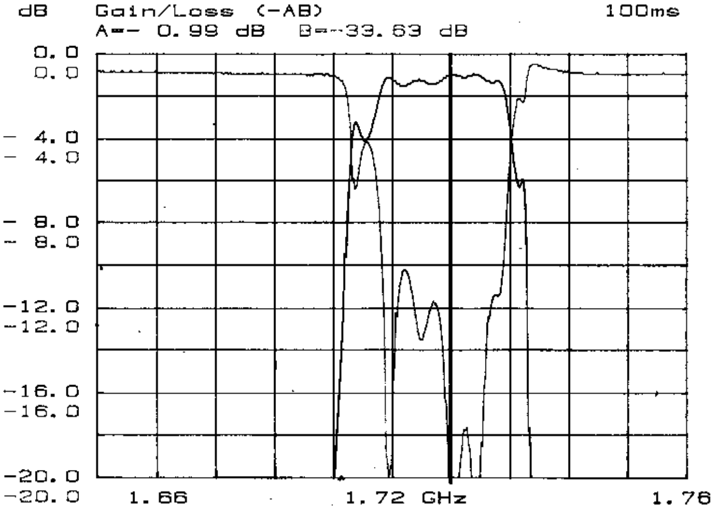

Fig.5 Frequency response of the 9-pole band-pass filter

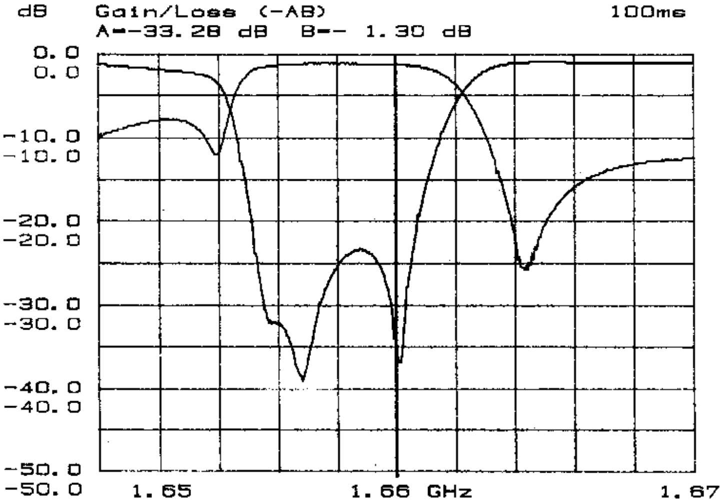

Fig.6 Frequency response of the 3-pole notch filter

The packaged filters were tested in a cryogenic system which can cool to 15 K. The cryogenic RF performance of the filters was measured, at the dewar flange, with a scalar network analyser. Fig.5 shows the frequency response and match of the band-pass filter, in the dewar, measured at an operating temperature of 16 K. The filter has a 30 MHz wide pass-band centred at 1.73 GHz (a fractional bandwidth of 1.7%) and very sharp skirts. After correcting for 0.5 dB loss in the RF cables in the dewar, the loss of the filter is estimated to be less than 0.6 dB. The filter has a return loss of better than -10 dB over most of the pass-band.

Fig.6 shows the frequency response and match of the notch filter measured at an operating temperature of 18 K. The filter has an attenuation of greater than 20 dB over a 6MHz band, centred at 1.66 GHz (a fractional bandwidth of 0.35%). After correcting for 1 dB loss in the RF cables in the dewar, the out-of-band loss of the filter is estimated to be less than 0.3 dB.

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[2] SPI Silver Paste “Plus”, manufactured by Structure Probe Inc, West Chester, PA.

The centre frequencies of both filters were observed to shift with temperature. The shift was due to temperature dependence of the kinetic inductance of the superconductor. This feature could be used to adjust the centre frequency of filters. Further measurements are planned to investigate the temperature dependence of the filter characteristics.

Future directions within CTIP

The successful demonstrations of the two kinds of HTS filters described above are very encouraging for the further research in HTS microwave applications. The future directions within CSIRO TIP will be in following three major areas.

HTS passive microwave components are still of primary interest because they can take full advantage of the distinct HTS features of extremely high-Q or low loss. Development of high-Q resonators and high performance multipole filters will continue, including fabrication of HTS filters to meet customers' specifications. Future research will address some important issues in filter development. First of all, HTS films are expensive and large size HTS wafers are difficult to fabricate and handle. Novel designs are required to make the compact structures required for low frequency components. Second, some form of tuning to meet the filter specifications needs to be devised. Tuning could be achieved through changing the kinetic inductance of HTS materials or the dielectric constants of the substrates by means of electrical, magnetic method or/and buffer technology. A significant amount of experimental work is needed to resolve this issue. Other issues such as packaging and cryogenic cooling systems also need to be addressed.

Another area of interests is in HTS microwave active devices such as mixers, detectors, flux flow transistors, amplifiers and oscillators. The advantages of such superconducting devices are extremely low noise which ultimately is only limited by quantum effects and low power consumption (in the order of nanowatts). CTIP has over a decade experience and broad expertise in Josephson Junction technology and HTS SQUIDs which can be applied to HTS active device research.

At this stage, very few adequate HTS active devices are available while, on the other hand, many III-V semiconductor microwave devices are readily available with improved performance at cryogenic temperature, so another approach is to combine HTS and III-V into hybrid devices. Currently, HTS/GaAs HEMT oscillators and amplifiers are under investigation within CTIP. It is anticipated that these oscillators will consist of an HTS high-Q resonator in the feedback loop of a GaAs amplifier to produce a device with high frequency stability. Similar kinds of hybrid HTS microwave oscillators and amplifiers have been achieved [7, 8]. Our near future goal is to construct a hybrid HTS/GaAs receiver front end, as sketched in a simple diagram in Fig. 7, comprising HTS filters, HTS mixer, hybrid local oscillator and amplifier. The obvious advantages are low noise, high gain and a compact system. The integration is at a subsystem level and will not be monolithic at this stage but a hybrid version. Flip-chip technology will be used to combine the HTS components with the GaAs HEMT oscillator and amplifier.

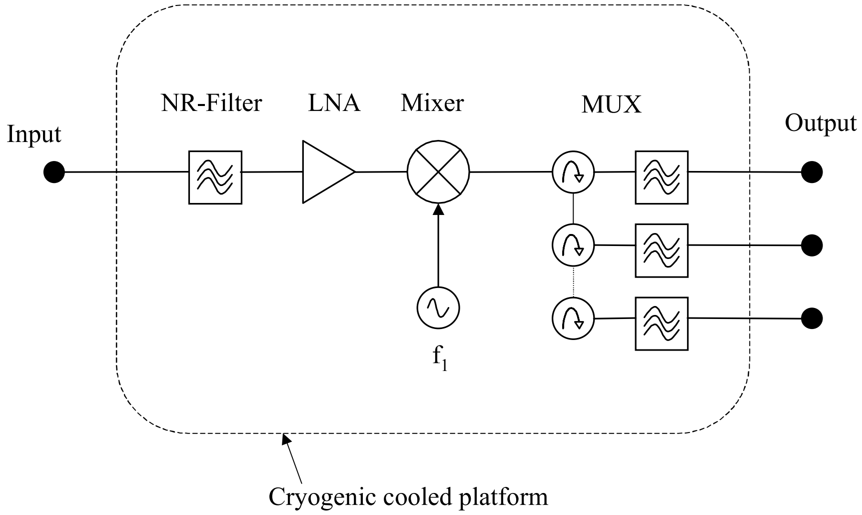

Fig. 7 Diagram of an HTS/GaAs hybrid receiver front end

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