Superconducting Microstrip Wide Band Filter for Radio Astronomy

Yuanzhi Li, Michael J. Lancaster, Frederick Huang, and Neil Roddis

School of Electronic, Electrical and Computer Engineering, The University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

Jodrell Bank Observatory, University of Manchester, Macclesfield, SK11 9DL, United Kingdom

Abstract — **A ninth order wide-band bandpass filter is presented for radio astronomy applications. The filter, for Jodrell Bank Radio Observatory, is designed to have a fractional bandwidth of 26.14% and a center frequency of 1.53 GHz. It uses both straight and hairpin resonators in order to achieve the wide bandwidth. In addition, the filter is integrated with two spur-line notch filters for second harmonic suppression. Good agreement between simulated and experimental results is obtained.**

I. INTRODUCTION

Since the discovery of high temperature superconductor (HTS) [1] in 1986, there has been increasing use of HTS materials in microwave components. HTS microwave filters started to emerge during the early 1990s, and much effort has been put into filter designs for narrow band applications [2]-[3]. However, there are still not many wide band HTS filters reported. Here we are interested in a wide band filter for radio astronomy application.

With the increasing radio communications activities of recent years, the radio spectrum is becoming intensely crowded and this trend is set to increase at an extraordinary rate. Radio astronomy is particularly sensitive to interference of this type. A high temperature-superconducting (HTS) filter, at the front-end of the receiver, has the potential to effectively eliminate the interference from adjacent bands. Such a filter will have negligible loss, have extremely sharp filter skirts and be small enough to fit into the current low temperature systems.

This work reports a nine pole Chebyshev HTS bandpass filter design and its fabrication according to the specification from Jodrell Bank Radio Observatory (Table I). The nine-pole filter structure (Fig. 1) consists of two types of half wavelength resonators, simple straight resonators and folded hairpin resonators. The coupling structure achieves strong coupling and gives the filter the required fractional bandwidth of 26.14%. In order to suppress the second harmonic, each feed line of the two ports, is integrated with one spur-line filter.

TABLE I
FILTER DESIGN SPECIFICATION FROM JODRELL BANK

Pass Band	1330 - 1730 MHz
Stop Bands	900 - 1310 MHz 1750 – 3000 MHz
Pass Band Insertion Loss	0.1 dB max
Stop Band Rejection	20 dB min
Connectors	K102 F
Maximum Dimensions (inc connectors)	100 × 50 × 15 mm^3
Operating Temp	20K

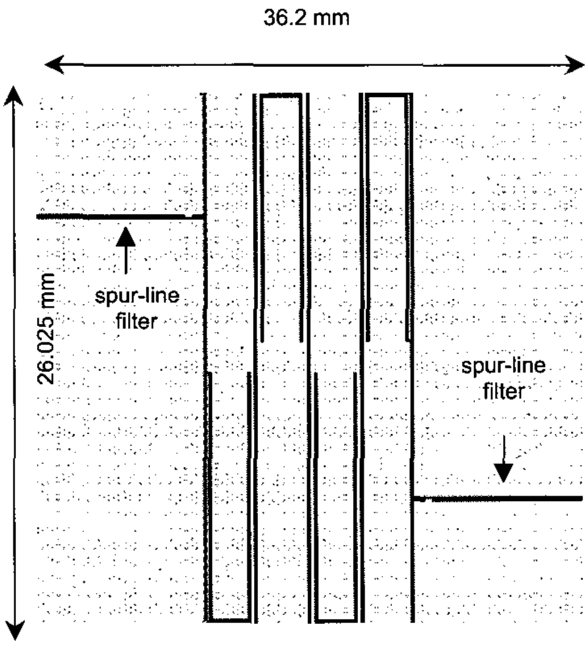

Fig. 1. Layout of the nine-pole filter for 0.5-mm-thick lanthanum aluminate substrate.

II. FILTER DESIGN

The nine-pole Chebyshev filter is designed to meet the Jodrell Bank specifications (Table I), which requires a bandwidth of 400 MHz and 20 dB second harmonic suppression. The synthesis of Chebyshev filters is well known, and the design procedure used here can be found in [4]. However, to achieve such a wide band response, strong coupling between adjacent resonators is needed. There are a few microstrip filters with fractional

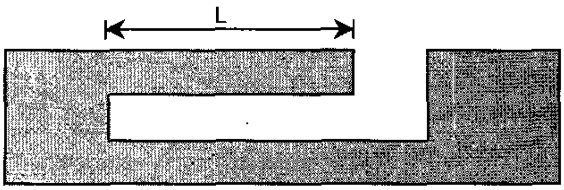

Fig. 2 Microwave spur-line filter

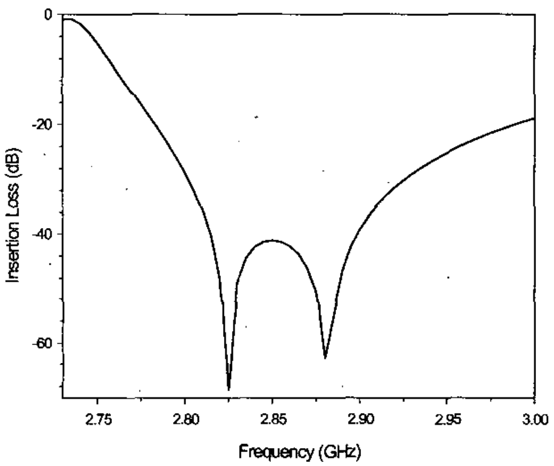

Fig. 3 Simulated responses of two integrated spur-line filter

bandwidth above 25% reported [5,6,7], but some of them [5,6] are not likely to be suitable for higher order filter design. For example, the stub-line filter [7] will introduce extra low frequency spurious responses. Hence, a new filter structure is introduced here, which consists of half wavelength and hairpin resonators. The positions of the hairpins (Fig. 1) give the highest coupling, as the gap between two resonators remains the same. Resonators with 0.2 mm line width are used in this filter. By adjusting the gap between resonators, the required coupling values can be obtained to realize the filter bandwidth of 400 MHz.

Fig. 2 shows a layout of a spur-line filter. It is essentially a simple bandstop filter suitable for moderate bandwidths (around 10%) [8]. The filter is embedded in the 50Ω microstrip feed. The spur-line filter consists of a pair of coupled lines a quarter wavelength long, one line is open ended; both lines are connected together at the other end. The length of the spur line L (Fig. 2), is determined from the center frequency of the stop band. The filter can be designed by the procedure described by Bates [8]. To increase the rejection, two spur-line filters are applied here, to produce notches at the band pass filter second harmonics. The two spur-line filters were simulated using the Sonnet EM simulator [9]. Fig. 3 shows that the two spur-line filters can achieve 20 dB rejection across bandwidth of at least 250 MHz when not connected to the main filter.

The complete filter topology depicted in Fig. 1 provides low cross coupling between non-adjacent resonators. However, such unwanted cross couplings cannot be completely avoided in a filter with such strong couplings. Hence, a circuit model has been completed in Microwave Office [10] in order to optimize the whole filter in terms of flat bandpass, low insertion loss and high harmonic suppression ratio. Sonnet EM simulator was used to provide final accurate responses.

III. EXPERIMENTAL RESULTS

The filter was fabricated on a 0.5 mm thick $LaAlO_3$ substrate with YBCO thin film deposited on both sides. The superconducitng ground plane of the filter was evaporated with gold to make good electrical contact to the packaging. To avoid thermal stress, the filter was bonded onto a gold-plated titanium carrier and packaged inside a titanium housing. Metallic screws are used for tuning the filter. The filter was cooled in a cryogenic cooler and was measured using an HP8722E vector network analyzer.

Fig. 4 shows the measured results at 20K of the nine-pole filter before tuning, compared with Sonnet EM [9] simulated results. They show excellent agreement. This filter is also tuned at 20K. Fig 4 gives the measured results after tuning. The maximum passband S_{11} observed is less than -15 dB. Most of the second harmonic has been suppressed to -20 dB. It can be seen from Fig 5, that the filter response has been considerably improved by the tuning process to a level better than the simulated results. The passband ripple (Fig. 6) has been reduced to 0.2 dB. Passband S_{21} is better than -0.3 dB, somewhat short of the original specification, and its bandwidth is from 1330 to 1730 MHz, which meets the specification in Table I. The minimum passband insertion loss of 0.1 dB has a

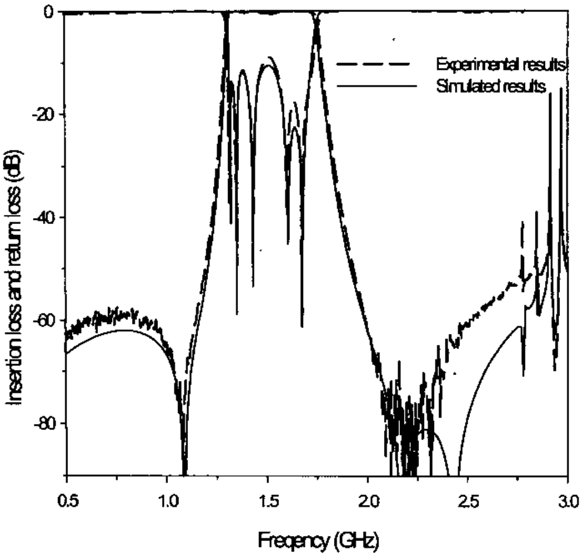

Fig. 4 Experimental and simulated filter responses before tuning

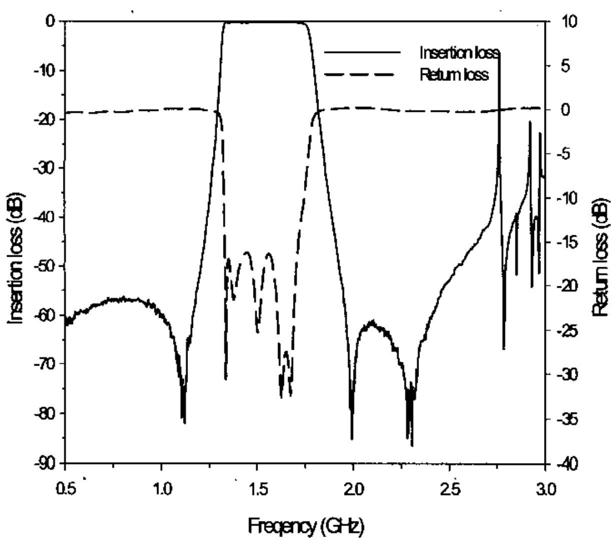

Fig. 5 Experimental filter responses after tuning

contribution from the connections at the input and output ports.

IV. CONCLUSION

A design of a nine-pole filter for radio astronomy has been discussed. The HTS filter was fabricated on a

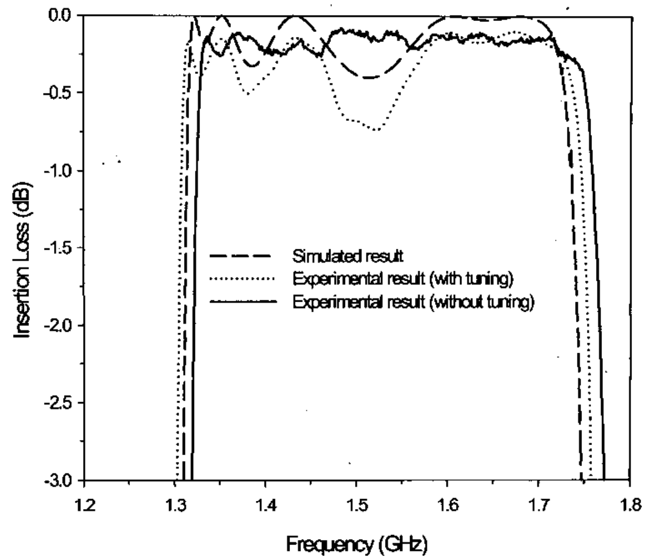

Fig. 6 Experimental and simulated passband responses

$LaAlO_3$ substrate with dielectric constant of 23.6. After tuning, the filter response has an insertion loss of less than 0.3 dB and maximum S_{11} of −15 dB. The -0.3 dB level of the filter passband has been tuned in the required frequency band of the specification. The good performance of the HTS filter demonstrates that wideband performance can be achieved with harmonic suppression in a filter suitable for radio astronomy applications.

The filter is currently being tested in Jodrell Bank Observatory.

ACKNOWLEDGEMENT

The authors would like to thank the Jodrell Bank Radio Astronomy Observatory for providing opportunity and support for the filter testing. The authors would also like to thank Dr. H. T. Su for his help in measurement, Dr. X. Xiong and D. Holdom for fabricating the HTS circuit, and Mr. C. Ansell for his technical support. The work was supported by the UK Engineering and Physical Sciences Research Council.

REFERENCES

[1] J. G. Bednorz, and K. A., Muller, "Possible high Tc Superconductivity in the Ba-La-Cu-O System", *Z. für Phys.*, vol. 64, pp. 189, 1986.

[2] J. S. Hong, M. J. Lancaster, J. C. Mage, "Cross-coupled HTS microstrip open-Loop resonator filter on LAO substrate", *IEEE MTT-S*, vol. 4, pp. 1559-1562, 1999.

[3] D. Zhang, G. C. Liang, C.F. Shih, Z. H. Lu, and M. E. Johansson, "A 19-Pole cellular bandpass filter using 75-mm-diameter High-Temperature Superconducting thin films", *IEEE Microwave and Guided Wave Letters,* vol. 5, No. 11, November 1995.
[4] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters Impedance-matching Networks and Coupling Structures*, Artech House, Inc., 1980.
[5] W. Menzel, L. Zhu, and K. Wu, "Aperture compensation technique for innovative design of ultra-broadband microstrip bandpass filter", *IEEE MTT-S Inter. Microwave Symp.,* Boston, pp. 315-318, 2000.
[6] J. T. Kuo, and E. Shih, "Wideband bandpass filter design with three-line microstrip structures", *IEEE MTT-S Inter. Microwave Symp.,* pp. 1593-1596, 2001.
[7] Y. Li and M. J. Lancaster, "Fifteen pole Superconducting Filter for radio astronomy", *6th IEEE High Frequency Postgraduate Student Colloquium,* University of Cardiff, Cardiff, UK, pp. 47-52, 2001.
[8] R. N. Bates, "Design of microstrip spur-line band-stop filters", *IEEE Microwave, Optics and Acoustics,* Paper T90M, 1997.
[9] SONNET, Version 8.0, *Sonnet Software, Inc.*
[10] Microwave Office 2001, *Applied Wave Research, Inc.*