Study of High-Temperature Superconductor Diplexers for Satellite Communications

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Abstract The high-temperature superconductor (HTSC) resonator and diplexer are simulated by full-wave tools. A newly developed miniature HTSC diplexer is designed and fabricated on double sided YBa$_2$Cu$_3$O$_7$ (YBCO) film (YBCO/LaAlO$_3$/YBCO), the thickness of which is 400 nm for YBCO and 0.5 mm for the LaAlO$_3$. The measured results show a good agreement with the simulation. The volume and mass of the diplexers are greatly reduced by miniaturized configuration.

Key words high-temperature superconductor; microwave; diplexer; satellite communication

Microwave diplexers are widely used in RF and microwave communication systems, such as mobile and satellite communications. Diplexer splits the frequencies up into two separate bands, it can be used in T/R (Transmission/Receiver) systems, multi-band receiver systems and multi-band transmission systems. In the design of high-temperature superconductor (HTSC) devices, the power handling capability must be considered for transmission systems, but in receivers the HTSC merits can benefit a lot \cite{1}-\cite{4}. The diplexer used in one multi-band receiver system is presented in this paper, low passband insertion loss and high out-of-band rejections are realized by HTSC merits. To meet the demands of high performance in satellite communications, a C-band HTSC diplexer is simulated by full-wave CAD tool and measured results show the advantage of small volume, light mass, low passband insertion loss and high selectivity.

1 Design and Simulation of HTSC Diplexer

A new type of HTSC diplexer with the bandwidth of 36 MHz is designed in C-band. In the design procedure of HTSC microwave diplexer, many of special features of HTSC component must be considered, besides the design method of conventional microwave components. For example: line width can’t be too narrow, because the etching to HTSC film different from normal metal film in the lithography of microwave strip circuits; the coupling between resonators of HTSC filter varies from conventional planar filter’s because of the high quality factor of HTSC film. Moreover, the soldering between HTSC film and metal are hard because the HTSC film is a sort of nonmetal material, so the connection between HTSC film and SMA connector and ground is important to the characteristics of HTSC component.

Two bandpass filters in the diplexer are synthesized as the first design step. The basic structure is a coupled double-resonators\cite{5}. Fig.1 presents the layout and current distribution of the two basic structures. As can be seen in Fig.1, the thicker the color, the stronger the current, which corresponds to the distribution of electronic and magnetic fields.

![Fig.1 The layout and current distribution of the two basic structures](image-url)

We can assume that the coupling between short arms of the resonators is mainly electrical, while the magnetic coupling dominates in the coupling between long arms. Using the structure of alternately electric and magnetic coupling leads to the cancellation effect for cross coupling, improves the frequency response of the filter, and has the same slope parameter.
corresponding to the Chebyshev prototype. According to the equivalent lumped-element circuit model for electric coupling structure, the electric coupling coefficient $K_E$ can be found as $^6$

$$K_E = \frac{f_m^2 - f_e^2}{f_m^2 + f_e^2} = \frac{C_m}{C}$$

(1)

where $f_m$ is the resonant frequency higher than that of uncoupled single resonator, $f_e$ is the resonant frequency lower than that of uncoupled single resonator, $C$ is the self-capacitance and $C_m$ is the mutual capacitance, which is identical with the definition of ratio of the coupled electric energy to the stored energy of uncoupled single resonator. Also, the magnetic coupling coefficient $K_M$ can be found as

$$K_M = \frac{f_m^2 - f_e^2}{f_m^2 + f_e^2} = \frac{L_m}{L}$$

(2)

where $L$ is the self-inductance, $L_m$ is the mutual inductance, which is identical with the definition of ratio of the coupled magnetic energy to the stored energy of uncoupled single resonator.

The dimension of the bandpass filters can be synthesized using the electric and magnetic coupling coefficient and the formula of Chebyshev prototype filter. Considering the limit of lithography technology, the width of microstrip line can’t be too narrow, and the resonators are 10.8 mm long, 0.3 mm wide, and the spacing between resonators are larger than 0.3 mm. A full-wave EM simulator is used to simulate and optimize the frequency response of the bandpass filter.

$$17 \times 10 \text{mm}^2 + 20 \times 10 \text{mm}^2 \text{[Fig. 3(a)]} \text{ and } 22 \times 20 \text{mm}^2 \text{ [Fig. 3(b)]. The simulated result of the HTSC diplexer using full-wave method shown in Fig.3(a) is presented in Fig.4. The data show performance comparable to conventional technology and promise of large reduction of mass and volume.}

Fig. 3 The layout of HTSC diplexer

(a) Diplexer with the area of $17 \times 10 \text{mm}^2 + 20 \times 10 \text{mm}^2$

(b) Diplexer with the area of $22 \times 20 \text{mm}^2$

Fig.4 Simulated result of the HTSC diplexer shown in Fig.3(a)

2 Fabrication and Test of the HTSC Diplexer

The diplexer is fabricated on a double-sided HTSC YBCO films with 400 nm thickness on a LaAlO$_3$ substrate that is 0.5 mm thick with Er=23.5$^7$. The capabilities of HTSC film can be influenced by H$_2$O and CO$_2$ in the air and the etching to HTSC film different from normal metal film in the lithography, high requirements to the air humidity in the process of fabrication and encapsulation are demanded.

The HTSC diplexer works at 77 K and the performance of YBCO film can be influenced by wet conditions, so the diplexer must be enclosed in compact hermetic package. Two test housings are...
designed according to the size of the two HTSC diplexers, with the dimensions of $43.5 \times 30 \times 12.9 \text{mm}^3$ and $44.5 \times 37.5 \times 7.5 \text{mm}^3$, that are pressurized by indium thread and the signal is transmitted by SMA connectors.

The test system using vector network analyzer HP8510 is presented in Fig.5. The design methods and experiment projects can be amended to improve the HTSC diplexer’s frequency response according to the tested curves by comparing the tested results with the simulated ones.

![Fig.5 The test system of the diplexer](image)

Conventional microwave test cable and microwave test receptacles can’t work at 77 K, so two transition cables are added between the HTSC diplexer and the connectors, cables & net analyzer to protect the latter. The cable has low insertion loss and high adiabatic capability in low temperature, so the accuracy of tested responses and the normal working condition of conventional components are ensured.

The measured performance of the HTSC diplexer shown in Fig.3(a) is presented in Fig.6.

![Fig.6 The tested curves of the HTSC diplexer shown in Fig.3(a)](image)

The solid line presents the tested response of the lower passband on 3.72 GHz. The passband insertion loss is about 0.67 dB. This is mainly due to the HTSC film’s small conductor loss. The stopband restrain is larger than 25 dB and the bandwidth of 1 dB is about 36 MHz. The dashed line presents the tested response of the higher passband on 3.80 GHz. The bandwidth and insertion loss is larger because the resonance frequency in passband is removed. The measured data in Fig.6 shows performance comparable to designed data in Fig.4.

The center frequencies of two passbands are a little lower than designed, which may be caused by the inaccurate parameter of substrate. The lower passband of the HTSC diplexer designed and fabricated in this paper is better than the higher passband in the sides of insertion loss and passband ripple. That is mainly caused by reasons that the surface resistance of HTSC film is inhomogeneous, and the technology of lithography is not matured, and the standing-wave ratio (SWR) of connectors is unstable because of the faulty connection technique, et al.

3 Conclusions

This paper builds a new type of HTSC diplexer using CAD programs by full-wave field solvers. The differences between HTSC device’s design and normal device’s design caused by the high Q factor of the HTSC film are fully considered. Also, the HTSC diplexer is fabricated, installed and tested, and then the tested curves are analyzed and discussed. The measured data shows that the HTSC diplexer has lower passband insertion loss than conventional planar diplexer and has large reduction in mass and volume comparing with conventional wave-guide diplexer. The advantages of the HTSC diplexer create the opportunity for the realizing of miniature satellite electronic systems, lower cost and faster development, and has extensive application perspective.

References


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