A Superconducting Thin Film Filter of Very High Wide-Band Rejection

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Abstract — **The wide band rejection of superconducting thin film filters was investigated. The cross talk between input and output ports for thin film filters was degrading the wide band rejection. We presented a thin film filter design based on a newly invented thin film resonator. The cross coupling between the input and output ports was reduced by a factor of more than ten. The fabricated thin film filter showed good performance and consistency with design and theory. The measured return loss in the passband was more than 23 dB. The insertion loss was 0.66 dB corresponding to a filter Q of 36,000. Steep rejection slopes at the band edges were obtained. The wide band rejection was 95 dB.**

I. INTRODUCTION

The ultimate low microwave loss of high temperature superconducting (HTS) materials has enabled the realization of thin film filters with low insertion loss and high selectivity for mobile and satellite communications [1-2]. The main advantage of HTS thin film filters is their compactness and the opportunity for designing filters with a large number of poles. However, the compactness of the thin film filter with a closely positioned ground plan also introduces unwanted cross couplings including the one between the input and output ports. As we will show in this paper, the cross talk between the input and output ports is degrading the wide band rejection of an HTS thin film filters. Figure 1 shows a measured filter characteristic of a GSM 900 thin film filter fabricated in our company. The wide band rejection is about 70 dB, which is comparable to the reported values from the literature [3-4].

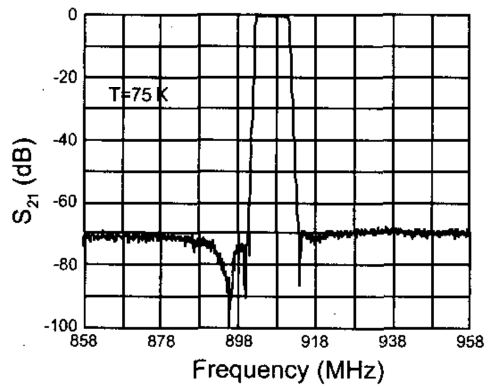

Fig. 1. Measured S_{21} of an eight-pole thin film filter designed for GSM 900. The wide band rejection is about 70 dB.

This paper analyzes the wide band rejection of a cascaded quadruplet (CQ) filter and presents the design and experimental results of an HTS thin film filter that shows very high wide band rejection.

II. MODEL AND DESIGN

The wide band rejection values can be modeled by introducing a cross coupling between the input and output ports. We have modeled various filters based on the CQ designs, and confirmed that the cross coupling between the input and output degrades the wide band rejection. The other unwanted cross couplings usually make the S_{21} characteristics asymmetric as well as make it more difficult to tune the filter. Figure 2 shows the model of an eight-pole CQ filter, where an additional coupling between the input

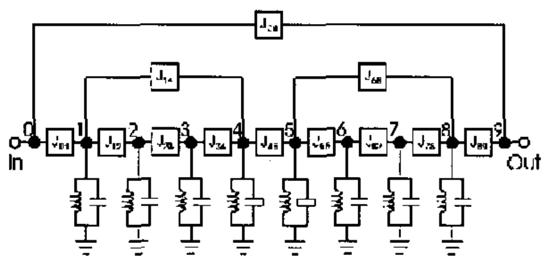

Fig. 2. Model of an eight-pole cascaded quadruplet filter with an additional coupling between the input and output.

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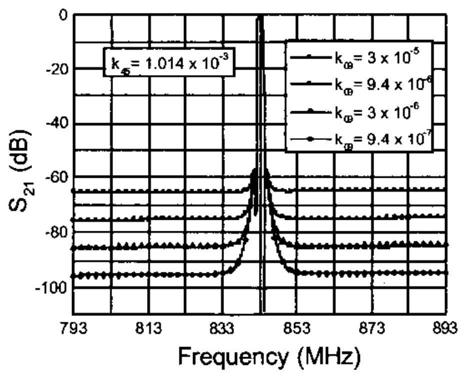

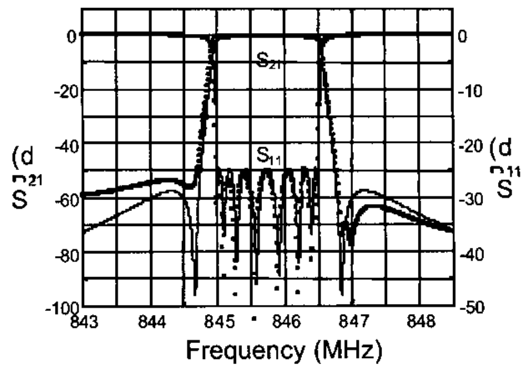

Fig. 3. Wide band rejection of an eight-pole CQ filter with different cross coupling value between the input and output.

Fig. 5. S_{11} (squares) and S_{21} (circles) for the layout in Fig. 4 simulated by full-wave IE3D Software. The linear circuit simulation is shown as full curves.

and output (J_{09}) is introduced. Here, the inter-resonator coupling is modeled with J-inverters.

For conventional cavity filters the input and output antenna are coupled to the first and last resonators where good isolation between the input and output is usually maintained. However, for the thin film filter, there is usually only one cavity for the entire filter where the cross talk between the input and output has increased to a level that may degrade the wide band rejection. Figure 3 shows the wide band rejection of an eight-pole filter for different coupling coefficient (k_{09}) values between the input and output. When the coupling coefficient between the input and output k_{09}=9.4 x 10^{-7}, the wide band rejection value is about 95 dB. The wide band rejection value degrades with increasing k_{09}. When k_{09}=3 x 10^{-5}, the wide band rejection is degraded to about 65 dB. The other couplings for this filter

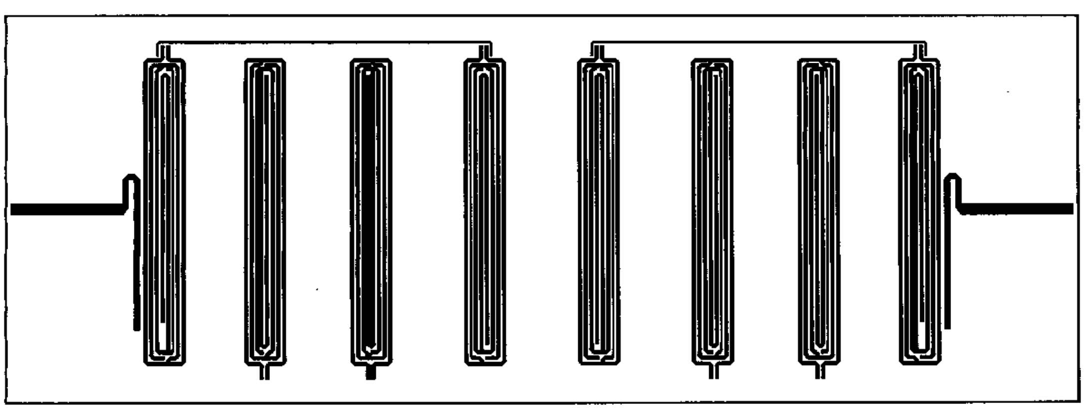

Fig. 4. Layout of an eight-pole thin film filter on the MgO substrate. The overall chip size is 45.1 mm x 16.2 mm. The linewidth of the resonator is 152 μm.

response are as follows: $k_{12}=k_{78}=-1.591 \times 10^{-3}$, $k_{23}=k_{67}=1.362 \times 10^{-3}$, $k_{34}=k_{56}=-9.724 \times 10^{-4}$, $k_{45}=1.014 \times 10^{-3}$, $k_{14}=k_{58}=-3.59 \times 10^{-4}$, and the external Q for the input and output couplings is 499.

A thin film filter was designed based on a newly developed thin film resonator [5]. Figure 4 shows a layout of an eight-pole CQ filter. The substrate is MgO and the chip size is 45.1 mm x 16.2 mm. The resonator linewidth is 152 μm. Figure 5 is the full-wave EM simulated response of this filter layout using IE3D Software [6]. Squares are for S_{21} and circles are for S_{11}. The center frequency is 845.75 MHz and the bandwidth is 1.5 MHz. As a comparison, the linear circuit simulation is shown as full curves (theoretical). Comparing this full-wave EM simulated response with the theoretical response, the passband responses are very similar. The EM simulated return loss is 24 dB, only slightly worse than the theoretical return loss of 25 dB. However, the out-of-band response of S_{21} differs appreciably with the theoretical curve. This is because IE3D Software cannot simulate the out-of-band response accurately and correctly [7].

III. EXPERIMENTAL RESULTS

Figure 6 shows the photograph of the fabricated eight-pole superconducting thin film filter. Some tuning screws are arranged on the top of the filter for the fine tunings of frequencies. The tuned filter responses at a temperature of 78 K are shown in Fig. 7. The circles are the measured S_{21} and the squares are the measured S_{11}. The measurement

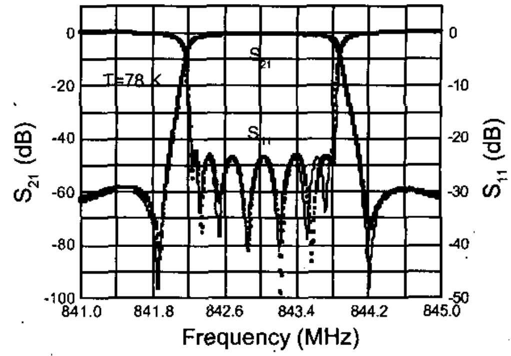

Fig. 7. Measured S_{21} (circles) and S_{11} (squares) of the eight-pole filter in Fig. 6 at 78 K. The full curves are the theoretical fits.

was taken with an HP 8753D Network Analyzer, and the loss from the cables was subtracted by performing a full 2-port calibration using HP 85033D 3.5 mm Calibration Kits. The bandwidth is 1.5 MHz and the center frequency is 843 MHz. The measured return loss in the passband is more than 23 dB, which is comparable to the full-wave simulated value of 24 dB and the theoretical designed value of 25 dB. The insertion loss at the passband center is 0.66 dB, which corresponds to a filter Q of about 36,000. Steep rejection slopes at the band edges are obtained and rejections reach more than 70 dB in about 300 kHz from the lower and upper

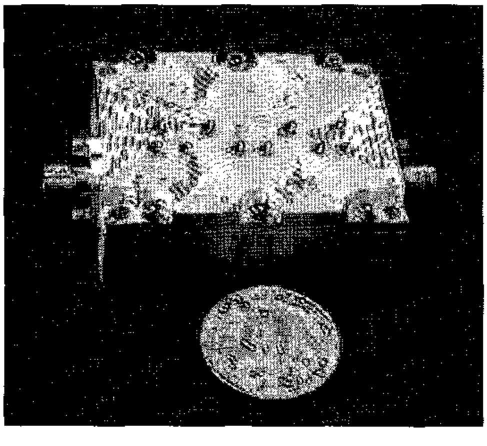

Fig. 6. Photograph of an eight-pole superconducting thin film filter.

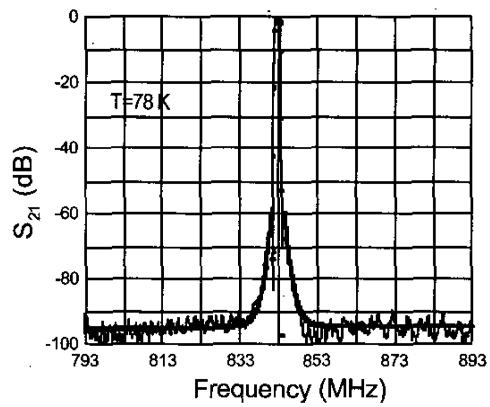

Fig. 8. Full curve is the measured wide band response of the eight-pole filter measured at 78 K. Circles are the theoretical fit with $k_{09}=9.4 \times 10^{-7}$.

passband edges.

The full curve of Figure 8 shows the measured wide band response of S_{21}. The circles are fit to the measured curve based on the theoretical model in Fig. 2. For this eight-pole filter, the wide band rejection is about 95 dB, which is significantly higher than the value of about 70 dB for an eight-pole thin film filter shown in Fig. 1. The theoretical fit in Fig. 8 with a wide band rejection value of 95 dB corresponds to a cross coupling coefficient value between the input and output k_{09}=9.4 x 10^{-7}. For a wide band rejection value of 70 dB, the corresponding k_{09}=1.7 x 10^{-5}. So the design in Fig. 4 represents an improvement (reduction) of the cross coupling between the input and output by a factor of more than ten.

V. CONCLUSION

We have modeled the wide band rejection of superconducting thin film filters by introducing a cross coupling between the input and output ports. We presented an eight-pole thin film filter design based on a newly invented thin film resonator. The fabricated filter showed good performance and consistency with design and theory. The measured return loss in the passband was more than 23 dB. The insertion loss in the passband center was 0.66 dB corresponding to a filter Q of 36,000. Steep rejection slopes at the band edges were obtained. The wide band rejection was 95 dB, which was considerably better than typical values of about 70 dB for thin film filters.

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