An Ultra-narrowband HTS Bandpass Filter

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Abstract — **This paper presents the measured results of an HTS ultra-narrowband bandpass filter with a 100 kHz bandwidth. This filter, with a fractional bandwidth of 0.014% and a center frequency of 700 MHz, represents a previously unrealized portion of filter parameter space. This filter was realized using a five-pole Chebyshev filter design and was fabricated using an HTS microstrip configuration. This filter required very high Q, very weak coupling, and a strong reduction in parasitics. Unloaded Q's of 135,000 were achieved with a resulting insertion loss of 1.37 dB. Even resonator Q's of 20,000 would lead to a filter loss of 9 dB. A noise figure of 1 dB was achieved for a complete system with this filter and a cryogenic low-noise amplifier.**

I. INTRODUCTION

Superconductor filters have found wide applications in the wireless communications industry. The very small insertion loss and sharp filter response in a compact package are basic market differentiators compared to the conventional filter products. Narrowband microwave filters in particular are one of the leading applications for high-temperature superconductor (HTS) thin films. A bank of narrowband HTS filters could be a key component in microwave channelized receivers.

There are three difficult conditions that needed to be met in order to realize an ultra-narrowband filter. First, a very high Q was needed to achieve an acceptable level of loss. Second, the very narrow bandwidth requires a very weak inter-resonator coupling that is difficult to achieve practically. Third, the very weak inter-resonator coupling magnifies the problem of unwanted parasitic coupling.

The impediments in the conventional technology to realize ultra-narrowband filters such as the low Q of the resonators and large separations between resonators to get very weak couplings were overcome by the use of high-Q HTS frequency-dependent resonators. We used wider HTS lines to achieve Q that were 25% higher than our standard process. We used the frequency dependent resonators to mathematically widen the bandwidth, so that the coupling capacitances could be more easily realized. We used partitions in the packaging to reduce the parasitic coupling.

In this paper, an approach to achieving ultra-narrowband filters with fractional bandwidths as small as 0.01% is outlined. We demonstrate a 5-pole lumped-element Chebyshev bandpass filter of center frequency 700 MHz with a bandwidth of 100 kHz. Also, we present the measurement results of the filter, such as insertion loss, return loss, noise figure and group delay.

II. FILTER DESIGN

In narrowband microstrip filter designs, the requisite weak coupling is always a challenge. It is hard to realize a very narrowband filter in the convenient microstrip configuration using conventional coupling schemes due to the slow decay of the coupling as a function of the resonator element separation. To realize the weak coupling required by a narrowband filter, resonator elements in the filter have to be kept far apart. This requires either a large circuit size or an elaborate package. We used a frequency dependent resonator to overcome these limitations.

An HTS tubular bandpass filter with spiral inductors was demonstrated in 1992 [4] and a filter frequency transformation technique introduced for the tubular bandpass filter circuit in 1995 [1]. The latter method used a frequency-dependent inductor that significantly reduced the inductor size without sacrificing the resonator unloaded Q's and provided great flexibility in choosing design parameters. Figure 1 shows a bandpass prototype filter using K-inverters and Figure 2 shows the topology of the equivalent lumped-element filter circuit [5].

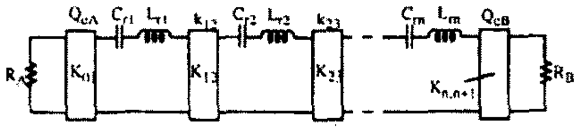

Fig. 1. Bandpass prototype using K-inverters.

As shown in Figure 2, L is a frequency-dependent inductor and the series capacitor Cc,i is the coupling capacitor between adjacent resonators. In the case of the desired ultra- narrowband filter with a center frequency of 700 MHz and a bandwidth of 100 kHz, the value of Cc,i to be realized is around 1 fF. This value is extremely difficult to realize due to limited wafer size, and the inability to reduce the coupling below a certain level even at large separations between resonators because of the parasitic coupling.

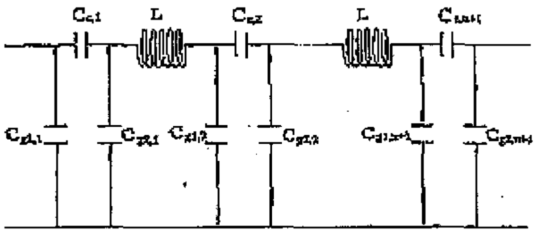

Fig. 2. Topology of the lumped element filter circuit.

However, using the frequency transformation method described by Zhang in [1] the realized bandwidth is the initial design bandwidth multiplied by the inductance slope parameter. The realized filter fractional bandwidth, after using the frequency transformation technique, will be

$$\frac{\Delta\omega}{\omega_0} = \frac{1}{1+\frac{\omega_0}{L}\frac{dL'(\omega)}{d\omega}}\frac{\Delta\omega_0}{\omega_0}$$

where ω_0 is the filter frequency, $\Delta\omega_0$ is the filter bandwidth in the circuit prototype and $L'(\omega)$ is the frequency dependent inductance, with $L'(\omega_0)=L$. Please refer to [1] for detailed description of the equations. Reference paper [3] describes in detail how to compute the required values of L and C for a given number of poles and frequency specifications.

Therefore, to achieve the ultra-narrow bandwidth, we designed the filter with a frequency dependent inductor having a slope parameter of 4.58. Then, a coupling capacitance of 5 fF, rather than 1 fF, could be used to realize the filter. Since the parasitic coupling is independent of this transformation, the fixed parasitic value becomes a smaller fraction of the needed coupling.

In order to achieve higher Q, the width of the resonator's inductor line was chosen to maximize Q given the physical size constraints. Table 1 shows the Q vs insertion loss for a 5-pole Chebyshev filter with a center frequency of 700 MHz and a bandwidth of 100 kHz. We have designed the resonator to achieve unloaded Q of the order 130,000 to 140,000.

Finally, the undesired coupling between input and the output terminal resonators affects the filter quality through the direct coupling from the input resonator to the output resonator. To reduce this undesired coupling, the filter package employed a partition wall in the cover of the package.

TABLE I

UNLOADED Q VS INSERTION LOSS

Q	**Insertion Loss**
60,000	-3.0 dB
80,000	-2.4 dB
100,000	-1.9 dB
120,000	-1.5 dB
140,000	-1.3 dB

III. MEASUREMENT

The filter was fabricated on a 2-inch YBCO thin-film-coated MgO wafer. Figure 3 shows the filter response at 60 K over 1 MHz span.. The insertion loss at the band center is about −1.37 dB. The transmission is flat to 0.25 dB across the desired bandwidth. This corresponds to a Q of 135,000. The return loss measured is in 5 dB per division. We see from Figure 3 that the return loss measured is around 15 dB. Figure 4 shows the rejection levels at +/- 150 KHz and +/- 300 KHz away from the center, and we see that they are better than 35 dB and 65 dB respectively. The slope on low side is better because of the parasitic zero that is present far away from band edge. The measured data agrees with the theoretical data, except for high side rejection. Figure 5 shows the clean response of the filter over a 20 MHz span. No harmonics or spurious modes were observed over this range of measurement. Figure 6 shows a measurement of the filter group delay. The measured group delay is 1.67 μs.

It is difficult to accurately measure the noise figure of such a narrow bandwidth filter. Even with the most sophisticated Noise figure analyzers like Agilent's N8975A , the minimum bandwidth can only be set to 100 kHz. We were able to measure a complete system with this filter and a cryogenic low-noise amplifier. This complete system had a noise figure of 1 dB. Using an insertion loss of −1.37 dB and a temperature of 60 K, we estimate that the contribution to the noise figure from the filter is approximately 0.45 dB. We also measured the frequency stability versus temperature for this filter. We found that for every 0.1 K variation in temperature, there is a drift of 4 kHz in frequency response of the filter.

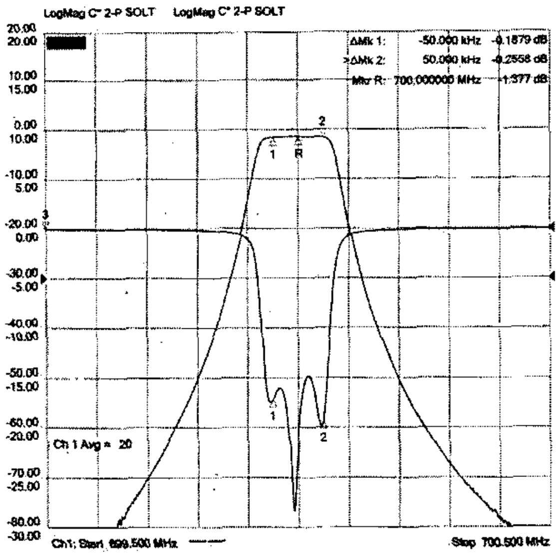

Fig. 3. Frequency response of the filter over 1 MHz span. Insertion loss at band center is 1.37 dB

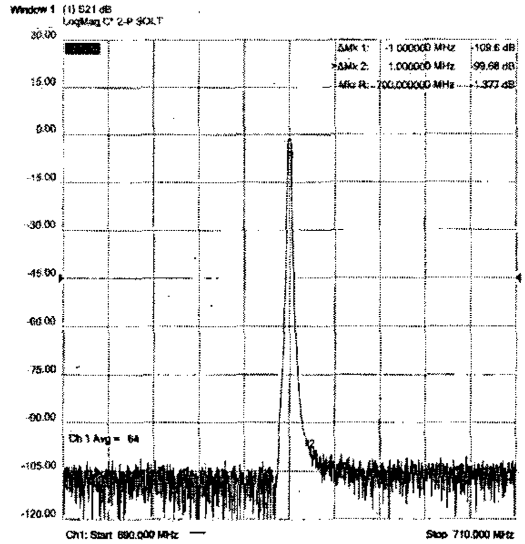

Fig. 5. Frequency response of the filter over 20 MHz span.

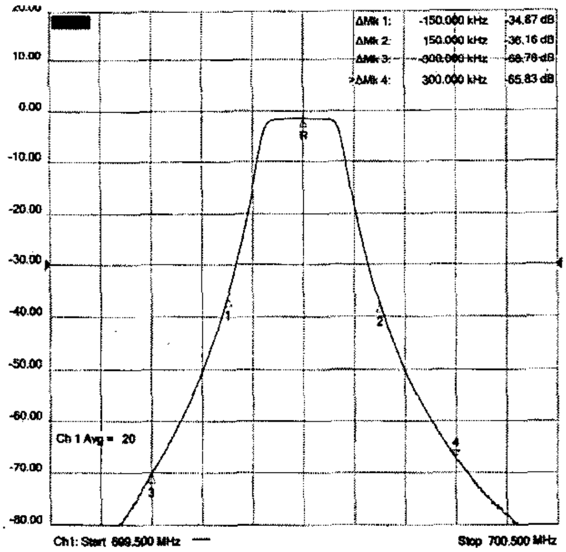

Fig. 4. Frequency response of the filter with rejections. At

–150 kHz away from center the rejection is –35 dB and
at -300 KHz away it is –69 dB.

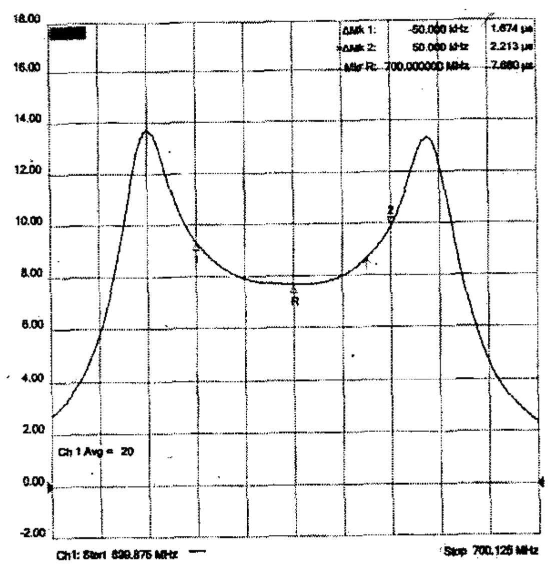

Fig. 6 Group delay of the filter at band edges was 1.67μs and 2.2 μs

IV. Conclusion

This paper presents the design of an ultra narrowband filter, a five-pole Chebyshev filter at 700 MHz center frequency with 0.014% fractional bandwidth. The measured filter exhibited 1.37 dB insertion loss at band center. The transmission is flat to 0.25 dB across the desired bandwidth. The return loss is better than 15 dB. The noise figure at 60K was 0.45 dB for the filter. We believe that the presented superconducting filter is the narrowest filter that is ever made in this frequency range. The measurements suggest that the unloaded Q's of the resonators are greater than 135,000. It is possible to improve the insertion loss performance by using better quality HTS wafers. The shape of the passband is very symmetric which shows good alignment of the resonators. Measurement results also shows that very weak couplings are possible to realize if an appropriate inductance slope parameter is chosen to realize the resonator.

Acknowledgement

The authors would like to thank Genichi Tsuzuki and Chien Fu Shih for their valuable suggestions and discussions and Jesse Danielzadeh, Suzette Corrales, Jill Pador for filter testing and Tom Heydman, Quang Thai for the filter tuning.

References

[1] D.Zhang,G.C.Liang,C.F.Shih,M.E.Johansson,and R.S.Withers,"Narrowband lumped element microstrip filter using capacitively loaded inductors", IEEE Trans.Microwave Theory Tech.,vol.43,pp3030-3036,Dec 1995.

[2] G. L. Matthaei, L.Young and E.M.T. Jones, Microwave Filters, Impedance-Matching networks, and Coupling structures, NewYork:McGraw-Hill 1964.

[3] Chung Haung, Ji-Fuh Liang, Dawei Zhang and Guo-Chun Liang, "Direct synthesis of tubular bandpass filters with frequency dependent inductors", in 1998 IEEE Int.Microwave Symp.Dig., June 1998.

[4] D.G.Swanson Jr, R.Forse and B.J.L Nilson, " A 10 GHz thin film lumped element high temperatutr super conducting filter", in 1992 IEEE Int.Microwave Symp.Dig.,pp 1191-1193,June 1992.

[5] Yoshio Kobayashi, Dai Yamaguchi,Kensi Saito,Nobuyoshi Sakibara , Yoshiki Ueno, Shoichi Narahashi and Toshio Nojima, "Design of a 264 MHz Superconductive Thin Film Lumped Element Filter", in 1998 Asia Pacific Microwave Conference.