Ultra Selective 22-Pole, 10-Transmission Zero Superconducting Bandpass Filter Surpasses 50-Pole Chebyshev Rejection

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***Abstract* — An ultra selective filter for 3G and 4G wireless application is presented. The demonstrated filter consists of twenty-two resonators and five cross couplings that produce ten transmission-zeros. The filter was designed at 1950 MHz center frequency with a 20 MHz bandwidth to meet existing 3G wireless applications. The measured data from the filter exhibited excellent selectivity, steeper than 30 dB/ 100 kHz skirt slope and 90 dB rejection at 350 kHz from the band edge. This filter surpasses the rejection of a 50-pole Chebyshev filter. To design a large number of resonators in a limited wafer area, a new compact resonator was developed. The filter was fabricated using a YBCO thin film on a 2-inch MgO wafer.**

I. INTRODUCTION

High-Temperature Superconductor (HTS) filter systems have been tested in 3G wireless base stations. Significant improvements, such as coverage area enhancement and *dropped-call rate reduction*, have been reported [1] by a cellular operator. However, higher selectivity filters are still required, due to the tightness of frequency resources and the problem of interference from out band signals. Especially in commercial frequency bands as 3G and in the future 4G wireless applications, sharper skirt filters for higher data rate communication are desired.

Several papers have reported progress toward realizing this requirement. A highly selective 32-pole Chebyshev HTS filter has been demonstrated using a 3inch HTS wafer [2]. A cross coupling technique to produce transmission zero at band edge for very sharp rejection slop has been reported [3], [4]. This technique has been applied to HTS planar circuit filters [5], [6].

In this paper we demonstrate ultra sharp skirt filter that has 22 poles and 10 transmission zeros. The rejection performance of the filter is able to surpass a 50-pole Chebyshev filter as shown in Fig. 1. To realize this filter, a quadruplet cross coupling technique was introduced to produce transmission zeros at the band edges. A new compact resonator was also developed to accommodate 22 resonators into limited wafer area. The size of new resonator is about a half of a conventional hairpin resonator.

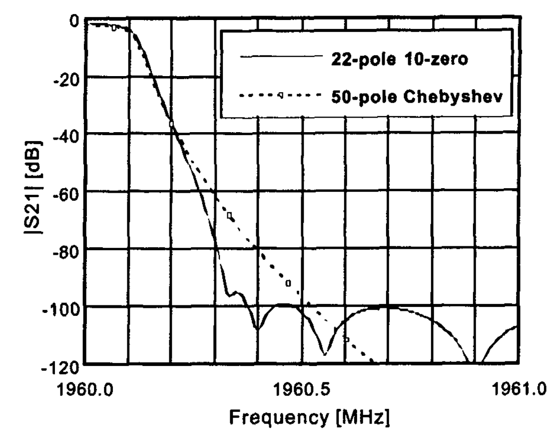

Fig. 1. Calculated response of the rejection slope at higher band edge for one of 3G cellular bands. High side band edge is at 1960 MHz. The solid line denotes the presented 22-pole filter's slope. The dashed lines denote a reference 50-pole Chebyshev filter's slope.

II. FILTER DESIGN

A. Resonator

To realize a 22-pole filter in a compact size with low insertion loss, the resonator has to be small and also has to have a high Q-factor. For that purpose we used a half wavelength distributed resonator to achieve higher Q factor, but the line was folded as meander to reduce its size compact. Dimension of the meander resonator was 2.15 mm width by 9.6 mm length and the line width was 0.3 mm, while a typical conventional hairpin resonator has 2.15 mm width by 15 mm length.

To fit twenty-two resonators on a 2-inch wafer, not only the resonator itself has to be small, but also the distance between resonators has to be close. For a 20 MHz bandwidth design in the 3G-Band, the coupling coefficient value between two adjacent resonators varies from 4E-3 to 9E-3. The distance between two adjacent resonators requires 3 mm for the meander resonator, but 4.2 mm for the

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hairpin resonator to realize a typical coupling value 5E-3. The meander resonator needs only 3mm by 9.6 mm area per one resonator unit, while the conventional hairpin resonator uses 4.2 mm by 15 mm area per one resonator unit. Hence the meander resonator can reduce the filter size 54% from the conventional hairpin layout.

It is also very important to reduce the parasitic coupling between non-adjacent resonators to maintain good return loss and rejection slope symmetry. In some cases, this parasitic coupling produces a transmission zero at its band edge, usually at either side of its slope. Although this effect makes the filter slope steeper, the location of the transmission zero is not controllable. We tried to reduce this unwanted parasitic coupling, in order to place the intended transmission zeros at desired locations. The intensity of major parasitic coupling caused by next-adjacent resonators was calculated as about 2% of its main coupling between adjacent resonators for the meander resonator case, while the ratio was about 5% for the typical hairpin resonator. Hence the meander resonator can reduce the unwanted parasitic coupling more than the hairpin resonator.

B. Coupling structure

Several kinds of cross coupling structures have been studied to produce transmission zeroes near the band edge. Figure 2 shows some typical structures of them. Cross coupling structures called canonical structure, as shown in Fig. 2 (a), can produce more numbers of transmission zeros using the same numbers of resonators as compared with others. However, this approach would be complicated for design and tuning of such high order filters. A tri-section structure, as shown in Fig. 2 (b), has the advantage that each correspondent cross coupling can control each transmission zero location independently.

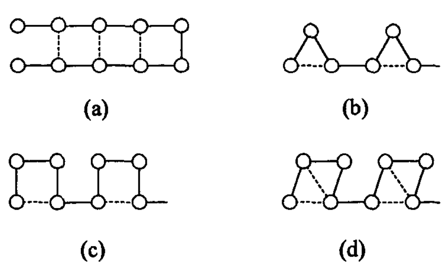

Fig. 2. Several kinds of cross coupling structure: (a) canonical structure, (b) tri-section structure, (c) quadruplet structure and (d) canonical asymmetric structure. Solid lines denotes main path and dashed line denotes cross coupling.

The quadruplet structure in Fig. 2 (c) can produce two transmission zeros at both band edges symmetrically. The pair of locations is adjustable by changing the cross coupling value. A quadruplet structure can make more transmission zero using fewer resonators as compared with tri-section structure. A cross coupling structure called canonical asymmetric block, as shown in Fig. 2 (d), had been proposed [7] to produce transmission zero effectively. This structure also provides independent adjustment of zero locations but tuning becomes more complicated. The end resonators on each cascaded unit fromFig. 2 (b) to (d), can be duplicated if it is desired.

We chose a quadruplet rather than a tri-section or a canonical asymmetric block as cross coupling structure for the 22-pole filter. The reason was that we tried to maximize the number of transmission zeros along with using a simple cross coupling structure. For the 22-pole filter, the tolerance for each cross coupling is small. Because zero locations are very close to edge, the impact on the filter response from a variation of the cross coupling value is serious. The balance between the main coupling, which is the coupling between adjacent resonators, and the cross coupling is very sensitive for the filter.

The 22-pole filter was designed to meet one of the existing 3G wireless bands; a 1950 MHz center frequency and a 20 MHz bandwidth. Figure 3 shows the coupling structure of the filter. Five cross coupling paths were added between the second and fifth, sixth and ninth, tenth and thirteenth, fourteenth and seventeenth and eighteenth and twenty-first. Figure 4 shows equivalent circuit of the first quadruplet cross coupling block of the 22-pole filter. As shown in Fig. 4, the cross coupling between the second and the fifth resonators were made through transmission line and physical gaps between the transmission line and the resonators. The coupling intensity was controlled by J_a. Each cross coupling produces a pair of transmission zeros at both band edges, so that the filter has five transmission zeros at each side of its pass band. Five cross couplings were designed to

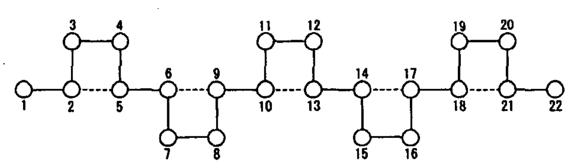

Fig. 3. A diagram of coupling structure of the demonstrated 22-pole with 10 transmission-zero filter. Solid lines denotes main path and dashed line denotes cross coupling path.

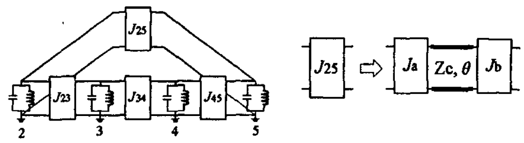

Fig. 4. An equivalent circuit of the first quadruplet cross coupling block of the 22-pole filter. Cross coupling structure was made through extra transmission line. The intensity of the cross coupling was controlled by a gap between the line and a resonator.

produce zeros located at 230 kHz, 300 kHz, 450 kHz, 800 kHz and 1,600 kHz apart from both band edges. Although the 3G band has a 20 MHz bandwidth, the filter was designed to have a 20.2 MHz bandwidth. Because the filter had a very sharp slope, the degradation of the insertion loss near band edge was very critical. So we introduced a 0.2 MHz margin for the design. Therefore, the designed band edge in the Fig. 1 was at 1960.1 MHz not at 1960 MHz. The insertion loss was −1.6 dB at 1960 MHz and −4.0 dB at 1960.1 MHz, respectively. In this calculation, the Q-factor of the resonator was taken as 100,000. A 50-pole Chebyshev filter response with the same designed bandwidth was also drawn in the graph as a reference. This Chebyshev filter has −2.3 dB insertion loss at 1960 MHz and rejects 90 dB at 1960.460 MHz while the 22-pole with 10 transmission zero filter rejects 90 dB at 1960.325 kHz. Therefore performance of 22-pole with 10 transmission-zero filter is able to surpass a 50-pole Chebyshev filter over both pass band and rejection region. This 22-pole filter also has the advantage of compactness as compared with a 50-pole Chebyshev filter, because it needs less than half number of resonators to achieve better performance.

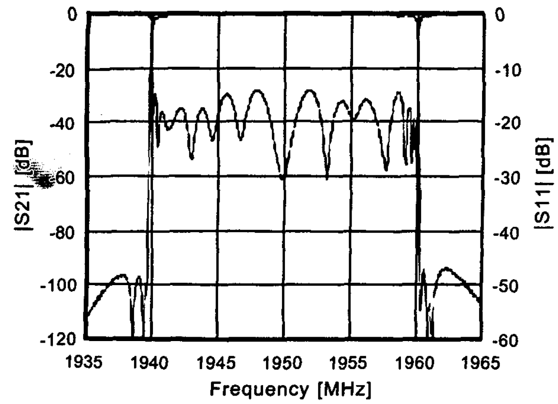

Fig. 5. Measured response of the 22-pole filter at 70K.

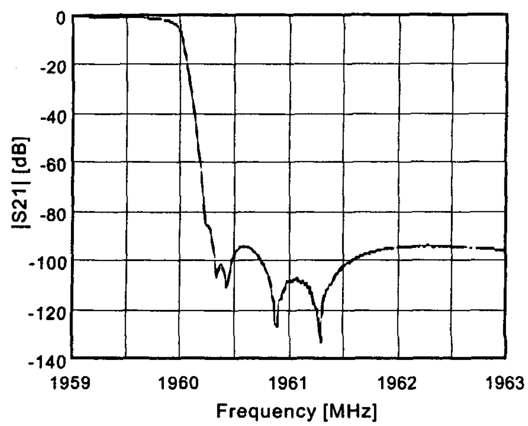

Fig. 6. Rejection slope at higher band edge at 70 K.

III. MEASUREMENT

The filter was fabricated on a 2-inch YBCO thin film coated MgO wafer. Figure 5 shows the filter response at 70 K. Nice brick wall selectivity and return loss was achieved. The insertion loss at the band center was about 0.2 dB. Ultimate rejection level exceeded 120 dB but its real value could not be measured because of limitation of the network analyzer's dynamic range. Figure 6 shows the rejection performance at the higher side. Input power for the measurement on Fig. 5 and Fig. 6 was set at +10 dBm to make transmission zero and bounce back visible. As a result, pass band edges rounded off the shoulder as compared with its curve measured below 0 dBm input power. There was no impact on shoulder when input power was set below 0 dBm. Five transmission zeros appeared clearly, because Q-factor of the resonator exceeded 100,000. Curve of the slope and bounce back agreed well with a simulation curve shown in Fig. 1. Five transmission zeros also appeared clearly at lower side and slope was quite symmetrical. Rejection points of 90 dB were at 1939.650 MHz, apart 350 kHz from the lower band edge and at 1960.300 MHz, apart 300 kHz from the higher band edge. Rejection slope was achieved over 30 dB/100 kHz.

IV. CONCLUSION

A distributed meander resonator was used to realize both compactness and high Q-factor. The quadruplet cross coupling technique was introduced to produce 10 transmission zeros. By combination of the resonator and the cross coupling technique, an ultra-sharp rejection slope was achieved on a 2-inch wafer area. The filter's performance surpassed a 50-pole Chebyshev filter, and it has exceeded every rejection performance that previously reported, to the authors' knowledge.

On the other hand, the demonstrated 22-pole filter has quite a large group delay deviation between its peak at band edge and its bottom at band center. This is unavoidable since a steeper slope rejection results in a larger group delay deviation. Although the demonstrated filter contributes quality improvement of the CDMA system by extreme reduction of out of band signal noise, its large group delay might impacts the quality of demodulation. This issue has to be considered as a next step.

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