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July 30, 1998

Dr. Martin Nisenoff
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Dear Dr. Nisenoff:

Enclosed please find the annual progress report on the project under the grant N00014-96-1-G017. This report will update you on the work we have done for the second year. We seek your advises and comments on the planned work for the next year.

With best regards,

Q. Y. Ma
Associate Professor

Enclosure:
Annual report.

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In the second year, the research work has been carried out in two directions: improving the old filter structure based on interdigital capacitor design and developing a new structure. Some modifications were made to the interdigital capacitor design and fabrications. The testing results showed some improvement on the device performance. However, these filters are too sensitive to matching capacitors, which are very small in capacitance. These matching capacitors can not be increased to achieve the purpose. New HTS three-pole bandpass filters of 24 MHz have been designed, fabricated, and tested using a spiral resonator structure. Three signal input/output coupling loops were used in the measurement of the filters: big-loop, small-loop-near, and small-loop-far. The best result so far is obtained from small-loop-far coupling which gives the three-pole center frequency of 24 MHz, an insertion loss of 2 dB, a return loss of 5 dB, and a stopband of < -40 dB. The project has made progress with the new design in decreasing insertion loss, increasing return loss and increasing stability and repeatability in fabrication. The new design is more flexible in terms of matching and adjustment of bandwidth or frequency. Based on the new filter results, a patent application has been filed.

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Annual Progress Report on the Project

Development of Low Loss Multipole RF Filters

Grant NO. N00014-96-1-G017

July 30, 1998

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Abstract

In the second year, the research work has been carried out in two directions: improving the old filter structure based on interdigital capacitor design and developing a new structure. Some modifications were made to the interdigital capacitor design and fabrications. The testing results showed some improvement on the device performance. However, these filters are too sensitive to matching capacitors, which are very small in capacitance. These matching capacitors can not be increased to achieve the purpose. New HTS three-pole bandpass filters of 24 MHz have been designed, fabricated, and tested using a spiral resonator structure. Three signal input/output coupling loops were used in the measurement of the filters: big-loop, small-loop-near, and small-loop-far. The best result so far is obtained from small-loop-far coupling which gives the three-pole center frequency of 24 MHz, an insertion loss of -2 dB, a return loss of -5 dB, and a stopband of < -40 dB. The project has made progress with the new design in decreasing insertion loss, increasing return loss and increasing stability and repeatability in fabrication. The new design is more flexible in terms of matching and adjustment of bandwidth or frequency. Based on the new filter results, a patent application has been filed.

A) Work Report

The technical objectives (modified in May, 1997 and on the first year report) for the second year include:

1) change the ground plane to superconductor,
2) test more meander lines,
3) test more interdigital capacitors,
4) modify the layout according to the results from 2) and 3),
5) fabricate, test and deliver several filters,
6) make several iterations of the design to optimize the filter performance.

1) HTS Wafers and Filter Fabrications

Two batches of double-sided YBCO wafers were purchased from Prof. Kinder's group in Germany. All films were deposited by co-evaporation on 20 mil LaAlO substrates. The films have very smooth surface and a Tc above 85 K and J_C above 2 x 10^6 A/cm^2 at 77K.

A total of 16 filters were fabricated using either the interdigital capacitor or spiral design in the Electrical Engineering Department at Columbia. Two of the filters were tested at cryogenic temperature by Dr. Jeff Pond at NRL. The rest devices were tested at Columbia at 77 K or below.

2) Continuing Work on Old Filter Design

a. Design

As stated in the last year report, we have continued the work on the 3-pole Chebyshev filter design with specifications shown as below.

Central Frequency f_0	2 - 30 MHz
Band width (BW)	0.1% f_0

Quality factor	1000
Insertion Loss (S_{12})	< -0.3 dB
Return Loss (S_{11})	< -20 dB
Stop Band at 4 times BW	< -40 dB

b. Fabrication and Testing

To improve this design, we need to verify first the individual elements, capacitor and inductor (see attached Fig. 4 of last year report), as the tasks 2), 3) and 4). Two testing structures were made and sent to NRL for testing in November 1997. The result, as shown in Fig. 1, agrees with our simulation. The phases of the inductor and capacitor are 90 degree and -90 degree at 15 MHz, respectively, which indicated that our model used in individual element design is satisfactory.

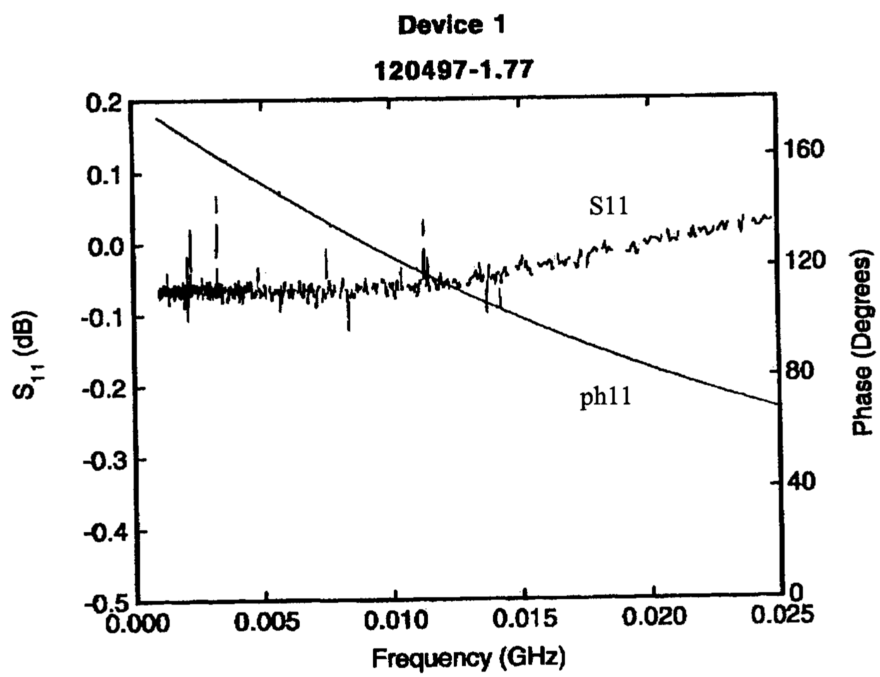
Based on the test results above, two filters with YBCO superconducting grounding plane (task 1) were made in February, 1998. We expected the changing of grounding plane from copper to YBCO would decrease the resistive loss of copper plate and increase Q and transmission. A cryogenic system to measure S-parameters was built and adjusted. In March 1998, the first filter with superconducting grounding plane was tested. However, the sample was broken during the process due to thermal expansion. Two more devices were made and tested at Columbia afterwards and the results (Fig. 2) are summarized as below:

Device	BW	I.L.	R.L.	Temp.	Power	comments
1	-	-	-	-	-	sent to NRL
2	-	-	-	-	-	sent to NRL
3	-	-	-	-	-	broken
4	8 MHz	-2 dB	-12 dB	26 k	-10 dBm	BW wide
5	8.4 MHz	-2 dB	-10 dB	26 k	-10 dBm	BW wide

Table1. Summary of continuing work on old design

c) Analysis

Compared with the results obtained in last year, the insertion loss and return loss are improved from -20 dB to -2 dB for insertion loss and from -1 dB to -10 dB for return loss. But the bandwidth of the filter response is widened. The individual elements testing results are in good accordance with our simulation. We believe that the deference in the performance of the filter from the design is due to the mismatching between resonators and the mismatching between the filter and the testing equipment. The whole structure is not widely tunable. To achieve narrow bandwidth and low insertion loss, our design are made from large capacitors (~200 pF) for resonant and very small capacitors (~0.2 pF) for matching. The performance of the filter is very sensitive to the values of matching capacitors. Therefore, the distributed parasitic capacitance or inductance and the variation of the values of the elements from fabrication are big enough to change the performance of the filter. Based on the analysis we shifted our focus to the new structure in the later stage of the project discussed below.



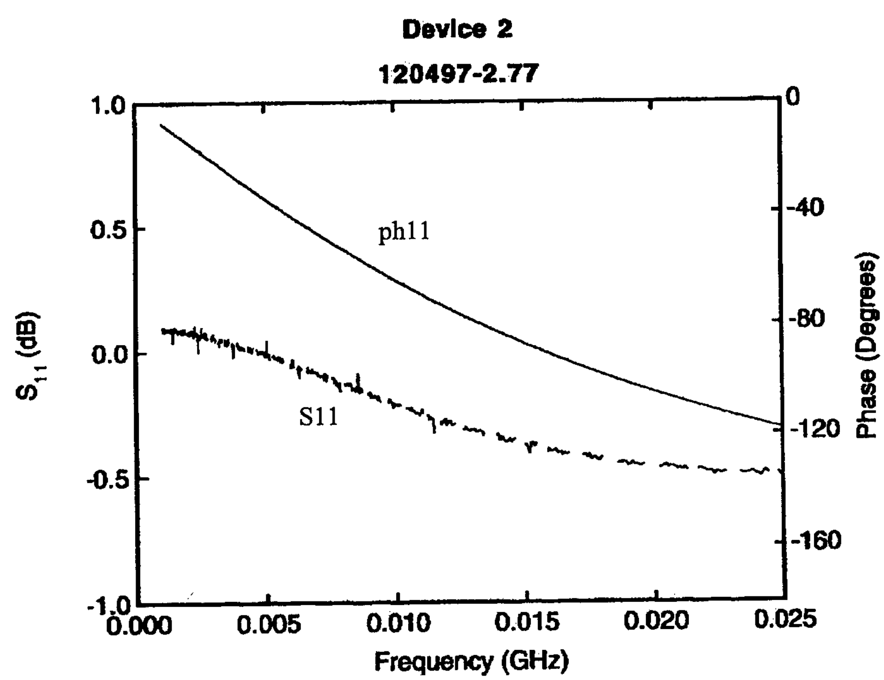


Fig.1 Testing results of an inductor (Device 1) and a capacitor (Device 2) made with YBCO film

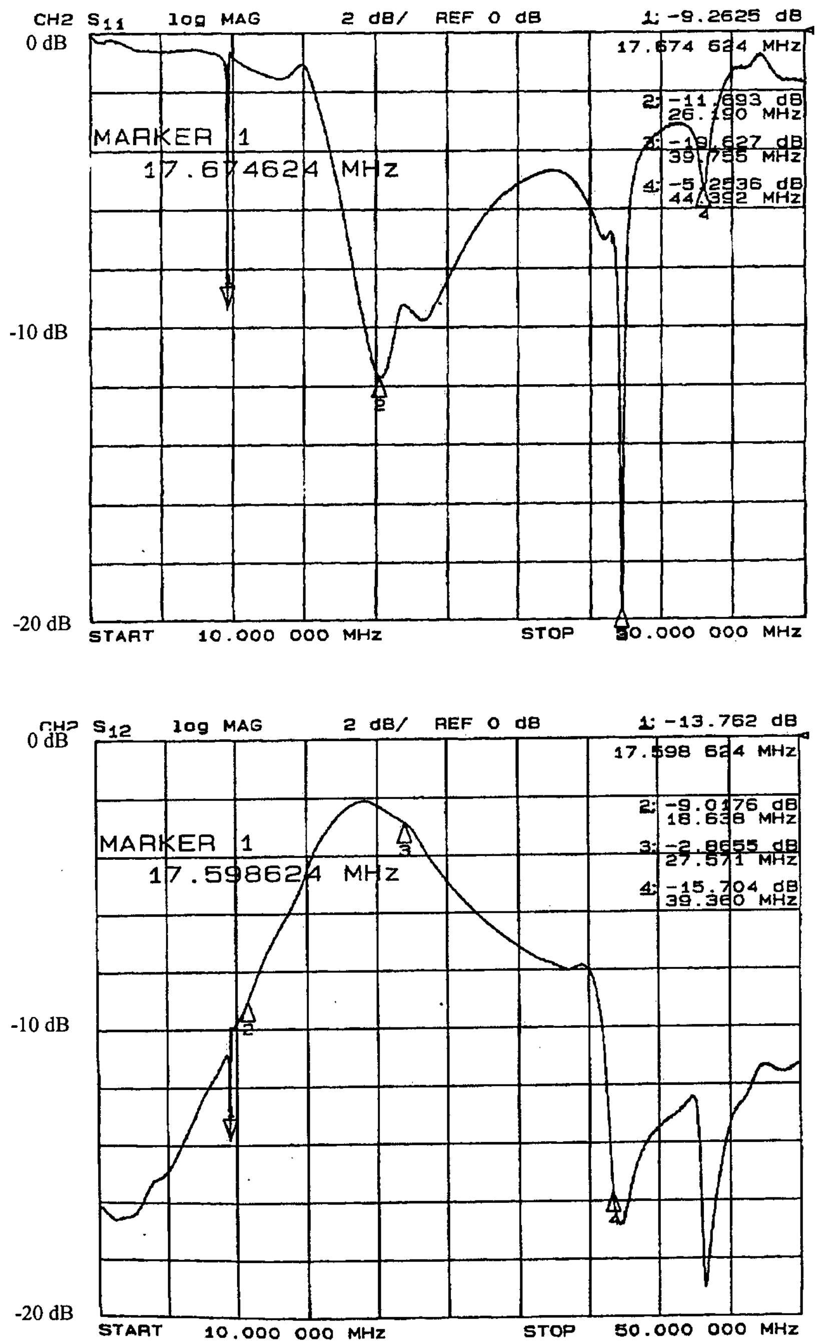


Fig. 2. Response of filter made in May 1998 shows lower insertion loss and high return loss, but with a widened bandwidth

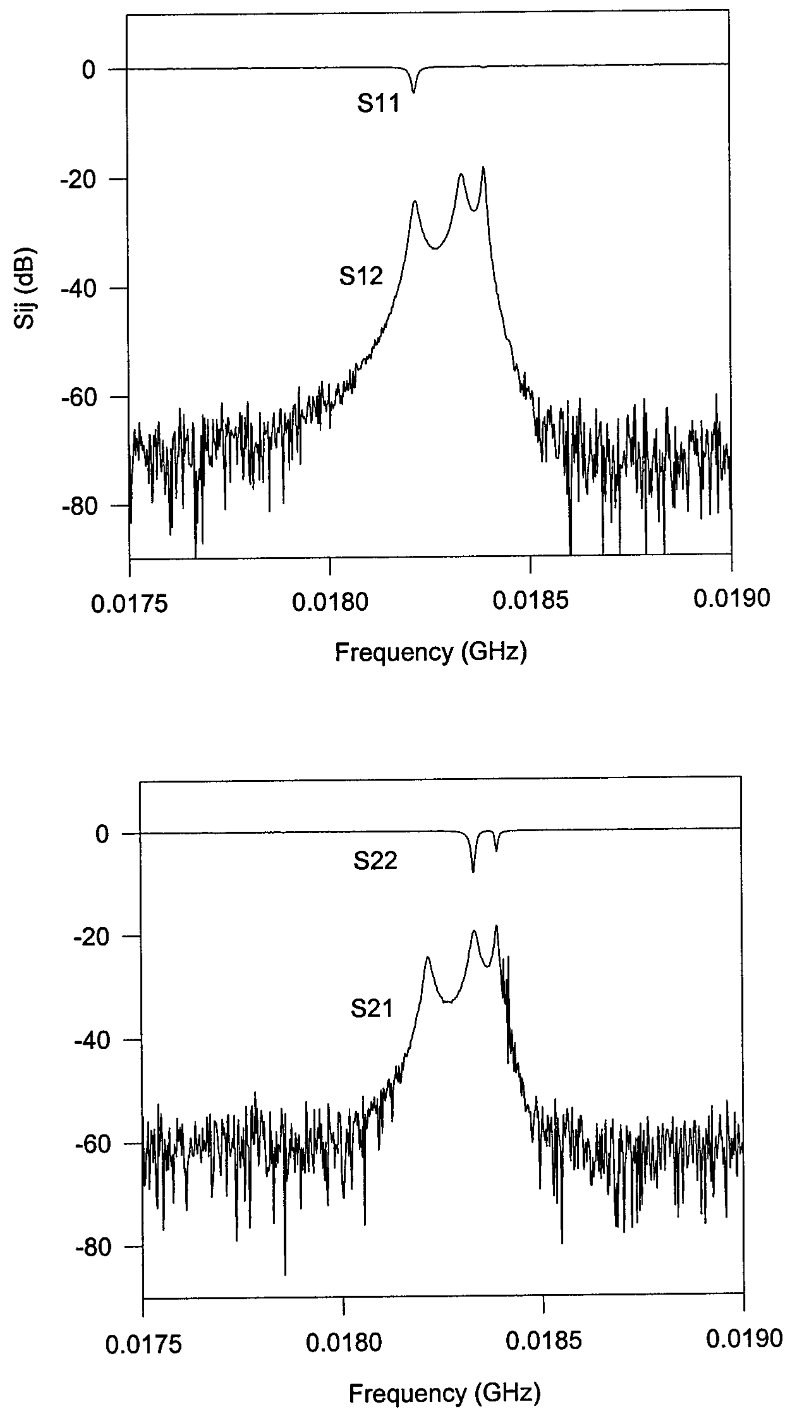


Fig. 3. Response of the filter made in May, 1997

3) New Three-pole Filter Design

a) Multiple-spiral Resonator

The key of our new 3-pole filter design is a multiple-spiral resonator which consists of three identical spirals. A 3-spiral resonator is shown in Fig. 4. These three spirals are patterned and fabricated on a two-inch HTS wafer. Each spiral contains 20 turns with homogenous separation between adjacent turns. These three spirals are arranged in parallel to each other and mutually coupled.

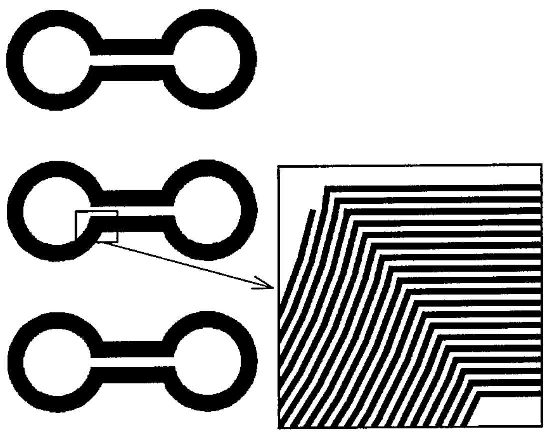


Fig. 4 A 3-spiral resonator

b) Three-pole Filter

A 3-pole-filter is made based on a 3-spiral resonator with two copper input and output coupling loops, as shown in Fig. 5. Several deferent layouts of the 3 spiral structures were designed and fabricated.

c) Input and Output Coupling Loops (copper wire)

Three different kinds of coupling are used: (i) big-loop, (ii) small-loop-near, and (iii) small-loop-far, as shown in Fig. 5. The coupling loops are made of fine copper wires and connected to coaxial cables.

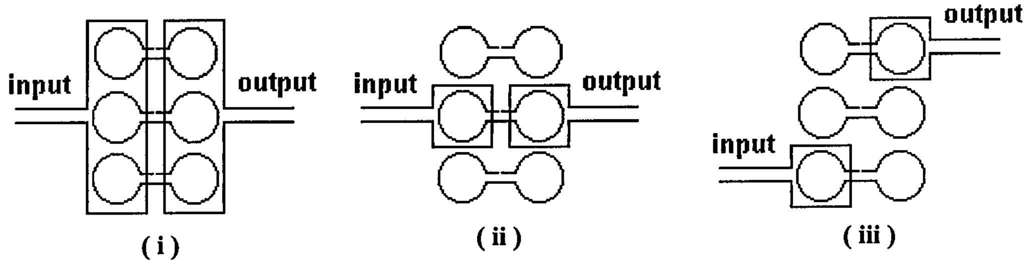


Fig. 5 Three coupling methods with two copper loops: (i) big-loop, (ii) small-loop-near, and (iii) small-loop-far

d) Results

Three 3-pole-filters were tested in liquid Nitrogen at 77K with three different coupling loops, as shown in Fig. 5 (i), (ii), and (iii). Return loss (S_{11}) and insertion loss (S_{12}) were measured with a HP-8712B RF Network Analyzer. Three peaks were found in S_{11} and S_{12} for all three filters. The three peaks measured with small-loop-far (iii) are much closer from each other and homogenous.

(i) Big-loop (#S1, Fig. 6)

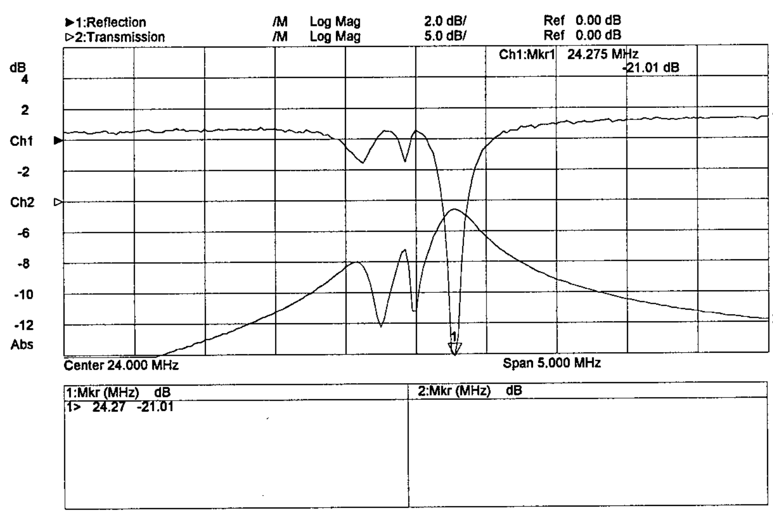


Fig.6 Return loss (S_{11}) and insertion loss (S_{12}) measured with big-loop (#S1)

(ii) Small-loop-near (#S2, Fig. 7)

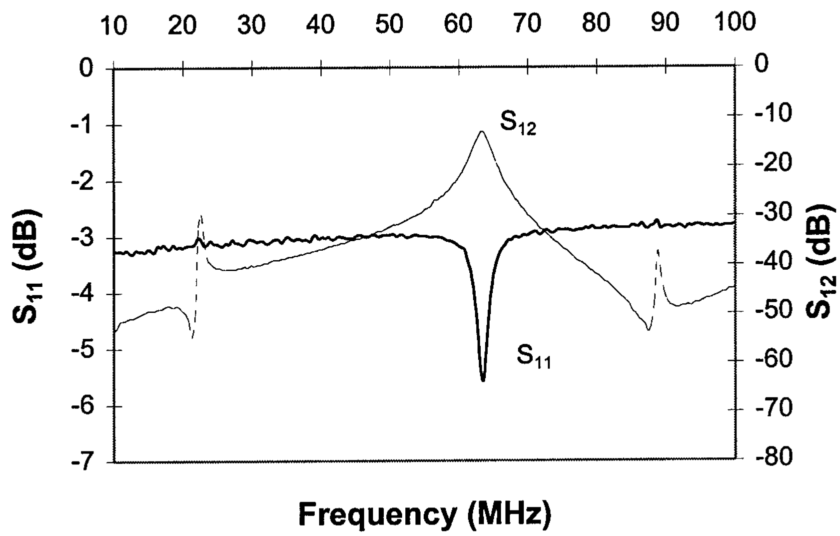


Fig. 7 Return loss (S_{11}) and insertion loss (S_{12}) measured with small-loop-near (#S2)

(iii) Small-loop-far (#S3, Fig. 8)

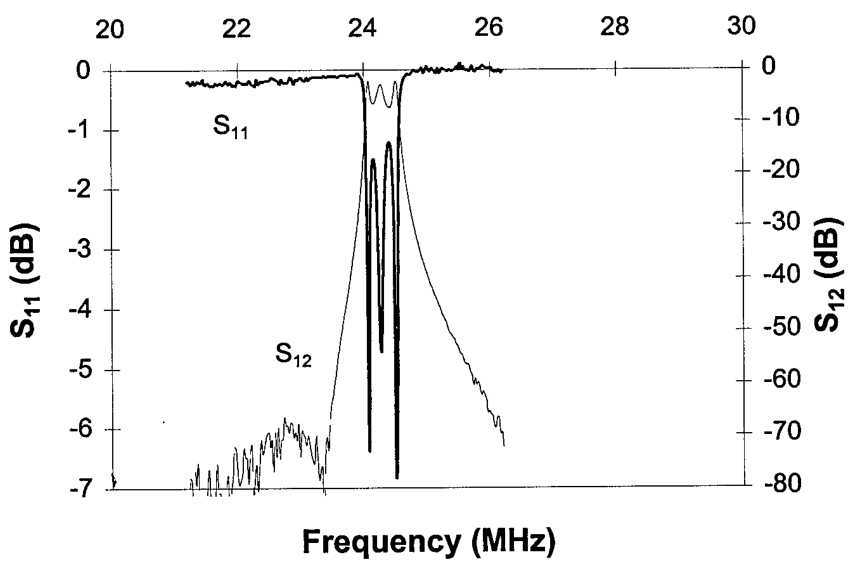


Fig. 8 Return loss (S_{11}) and insertion loss (S_{12}) measured with small-loop-far (#S3)

		Peak #1		Peak #2		Peak #3	
		S_{11}	S_{12}	S_{11}	S_{12}	S_{11}	S_{12}
#S1	f (MHz)	23.65		23.9		24.27	
	loss (dB)	-3.5	-8	-3.5	-7	-21.01	-5.5
#S2	f (MHz)	22.55		63.33		88.74	
	loss (dB)	-3.03	-29.56	-5.48	-12.88	-2.7	-37.28
#S3	f (MHz)	24.07		24.28		24.5	
	loss (dB)	-6.37	-2.02	-4.62	-2.56	-6.55	-2.05

Table 2. Summary of three different 3-pole filters based on new designs

The bandwidth is about 0.43MHz. The maximal insertion loss between 24.07 and 24.50 MHz is -6.91 dB. At lower (<23.77 MHz) or higher (>25.03 MHz) frequency the insertion loss are lower than -40 dB. Based on these results a patent application was filed for the new design.

e) Analysis

The new designed 3-pole filters with two small coupling loops (far) have three poles at about 24 MHz and distributed in about 0.5MHz. The insertion loss is about -2dB and return loss is about -5dB. Even though this design is not satisfactory, it is closer to our aims. The flexibility of the new filter design provides us with easy ways to improve.

Three spirals are identical in terms of their structures. However, when three spirals are coupled with each other, they become a resonator with three peaks. The separation between peaks depends on the strength of coupling. The stronger coupling, the bigger separation. To bring three poles closer, in the future designs, we can reduce the coupling between spirals. There three ways to reduce the coupling: (1) increasing spatial separation between spirals, (2) decreasing inductance of each spiral, and (3) changing two spiral frequencies by removing a small amount of spiral (for instance 0.1 turn).

We have learned experience in frequency manipulation of spiral resonators. The new design allows us to precisely adjust relative positions of three spirals which leads to better matching. We believe that with this design we can decrease bandwidth and insertion loss and increase return loss in the future work.

B) Work in the Next Year

In summary, we have finished all six tasks of the project in the second year. The work in the third year will be to continue the three-pole filter project with the new design by several modifications:

(1) manipulating spiral resonator frequencies to bring peaks closer;
(2) improving matching mechanism to get lower insertion loss and higher return loss;
(3) adjusting capacitance and inductance of a spiral by changing inter-turn spacing and the number of turns to get higher Q resonator and filter;
(4) trying to design, fabricate, and test multilayer HTS filters.