Precision Band Pass Filters for The Debuncher Stochastic Cooling System

Ding Sun
07/2002

I. Introduction

According to RFI TECHNOTE 024 [1], the band pass filters currently used in debuncher cooling system have wider pass bands than the pickup response. Bandwidths of most of these filters are almost twice as much as the signal bandwidth (see Table 1.) To improve the performance of the cooling system, band pass filters with narrower bandwidth and steep cutoff are highly desired. Therefore 24 new band pass filters (3 systems: momentum, horizontal and vertical, 4 frequency bands for each system, 2 sub-bands in each frequency band: lower and upper sub-band) have been designed and fabricated. Each one of them has its own frequency range and bandwidth.

II. Design and Fabrication

Parallel coupled resonant lines made of stripline structures are used for these band pass filters. Since in most bands the adjacent lower/upper sub-band signals are very close to each other, these filters should meet the following requirement: have exact frequency range and bandwidth, steep cutoff, and flatness of both amplitude and phase within the pass band. To achieve these design goals, 6 parallel coupled resonant lines circuit is chosen for most of filters (Figure 1.) Both simulation and measurement results show that with same -1 db bandwidth, -10 db bandwidth of 4 coupled resonant lines is ~200 MHz wider than that of 6 coupled lines. Since 1 db bandwidth of these filters is about ~400 – 600 MHz, 200 MHz increase in bandwidth (even at –10 db level) is obviously not a negligible number, which means the 6 parallel coupled lines structure is much better than the 4 parallel coupled lines structure. However in some of band 3 and 4 systems, transmission line length cannot be shorten by 1 - 2 nano seconds, 4 edge-coupled resonant line structures are used.

All 24 filters are designed symmetrically: parameters (line width, length and spacing between lines) of left half circuit are the same as that of right half ones. These parameters are listed in Table 2. Hewlett Packard ADS (Advanced Design System) software is used for design. The optimization of these filters is done manually since manual optimization is much better (and much faster) than the software's optimizer. There is a systematic deviation of frequency range between the real filters and simulation results from ADS or another software Ensemble (Ansoft Inc.) The parameters in Table 2 have taken this deviation into consideration. However manufacturing tolerance often masks the true systematic deviation. So to make filters at an exact frequency range, one has to analyze the data from prototype filters very carefully. This can be seen in Table 1: some filters have larger deviation than others, though they are designed using same design principal.

How to reduce manufacturing tolerance and increase repeatability is a key to get right frequency range. The local manufacturer has the capability to fabricate circuit line with width of as small as 5 mil (0.005 inch.) However the variation of line width can be easily at 1 mil level. This line width variation would cause spacing variation of ~ 1 mil which affects the frequency drift more than line width does. A desired tolerance on line width and spacing is less than 0.5 mil. In order to improve the manufacturing tolerance, a quality control procedure on line width and spacing is adopted: (1) visually check (measure) the line width and spacing on the photo mask film after it is made, (2) fabricate a test circuit board using this photo mask film and visually check (measure) the line width and spacing on this board, and (3) fabricate the production board and visually check (measure) the line width and spacing of final products (filters).

In addition to line width and spacing, the total height of the stripline structure is also a critical quality factor to be controlled. The specification for Arlon CuClad 233 45 mil certified board is 45 mil +/- 2 mil. The actual variation of thickness for a board is less than 0.5 mil. After lamination process, however, the variation of total height of a filter can be as much as 5 mils. This can cause frequency shift of up to ~200 MHz randomly. After several trials, it was concluded that it is beyond this local manufacturer's capability to get uniform and constant total height. Therefore the lamination process is no longer used. Instead, 6 metal screws are used to hold two boards together (Figure 1) to form stripline structure. These screws also serve as via holes. Though it looks like a primitive solution, it not only completely eliminates the frequency shift due to fluctuation of total height but also makes the filters tunable and easier for mounting the launcher.

III. Performance

Shown in Figure 2 is a typical S parameter measurement result of one of these filters. Other filters have similar performance. These filters are well matched: S11 of all filters are around –20 db within the pass band. Since main goal for the design of these filters is to get exactly right frequency range and band width, these data are listed in Table 1 in stead of a plot for each filter.

Listed in Table 1 are measured frequency ranges of pass band of new filters and corresponding pickup signals to be filtered. Listed in column 1 of Table 1 are the band edges (at -15 - 20 db level) of pickup signals drawn from transfer function measurement. Listed in column 2 of Table 1 are the same band edges drawn from signal to noise measurement. Listed in column 3 of Table 1 are band edges (-1 db) of new filters measured with a Network Analyzer. The new filters are designed to be as close as possible to (and slightly wider than) the data in column 1 of Table 1. Therefore the data in column 3 should be compared with the data in column 1 for evaluating these new filters. Listed in column 4 of Table 1 are frequency ranges of currently used filters (to be replaced.)

In summary, the data in column 3 of Table 1 show that: on average the pass band of six band 1 filters are ~10 MHz wider than the pickup signals on both lower and upper edge, the six band 2 filters are ~20 MHz wider on both lower and upper edge, the six band 4 filters are ~ 25 – 30 MHz wider on lower edge and ~ 5 MHz wider on upper edge, and the six band 3 filters are ~25-30 MHz wider on lower edge and ~ 5 MHz narrower or ~10 MHz wider on upper edge.

All filters are measured at room temperature (~74 F). Since operating temperature will be higher than ordinary room temperature, the temperature effect has been investigated. Frequency shift is ~5 MHz (higher) for one of band 1 filters and ~15 MHz (higher) for one of band 4 filters when board temperature increase to 100 F from 74 F. Even with these possible frequency shifts, the pass bands of these new filters will still cover the signal bands very well. This is due to a design feature that these filters cover lower edge of the pickup signals a little bit more than upper edge (see Table 1.)

Name nomenclature: The name of each filter in column 3 of Table 1 is also the name of its ADS design file. The first 4 letters in the name of a filter indicates which sub-system they should be used for. For example, b1Hu (in the name of b1Hu1) means band 1, horizontal, upper band, and b4mL (in the name of b4mL4c4) means band 4, momentum, lower band.

Reference

[1] R. Pasquinelli, "Debuncher Momentum Cooling Systems Signal to Noise Measurements", RFI TECHNOTE 024

Table1. Frequency of Band Edges (GHz)

	Band edge of pickup signals from Transfer Function Measurement (Network Analyzer)	Band edge of pickup signals from Signal to Noise Measurement (Spectrum Analyzer)	Band edge (-1 db) of new filters from Network Analyzer measurement	Band edge of filters to be replaced
	BAND 1 L			
M	4.097 - 4.488	4.0 - 4.5	4.087-4.495 (b1mL7, 1-2)	3.8 - 4.6
H	4.091 - 4.455		4.080- 4.473 (b1HL1, 1-2)	3.8 - 4.6
V	4.021 - 4.436		4.006 - 4.455 (b1VL1, 1-2)	3.8 - 4.6
	BAND 1 U			
M	4.488 - 4.876	4.5 - 5.0	4.473 - 4.877 (b1mu7, 1-2)	4.2 - 5.1
H	4.455 - 4.935		4.442 - 4.944 (b1Hu1, 1-2)	4.22 -5.13
V	4.436 - 4.819		4.408 - 4.831 (b1Vu1, 1-2)	4.2 - 5.1
	BAND 2 L			
M	5.016 - 5.424	5.0 - 5.45	4.980 - 5.431 (b2ML5, 1-1,1-2)	4.7 - 5.6
H	4.921 - 5.370		4.900 - 5.384 (b2HL5, 1-1, 1-2)	4.7 - 5.6
V	4.963 - 5.399		4.940 - 5.419 (b2VL5, 1-1,1-2)	4.7 - 5.6
	BAND2 U			
M	5.424 - 5.920	5.45 - 5.9	5.400 - 5.927 (b2mu5, 1-1,1-2)	5.1 - 6.0
H	5.370 - 5.866		5.351 - 5.875 (b2Hu5, 1-1,1-2)	5.1 - 6.0
V	5.399 - 5.852		5.379 - 5.858 (b2Vu5, 1-1,1-2)	5.1 - 6.0
	BAND 3L			
M	6.050 - 6.523	6.0 - 6.57	6.019 - 6.539 (b3mL4c2, 1-1)	5.7 - 6.5
H	5.796 - 6.401		5.769 - 6.391(b3HL1, 1-1)	5.7 - 6.5
V	5.801 - 6.434		5.778 - 6.431(b3VL1, 1-1)	5.7 - 6.5
	BAND 3U			
M	6.565 - 7.134	6.57 - 7.13	6.535 - 7.144 (b3mu4c4, 1-2)	6.4 - 7.6
H	6.258 - 6.981		6.234 - 6.976 (b3Hu1, 1-2)	6.0 - 7.0
V	6.255 - 6.996		6.250 - 7.015 (b3Vu1, 1-1-T)	6.0 - 7.0
	BAND 4L			
M	7.315 - 7.876	7.30 - 7.90	7.260-7.901 (b4mL4c5,1-1,1-2)	7.0 - 7.9
H	6.980 - 7.593		6.950-7.588 (b4HL4c6,1-1,1-2)	6.5 - 7.7
V	6.862 - 7.689		6.836-7.692 (b4VL4c6,1-1,1-2)	6.5 - 7.7
	BAND 4U			
M	7.798 - 8.430	7.90 - 8.40	7.772-8.430 (b4mu4c5,1-1,1-2)	7.4 - 8.4
H	7.456 - 8.022		7.428-8.028 (b4Hu4c6, 1-1,1-2)	7.0 - 8.4
V	7.475 - 8.118		7.451-8.115 (b4Vu4c6,1-1,1-2)	7.0 - 8.4

Table 2. Circuit Line Parameters (mil)

	W1	S1	W2	S2	W3	S3	L	W0	L0	W7	L7	Edge
b1ML7	36	8	47	27.5	55.5	34	420	76	547	74	100	15.5
b1HL1	36	8	47	28	56	34.5	421.5	76	542.5	74	100	15.5
b1VL1	34	7	44.5	25	53	31.5	426	76	529	74	100	15.5
b1Mu7	36.5	7.5	47	29	55.5	35.9	383	76	658	74	100	15.5
b1Hu1	36	7.8	47	26.5	55	31.7	382	76	661	74	100	15.5
b1Vu1	38.4	7.8	47	30	54	36	388	76	643	74	100	15.5
b2ML5	41	7.5	57	28	62.5	35	340.5	71	785.5	71	100	15.5
b2HL5	41	7.5	57	27	61	34	345.5	71	770.5	71	100	15.5
b2VL5	40	7.5	56	27	60	34.5	343	73	778	73	100	15.5
b2Mu5	42	7.5	56.5	27.5	61	34	311	73	874	73	100	15.5
b2Hu5	42	7.5	57.5	27	61.5	34	314	73	865	73	100	15.5
b2Vu5	43	7.5	58	28.5	61.5	36	313.5	73	866.5	73	100	15.5
b3mL4c2	43	9	71	26			276.6	78	1284.8	73	100	15.5
b3HL1	40	7.5	58.5	24.2	63	31.5	287	73	946	73	100	15.5
b3VL1	39	7.5	58	23.5	62	30.8	286	72	949	72	100	15.5
b3mu4c4	47	8.5	61	29			252.2	79	1333.6	73	100	15.5
b3Hu1	37	7	48	26	55	31	262.7	70	1018.9	70	100	15.5
b3Vu1	37	7	48	25.6	55	30.6	262.5	72	1019.5	71	100	15.5
b4mL4c5	45	7.5	59	30			224.7	70	1388.6	70	100	15.5
b4HL4c6	44	7.5	57.4	29			235.7	70	1366.6	70	100	15.5
b4VL4c6	39	7.5	55	22.9			236.2	70	1365.6	70	100	15.5
b4mu4c5	47	7.5	59.5	31			208.7	70	1420.6	72	100	15.5
b4Hu4c6	44.5	7.5	61	32.2			220	70	1398	70	100	15.5
b4Vu4c6	44.5	7.5	60	29			218.3	70	1401.4	70	100	15.5

W1: width of coupled line #1
S1: spacing of coupled line #1
W2: width of coupled line #2
S2: spacing of coupled line 2
W3: width of coupled line #3
S3: spacing of coupled line #3
L: length of all coupled lines
W0: width of transmission line
L0: length of transmission line
W7: width of matching section (transmission line)
L7: length of matching section (transmission line
Edge: extension of coupled lines at each end
Only half of circuit line parameters are listed since circuit is symmetric.
Arlon Cuclad 233 45 mil board with permittivity of 2.32 is used for all filters.

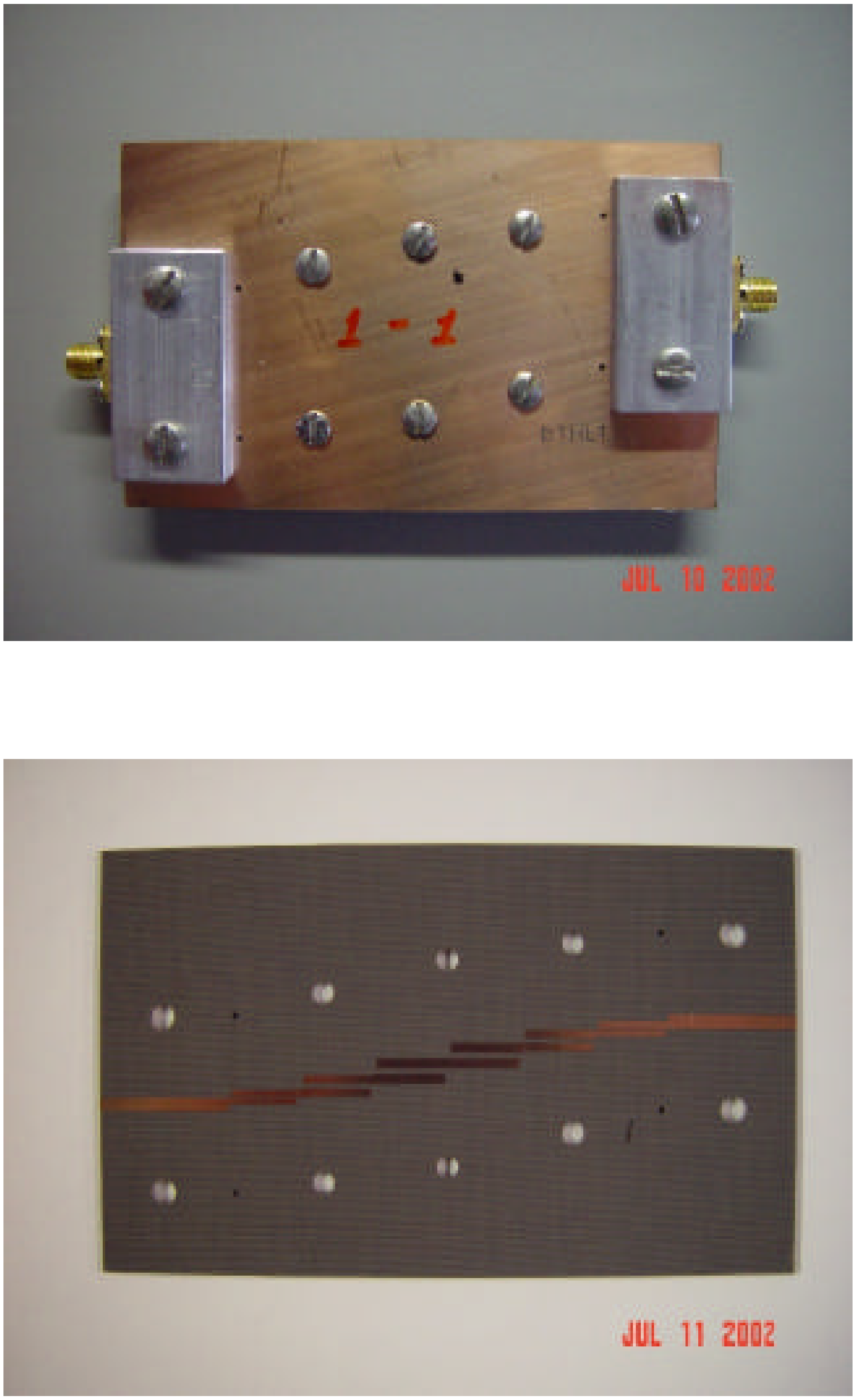

Figure 1. Assembled Filter and Circuit Line

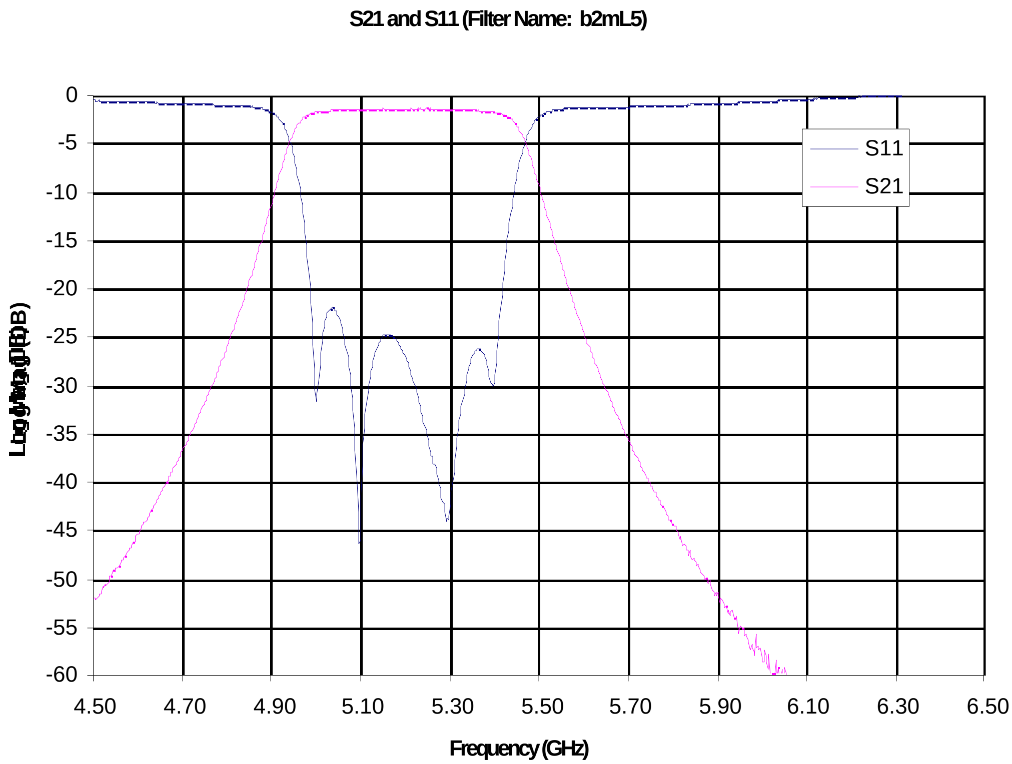

Figure 2. Measured S Parameter of Filter b2mL5