Overview

The project involves the design and implementation of a bandpass filter that has two separate passbands; the lower frequency band passes the frequency range between 3 and 5 Gigahertz, whereas the higher one passes frequencies between 6 and 9 Gigahertz. The purpose of the filter is to eliminate the frequency range from 5 to 6 GHz, which is the frequency band used by personal area networks. The commonplace approach to achieve this kind of a response is to build two separate filters, each passing one of the bands, and combining the responses of the filters by either a power divider or by a multiplexer. This approach has a number of disadvantages among which are the use of lumped elements and accumulated insertion loss, not to mention making the filter much complex. The design proposed in this project, however, is quite unorthodox in that the overall response is achieved in a single stage, thus eliminating the drawbacks observed in the aforementioned approaches. The design is basically a Stub Bandpass Filter with open circuit terminated stubs. The desired response of two passbands is obtained by virtue of the filter repeating its response quasi-periodically over the frequency range.

Design

To obtain the desired response, I tried out quite a few different designs from the pool of commonly used filters before coming up with my final design. I first assessed the response of several filters built using combinations of lumped elements and transmission lines, however, none was adequate. Having failed with lumped element designs, I tested some microstrip transmission line filters including combline filters, interdigital filters, parallel coupled line filters, and hairpin filters. These had good frequency responses in a confined interval, however, with this approach I would have to build two separate filters and combine them using a power divider or a diplexer. In the process of trial and errors to find the best design, I utilized the Design Assistant in ADS to speed up the process. One of the design blocks I tried in the Design Assistant was the Stub Bandpass Filter. Upon observing the repeated pattern of passbands and stopbands in the frequency response of the SBF I came up with the idea of the possibility of implementing the design in a single stage using this SBF. Then I tweaked the design parameters such that the SBF would give the response I required. My design used a Chebychev filter rather than a maximally flat filter to have less insertion loss at the expense of ripples in the passbands. Still, the amplitudes of these ripples are kept under 0.15 dB. To ease the implementation I designed the filter so that there would be a single set of stubs, all of which end in open circuits instead of short circuits to avoid having to drill a hole through the substrate to reach to the ground. The dialog box of my final design is given below:
The block diagram of the SBF in the schematic window is the following:
The component labeled **DA_SBFilter1_main_schem** is the Stub Bandpass Filter, which is a hierarchical block in the schematic window. Pushing into this block, the actual design of the filter in microstrip lines is revealed:
Simulation

The simulation of the above design from 20 MHz to 11 GHz in steps of 20 MHz is shown below:
As it can be seen from the plot of the magnitude of the filter’s frequency response, the ports are fairly matched in the passbands and the response is quite flat. For the stopbands, nearly all the power is reflected back at input ports and attenuation is well below 20 dB. Below is the plot of magnitude and phase of $S_{11}$ for the same frequency range.
The following is the plot of magnitude and phase of $S_{12}$ for the same frequency range of 20 MHz to 11 GHz. The phase response of the filter is quite linear in the passbands as it is seen from the plot:
After coming up with a satisfying design, I went on to implementing the layout of the circuit in the schematic. Here again I made use of the automatic layout capabilities of ADS to hasten the process and avoid DRC errors. The first layout had very poor response in the simulation; in particular ports were severely lacking in matching. I overcame this problem by adding a small length of transmission line matched to the ports’ impedance. The final layout and its response in the simulation is given below. (The line reads “Ali Nazmi Ozyagci * TE401 Hatirasi * Jan 2005”)

![Layout Image]
Response of the filter obtained in layout simulation:

The matching at the ports as well as the response at the passbands are considerably worse than those in the schematic simulation, but are still tolerable nevertheless.
The phase response is, however, much worse compared to the schematic simulation as linearity is lost in the layout simulation.
**Implementation**

Upon completing the design both in schematic and in layout, the next step in the process of building the filter was to print it on an FR4 board. To print the circuit, I followed the standard process to build a homebrew PCB. I first printed the mask of the filter on acetate. Then I coated the board to be printed in Positive20 and applied the mask under UV light for two and a half minutes. After the mask was applied I washed the board in the base solution. Before dipping the board in the acid solution I covered the back of the board in nail polish to prevent the ground metal from being washed away. Then for some ten minutes I washed the board in the acid solution. Finally when I cleaned both faces of the board with acetone it came out to be a fine sample of homemade PCB. The front and back photos of the board are seen below:
The ports were soldered to the board with an abundance of soldering iron to achieve good grounding.
This is the mask I used to print the board. Unfortunately there is a typo in the mask, the date reads as Jan 2004 instead of 2005:
When the board was printed and the ports soldered I tested the board using the network analyzer. The response of the printed board was much better than I had expected. $S_{12}$ and $S_{21}$ are nearly identical, indicating the filter being reciprocal. The lower passband is above -3dB from 3 to 5 GHz, perfectly meeting design requirements. The magnitude response of the upper passband, however, is somewhat lower than the requirements; it goes down to as much as -7dB.

Magnitude plot of $S_{12}$:
Magnitude plot of $S_{21}$:
The matching of the ports is also much better than those calculated in the layout simulation. The lower passband is well below -10dB in magnitude, however, the upper passband needs improvement, as the response goes higher than -5dB at certain points.

Magnitude plot of $S_{11}$:
Magnitude plot of $S_{22}$:

Conclusion

The design worked both in simulation and in implementation. At the end I achieved the two-passband filter response using only a single stage, thus eliminating the need to use lumped elements and avoiding accumulated insertion introduced by additional stages. It is intriguing that the test results in the network analyzer rather followed the simulation results of the schematic instead of the simulation results of the layout. The upper passband had poorer response compared to the lower passband, because design frequency was closer to the operating frequencies of the lower passband. It is hard to achieve a single design that will work in both frequency ranges, however, the response of the upper band can still be improved by tweaking this design frequency.