A Design for a Microstrip Filter with the Help of the Advanced Design System Package

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ABSTRACT: *We in this work, we have made a design for a microstrip filter with the help of the Advanced Design System package. We have employed sodium per sulfate for the etching so as to prepare the filter to be fabricated one-sided FR-4 sub-strate, Further, we have compared the fabricated filter and the virtually designed one.*

1. Introduction

New technologies for designing filter are being research all over the world to meet the growing demand for advance filter design with greater frequencies response and characteristic. Filter design often grapple with the trade-off among electrical and physical parameters such as physical size, insertion loss, loss variation, isolation, group delay, and production cost. Different techniques in designing filters have some advantage and disadvantages that need to be considered [1].

Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board technology, and is used to convey microwave-frequency signals. It consists of a conducting strips separated from a ground plane by a dielectric layer known as the substrate. In such a technology, reciprocal and non-reciprocal, passive components are obtained by varying the configuration and dimensions of the printed metallic strips [2].

Microstrip filter design techniques are very compatible, quite durability, but the devices are not size efficient and with a high cost of production. They have been vastly researched all around the world [1].

A band-pass filter is a circuit which is designed to pass signals only in a certain band of frequencies while attenuating all signals outside this band. The LC rather than having a single element in each leg of the filter as in the case of the low pass and high pass filters, the band pass filter has a alternating parallel and series resonant circuit in each leg [3]. The parameters of importance in a bandpass filter are the low passband (f_{P1}) and the stop-band (f_{S1}) frequencies, the high passband (f_{P2}) and the stop-band (f_{S2}) cut-off frequencies, the bandwidth (B or BW), the center frequency (f_C), and the a maximum and minimum attenuations in respectively the passband and the stop-band [4].

2. Parameters of the Filter

The goal is to design a microstrip Chebyshev band-pass filter that has to cover the following requirements: a maximum attenuation in pass-band (α_{max}) of 1 dB; a minimum attenuation in stop-band (α_{min}) of 30 dB; a low cut-off stop-band frequency (fS1) of 1 GHz; a low cut-off pass-band frequency (f_{P1}) of 1.5Ghz; a high cut-off pass-band frequency (f_{P2}) of 2Ghz and a high cut-off stop-band frequency (fS2) of 2.5GHz. All of the given parameters are shown in Figure 2.

For lowest cost, microstrip devices may be built on an FR-4 (standard PCB) substrate. However it is often found that the dielectric losses in FR4 are too high at microwave frequencies, and that the dielectric constant is not sufficiently tightly controlled.[2].

In this document a double sided FR4 substrate with a photo resistive layer on each side will be used. The photo restive coating is used to protect the microstrip stubs while etching the whole PCB substrate in the iron trichloride solution.

The FR-4 substrate has a relative dielectric constant of ε_r = 4.2, thickness of H = 1.5 mm, loss tangent of $tan\delta$ = 0.02 and a metallization thickness of t = 35 μm .

3. Design of the Filter

In the virtual designing of the filter, the software package ADS (Advanced Design System) is going to be used. ADS is an electronic design automation software system produced by Keysight Technologies [5]. It provides an integrated design environment to designers of RF electronic products such as mobile phones, pagers, wireless networks, satellite communications, radar systems, high-speed data links and even filters [6]. It has lots of functions that make design and production of all kinds of devices much easier.
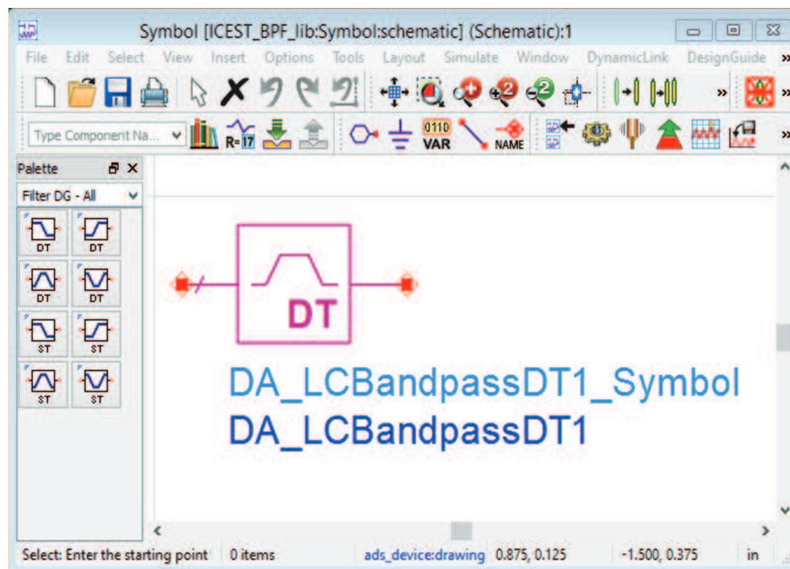

Figure 1. The symbol of the bandpass filter and the "Filters DE-ALL" library

The design procedure in ADS begins with making a project which consist of choosing: a name; directory where the project will be stored; the libraries needed for the schematic; the technology that will be used. After that a schematic needs to me made. The ADS system has a really helpful library – "Filters DE-ALL" (Figure 1) which have interactive filter devices. By interactive it is meant that they use a function called "Filter Design Guide" to synthesize the filter structure consisting of lumped elements either singly terminated or not. The window of the function is shown in Figure 2. After the desired parameters (attenuations, cut-off frequencies, source and load impedances) are inserted and the resonance type is chosen (in this case Chebyshev) the order of the filter (n) (in this case its 3) automatically calculates. An order of three means that the filter will consists of 3 resonant circuits.
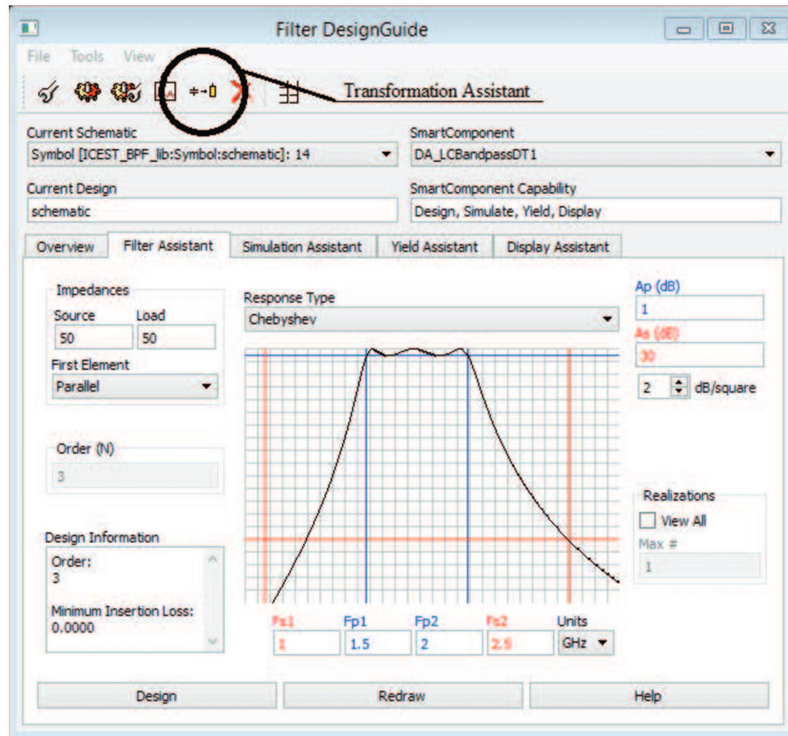
Figure 2. The "Filter Design Guide" window consisting all the parameters of the filter

There are two topologies that can be used for the filters - the *Pi* and the *T* configurations. The "**Π**" (the Greek letter "*Pi*") configuration starts with a parallel resonant circuit while the "*T*"- with a series one [3]. "**Π**" filters present very-low impedances at high frequencies at both ends due to the capacitive shunting. "*T*" filters conversely have very-high impedances at high frequencies because of the inductive coupling [7]. For this filter a "**Π**" configuration is used.

After all the needed information about the device is filled or chosen in the "Filter Design Guide" window the "Design" button in the bottom right corner needed to be pressed. This triggers the automated design function which creates the filter prototype that consists only of lumped elements. The schematic of the prototype is shown on figure 3.
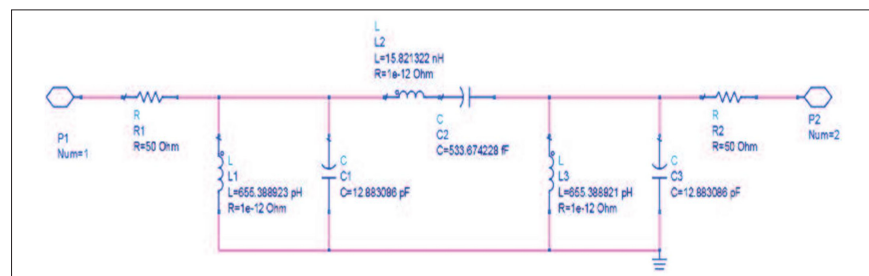

Figure 3. Schematic of the filter's prototype

As you can see it has three resonant circuits – a parallel circuit (consisting of L1 and C1) followed by a series one (consisting of L2 and C2) and again a parallel one (consisting of L3 and C3) at the end (this is the "**Π**" shape). The resistors R1 and R2 are respectively the source's and the load's resistances. They have a value of 50Ω that has been chosen in the "Filter Design Guide" window (Figure 2). The P1 and P2 are the input and output pins.

The next step is to use the "Transformation Assistant" window and transform the lumped elements into microstip lines. The

button for opening this utility is in the "Filter Design Guide" window, located in the AJ_FilterToolbar (the exact position is circled on figure 2).

The "Transformation Assistant" utility is used to convert reactive lumped elements such as L – inductors, C – capacitors, and resonant circuits into either a transmition line (TLine) or microstrip line (Microstrip). It also can use the "Kuroda Identities" transformation that remodels a certain transmission line in another without changing any parameters or characteristic of the initial line. Figure 4 shows the window of the "Transformation Assistant" when transfiguring into a microstrip line.
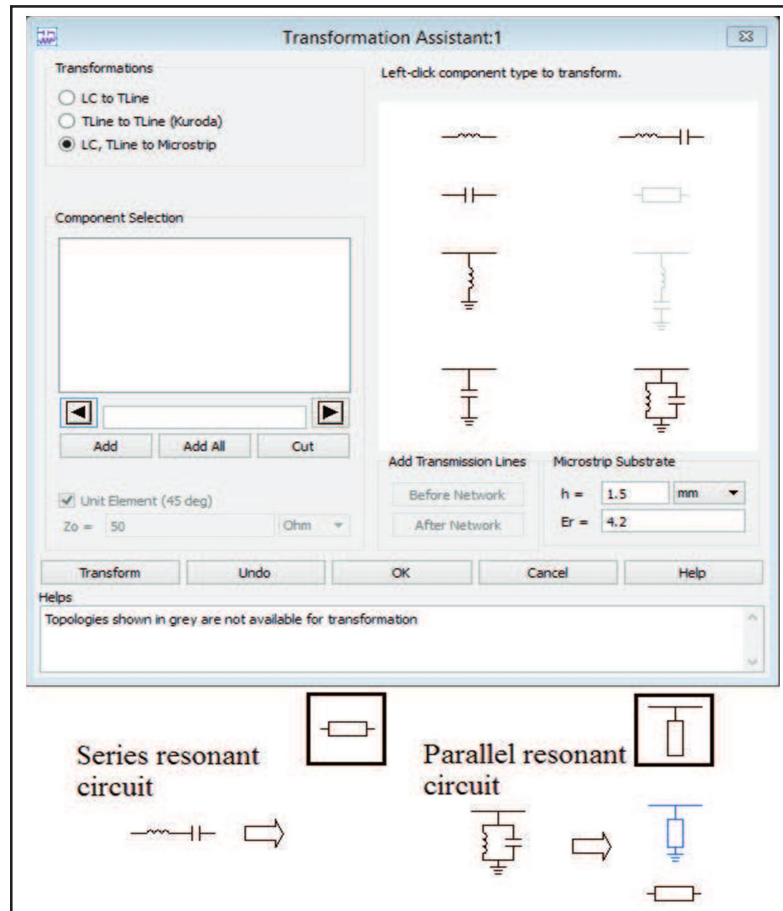

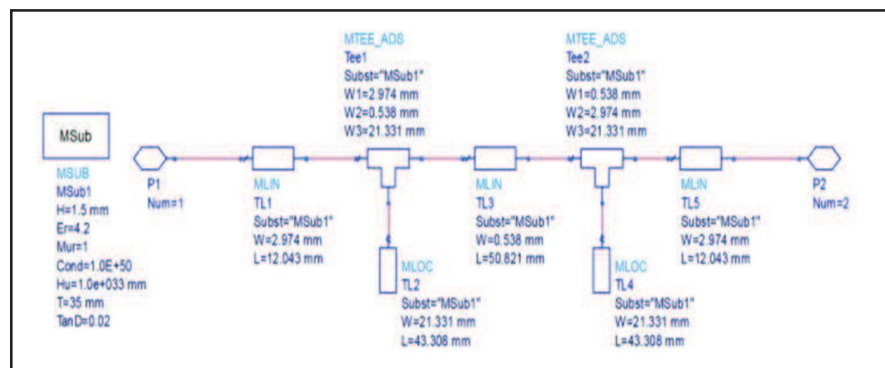Figure 4. The "Transformation Assistant" window and the used transformations

Figure 5. Schematic of the microstrip filter

For our band-pass filter we are going to use the straight LC to microstrip line transformation. In order for it to be applied the parameters of the used substrate must be loaded onto the system. In the second paragraph it is said that the filter will be fabricated on a FR-4 substrate, so its characteristics (relative dielectric constant of $\varepsilon_r = 4.2$ and thickness of $H = 1.5$ mm) must be inserted. After that by left-clicking on the type of components that you want to transform a list on conversions is given (look at the bottom of figure 4). A series resonant circuit is going to become a series microstrip line, while a parallel resonant circuit – an open-circuited microstrip stub.

After all transformations are done and the lumped prototype is fully transmogrified into the microstrip filter the new schematic can be seen (Figure 5). The scheme has a new "MSub" block consisting of all the characteristics of the used substrate. The source resistance is transformed into the TL1 mirostrip line, L1 and C1 into TL2, L2 and C2 into TL3, L3 and C3 into TL4 and the load resistance into TL5. In order to optimize the design we have added two microstrip T-junctions (Tee1 and Tee2). They are fundamental passive components. in microwave and millimeter-wave circuits [8]. We have added them so that the lengths of the lines match better, they are not lossless and will change the end characteristics of the filter, but because of their small dimensions they won't worsen it much. TL1, TL3 and TL5 are MLIN, which stand for microstrip line and TL2 and TL4 are MLOC - open-circuited microstrip stub. All TLx components have the same parameters – their size – the length and the width. The Tee1 and Tee2 have the widths of all their adjacent components.
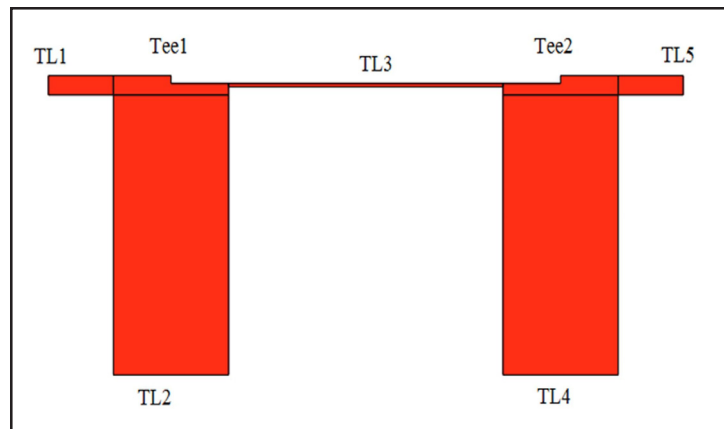

Figure 6. "Gerber/Drill" file

In order to fabricate the filter a layout is needed to be generated. This is done by clicking the "Generate/Update Layout…" button in the "Layout" toolbar. This creates the actual two-dimensional filter. The exporting of the layout is done in from "Export…" in the "File" toolbar. There are a moderate amount of file types that the layout can be exported to, like: DXF/DWG, GDSII Stream Format, Gerber/Drill, IGES, MaskFile (.msk), Cadance/PCB etc. Figure 6 is an exported "Gerber/Drill" file. This file is usually used by some specialized software in order to drill the filter onto a PCB.

The different dimensions of the microstrip lines can be easily seen in figure 6.

Because any specialized software or hardware for the fabrication won't be used we are going to open the file with an ordinary picture processing software to print the layout onto some kind of a hard cardboard.

4. Fabrication of the Filter

For the fabrication of the band-pass filter all items shown on figure 7 have been used.

The procedure begins by cutting a suitable portion of a 150x300mm PCB. The used piece is 61x130mm (Figure 7.1). After that a mask is need to be printed out, in this case the mask (Figure 7.2) is printed onto a carboard using a laser printer. In order to use this mask its middle part must be cutter out, which is done by a market knife (Figure 7.3). For the mask to be used the chopped-out PCB's surface must first be prepared by scrubbing it down with the scouring pad of an ordinary kitchen sponge (Figure 7.4)

and by putting a coat of scotch tape over the whole PCB. After the preparation has been done the mask (Figure 7.4) needs to be taped to the circuit board and using it and the knife (Figure 7.3), the shape of the filter must be carved onto the scotch tape layer. The excess scotch tape must be removed in order for the filter to be etched-out.
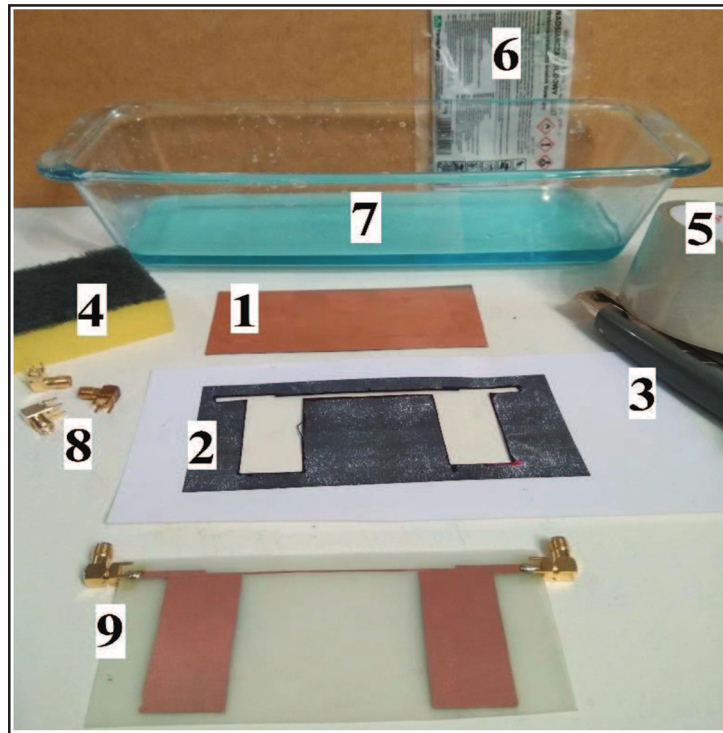

Figure 7. Items needed for the fabrication of the filter; 1-Initial PCB; 2-Cardpoard mask; 3-macket knife; 4-kitchen sponge; 5-scotch tape; 6-sodium persulfate powder; 7- sodium persulfate solution; 8-SMA coaxial connectors; 9-the fabricated filter

For the etching solution (Figure 7.7) to be made warm water , about 40° to 50°C, must be combined with the sodium persulfate powder (Figure 7.6). Once the blend is homogeneous the circuit board can be inserted in and the process can begin.

Sodium peroxosulphate, short form NaPS (sodium persulfate is its trade name) is the salt of peroxodisulphuric acid. It is a strong oxidizer and it is almost non-hygroscopic and has particularly good ability to be stored for long time. It is easy and safe to handle. Although it is not combustible, it releases oxygen easily and assists combustion of other materials. It is clear, so you can see how well it is working and is compatible with resist pens [9].

When all excess copper is removed the filter can be removed from the solution, washed with water to stop the etching process and wiped-out with a towel. After the device is all dried-up the scotch tape layer should be removed and the SMA coaxial connectors can be soldered on using a soldering iron and some lead solder.

The fabricated filter can be seen on figure 8.

5. Simulations and Comparison

Comparison of measured from the fabricated filter and simulated results for the transmission and reflection parameters of the microstrip structure is shown in Figure 9. The filter responses were measured by a setting consiting of a Hewlett Packard 8753C Network Analyzer and a Hewlett Packard 85047A S Parameter Set at the frequencies from 900 kHz to 2.8 GHz . The measurement was performed using the SMA connectors. The simulated results are obtained by a Momentum simulation in ADS.

The measured result shows a small difference in comparison with the simulated results.
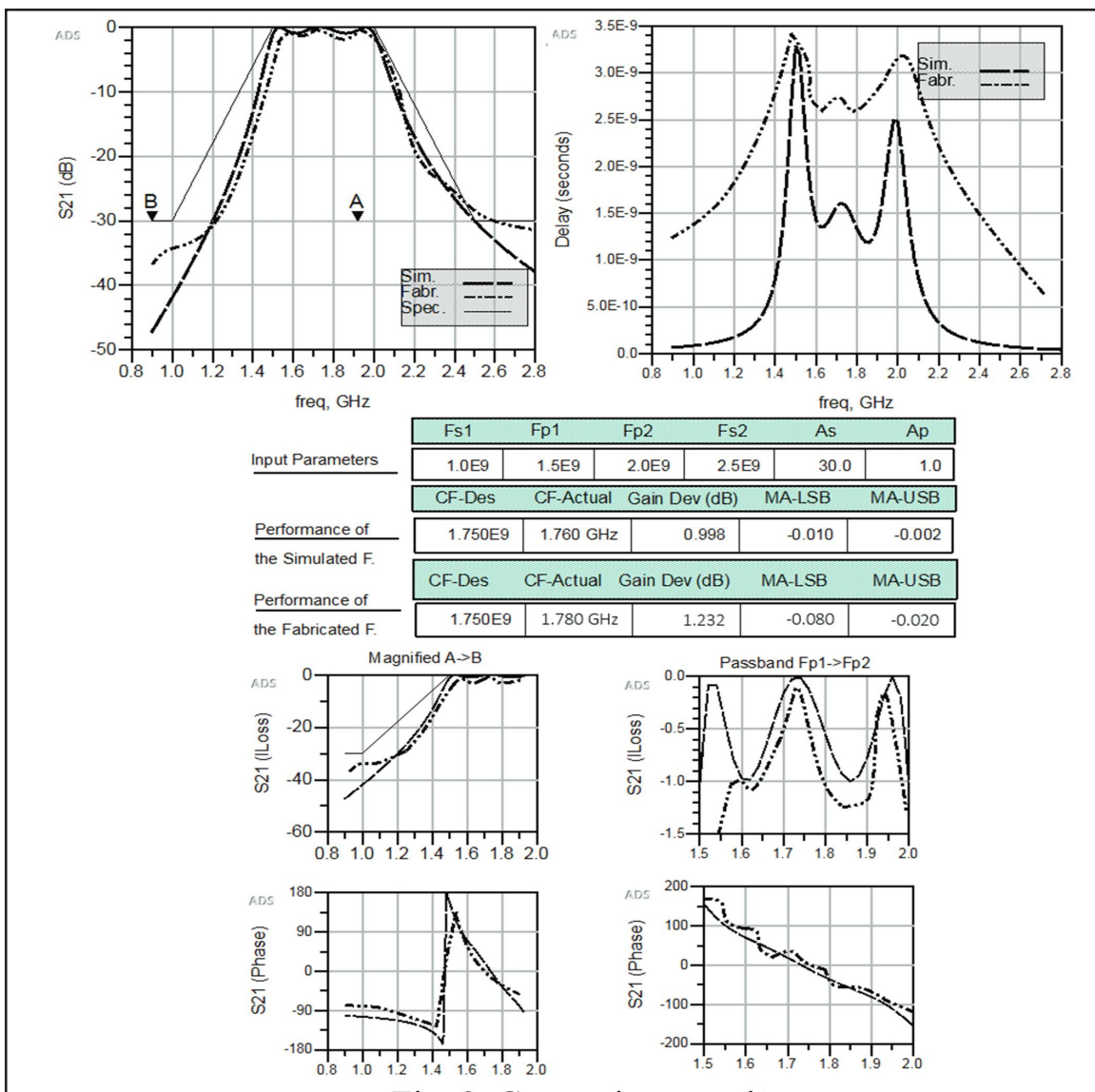
Figure 8. The fabricated filter

	Fs1	Fp1	Fp2	Fs2	As	Ap
Input Parameters	1.0E9	1.5E9	2.0E9	2.5E9	30.0	1.0

	CF-Des	CF-Actual	Gain Dev (dB)	MA-LSB	MA-USB
Performance of the Simulated F.	1.750E9	1.760 GHz	0.998	-0.010	-0.002

	CF-Des	CF-Actual	Gain Dev (dB)	MA-LSB	MA-USB
Performance of the Fabricated F.	1.750E9	1.780 GHz	1.232	-0.080	-0.020

Figure 9. Comparison results

The first graph on the left is the transmition characteristic (S21(dB)). The second graph on the right shows the delay of the filter. There are some big differences but considering the scale they are actually quite negligible. The two simulations are followed by a table consisting of all input parameters and the performance of both the simulated and fabricated filters in their central frequency. After the table there are two magnified parts of the S21 graphic (from point A to point B and the pass-band of the filter). On the bottom there are the phases of the signals for the same parts of the S21 graphic as above.

Acknowledgement

References

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