How to write A standalone Windows application that designs Stepped Impedance Low Pass Filters using Python?

A THEORITICAL AND ALGORITHMIC GUIDE
BY

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Uniqueness of this Application Software: First of its Kind

Nowadays there are many CAD tools for designing active and passive Microwave Components. They all come with their very own line calculation tools which are very useful and easy to use. But for using these CAD tools one has to purchase a license and for that one has to spend a small fortune. Again there are many online free line calculation tools available in the internet which do a good job in calculating various planar transmission line dimensions. So if a Microwave Design Engineer wants to design say a low pass filter with some specifications, then that designer has to do some prior complex calculations(in this case the order, the g values, electrical lengths, etc), use the line calculation tools in the CAD software and design the layout of the filter in the Layout Window of the CAD tool. An important thing to point out at this stage will be, probability of making errors and designing faulty layout for a novice designer is rather high.

Now let us think of a hypothetical software which just takes the filter specifications as input.It finds out the filter order by itself.It finds out the g values by itself.It finds the dimensions of the Microstrip lines by itself.It hence designs the complete layout by itself.May a software like this be made?The answer is Yes. Very Easily. All we need to have is a good understanding of how microwave filters work and what are the steps taken by an experienced designer to design the layout.The way an experienced designer designs filters, the same way the process can be automated and make a computer do all the calculations and all the hard work for us.

The software, that we will learn to write in this page takes care of everything and gives us the complete layout with all the dimensions.

Why is this page worth the readers' precious time?

Following is the detailed process of how to write a standalone windows application using Python and its Tkinter toolkit, which does not require a designer to design or calculate anything for a LPF design. The designer just needs to come up with a set of specifications and the application will design the LPF using stepped impedence technique and show the properly scaled layout of the filter colourfully. The application is written with the sole aim to facilitate faster low pass filter generation and is free. The link to download the software and the python code will be given in the downloads section.

In this page step by step the design process of the application is explained with the help of flowcharts. But if the reader directly wants to use the application, the user of the application just needs a set of specifications for the LPF namely:

- The cut off frequency of the filter.
- The maximum allowable passband attenuation.
- The min attenuation required at a specific frequency.

- The substrate thickness.
- The substrate permittivity.

  And that's all that a user needs to use the application(download link in the end)!!!!

But if the readers want to write the standalone windows application themselves, and write such automated layout design softwares for different active and passive microwave components themselves, they are in for a treat!!What follows will guide the readers through the entire process of designing such wonderful automated layout design softwares. The readers are very much appreciated to use this knowledge and come up with something new and beautiful.

Having said all that lets dive into the tools requirements to write the application software.

PREREQUISITES

The following softwares and tools are used in writing the application:

- Python 3+
- Any IDE(PyCharm by JetBrains is a free and excellent IDE)
- pip and pyinstaller
- Nullsoft Scriptable Install System(NSIS)

  All these tools and softwares are free and open source.
  Downloads link for all will be given in the downloads section.

SOME FREQUENTLY USED TERMINOLOGY IN THIS PAGE

Insertion Loss Method

The insertion loss method,allows a high degree of control over the passband and stopband amplitude and phase characteristics, with a systematic way to synthesize a desired response. The necessary design trade-offs can be evaluated to best meet the application requirements.

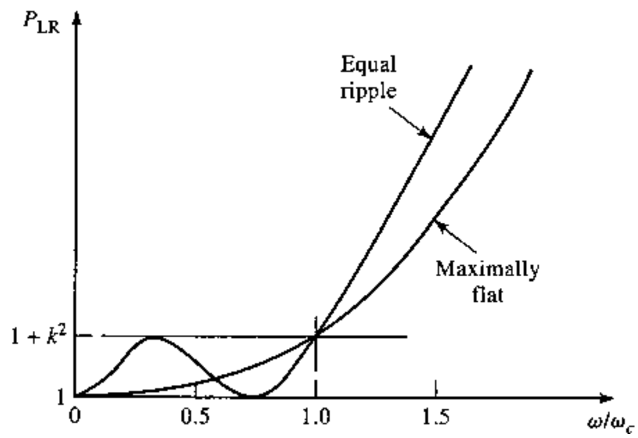
If, for example, a minimum insertion loss is most important, a binomial response could be used; a Chebyshev response would satisfy a requirement for the sharpest cutoff. We will use Chebyshev responses in our application program. If it is possible to sacrifice the attenuation rate, a better phase response can be obtained by using a linear phase filter design. In addition, in all cases, the insertion loss method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter.[1]

Equal Ripple Filters

If a Chebyshev polynomial is used to specify the insertion loss of an Nth order low-pass filter as

$$P_{LR} = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c} \right)$$

then a sharper cutoff will result, although the passband response will have ripples of amplitude $1 + k^2$, as shown in Figure below for N=3, since TN (x) oscillates between ±1 for |x|^{2}1. Thus,



K^2 determines the passband ripple level. For large x, $T_N(x) = (1/2)*(2x)^N$, so for ω>>ωc the insertion loss becomes

$$P_{LR} \simeq \frac{k^2}{4} \left(\frac{2\omega}{\omega_c} \right)^{2N}$$

which also increases at the rate of 20N dB/decade. However, the insertion loss for the Chebyshev case is $(2^{2N})/4$ greater than the binomial response at any given frequency where ω>>ωc.[1]

Order of Chebyshev filters

If A_p=Maximum allowable passband attenuation

A_s=minimum attenuation at frequency Ω_s

Ω_p=cut off frequency

$$N = \frac{\cosh^{-1}\left(\sqrt{\frac{10^{A_s/10}-1}{10^{A_p/10}-1}}\right)}{\cosh^{-1}\left(\frac{\Omega_s}{\Omega_p}\right)}$$

g values for normalized Chebyshev low pass prototype filter

$$r = 1 \text{ for } n \text{ odd}, \qquad r = \tanh^2(\beta/4) \text{ for } n \text{ even}$$

$$g_1 = 2a_1/\gamma$$

$$g_k = \frac{4a_{k-1}a_k}{b_{k-1}g_{k-1}}, \qquad k = 2, 3, \cdots, n$$

$$\text{check: } g_n = g_1 r$$

$$a_k = \sin\left[\frac{(2k-1)\pi}{2n}\right], \qquad k = 1, 2, \cdots, n$$

$$b_k = \gamma^2 + \sin^2\left(\frac{k\pi}{n}\right), \qquad k = 1, 2, \cdots, n$$

$$\beta = \log_e\left(\coth\frac{A_m}{17.37}\right), \qquad A_m \text{ in db}$$

$$\gamma = \sinh\left(\frac{\beta}{2n}\right)$$

$$A = 10\log_{10}\left[1 + (10^{A_m/10} - 1)\cos^2(n\cos^{-1}\omega')\right]\text{db}, \qquad \omega' \leq 1$$

$$A = 10\log_{10}\left[1 + (10^{A_m/10} - 1)\cosh^2(n\cosh^{-1}\omega')\right]\text{db}, \qquad \omega' \geq 1$$

[2]

Stepped Impedance LPF design

Approximate equivalent circuits for short sections of transmission lines.

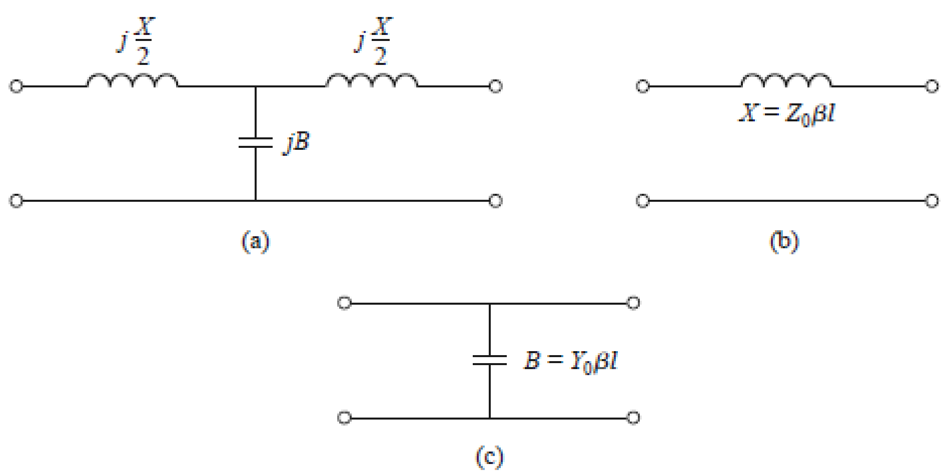


Fig:(a) T equivalent circuit for a transmission line section having βl <<π/2. (b) Equivalent circuit for small βl and large Zo. (c) Equivalent circuit for small βl and small Zo.

Here we assumed, The highest and the lowest characteristic impedances possible to be fabricated let be 120 ohms(Z_h) and 20 ohms(Z_l) Respectively.

<u>The normalized series inductance L and shunt capacitances C can be found from the g values,then the electrical lengths are given as:</u>

$$\beta\ell = \frac{L R_0}{Z_h} \quad \text{(inductor)} \qquad \text{......(a)}$$

$$\beta\ell = \frac{C Z_\ell}{R_0} \quad \text{(capacitor)} \qquad \text{......(b)}$$

HOW THE PYTHON CODE WORKS?

How to design an algorithm which generates the Layout on its own with a given filter specifications?

<u>Algorithm for the backbone of the application program.</u>

A designer has to come up with a set of LPF filter specifications.The specifications are the cutoff frequency of the Low Pass Filter,the maximum allowable attenuation in the passband,a frequency at which some minimum attenuation is desired,the height of the substrate to be used and the relative permittivity of the substrate.

1.Taking the specifications, the program will first find the order of the equiripple filter.

2.Then it will pass the order and the maximum allowable passband attenuation to a function which computes g values of the LPF of any order and stores in an array.

3.The stepped impedence LPF design formulas(equations a and b) to find the electrical length of each sections is used to find the electrical lengths of each section and again stored in an array.

4.A function to calculate line width and length of a microstrip line is written.It takes as input the characteristic impedence,electrical length,frequency of operation,height of substrate,relative permittivity of the substrate.

5.These line length and width is put in another array.So,this array has (order+2) no of elements and each element again has 2 elements.

So,we got the line length and width of each section of a stepped impedence low pass filter.

Algorithm for the GUI in Python using Tkinter toolkit:

1.A root window is created.

2.A frame is created which takes the users name as input.It is packed to the root window.

3.As the name is put and <<Enter>> is hit, a new frame is created and the previous frame is destroyed.

4.It welcomes the user and here we have to put the specifications of the LPF filter.

5.As soon as we put the specifications and hit enter,out comes the beautiful golden coloured, absolutely scaled layout of the filter along with all the dimensions.These are all put in a canvas.

How to create a standalone windows application with this python code?

1.We go to cmd(command prompt)

2.We put the path to the python scripts(we have to find out where the scripts for python are stored in our computer)

3.Then we type pip install pyinstaller

4.Then we type pyinstaller - - onefile - w filename.py

Our computer will generate a executable(.exe) file for us.

How to create the installable file using NSIS?

1.We put our .exe file in a .zip file

2.We install NSIS and open it.We then click installer based on .zip file and hit next a couple of times.

NSIS will generate a installable file for us which can be shared to anyone and installed in any device irrespective of whether that person has python or any other softwares mentioned here installed in their system or not.

If the above steps are boring, I have created a flow chart for all of you.

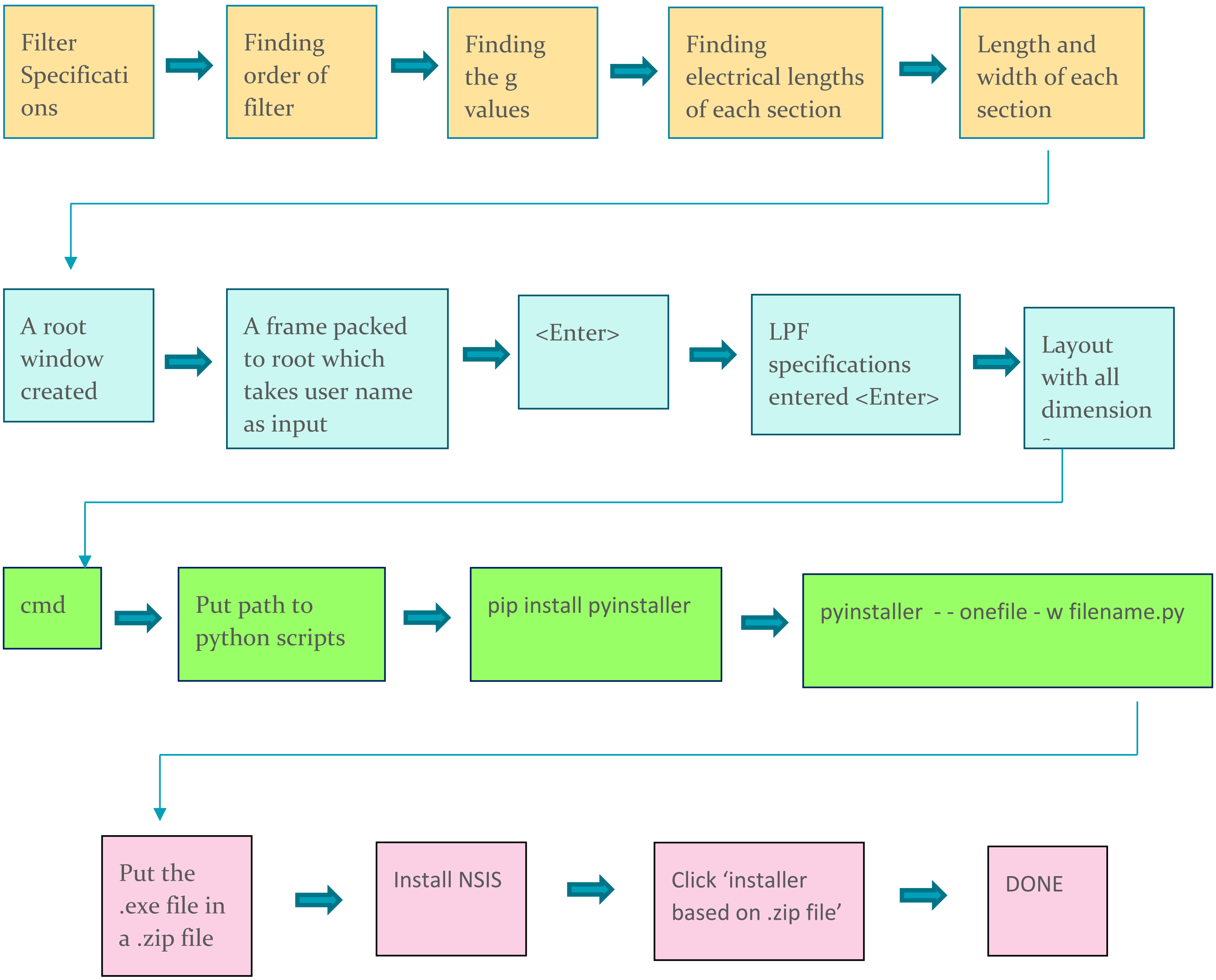


Fig : Flow Chart to write the windows application

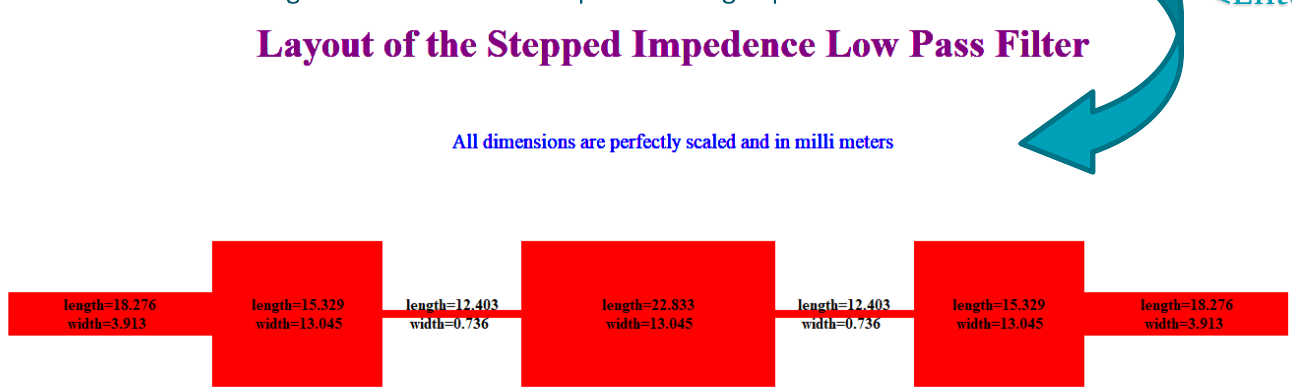
SOME SNAPS FROM THE APPLICATION

<Enter>

Fig: The welcome Screen

<Enter>

Fig: The Screen where we put the Design Specification



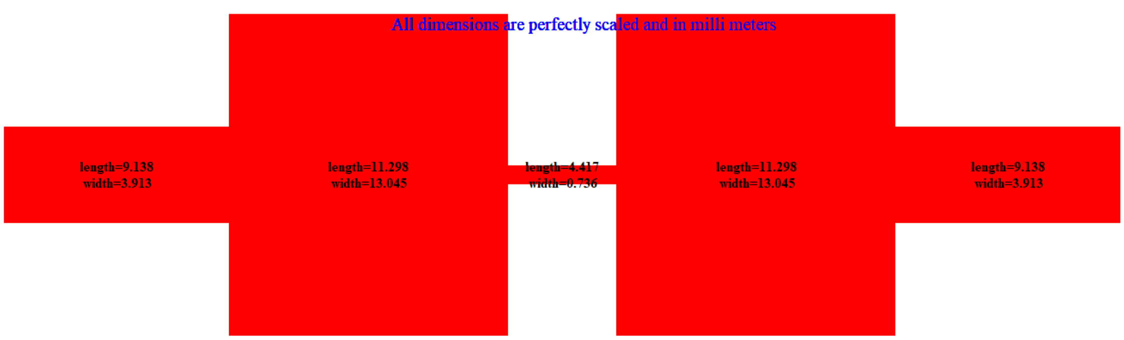
Lets see for another filter specification….

Hello Debrup!!

Welcome to LPF design Software

Enter the cut-off frequency in GHz	3
Enter the Maximum Passband Ripple in dB	1.7
Enter the frequency for desired attenuation in GHz	4
Enter the desired attenuation at this frequency in dB	10
Enter the substrate thickness in mm	1.27
Enter the relative permittivity	2.2

Layout of the Stepped Impedence Low Pass Filter



CHECKING THE CORRECTNESS OF THE GENERATED LAYOUT BY THE APPLICATION WITH ADS EM SIMULATION TOOL

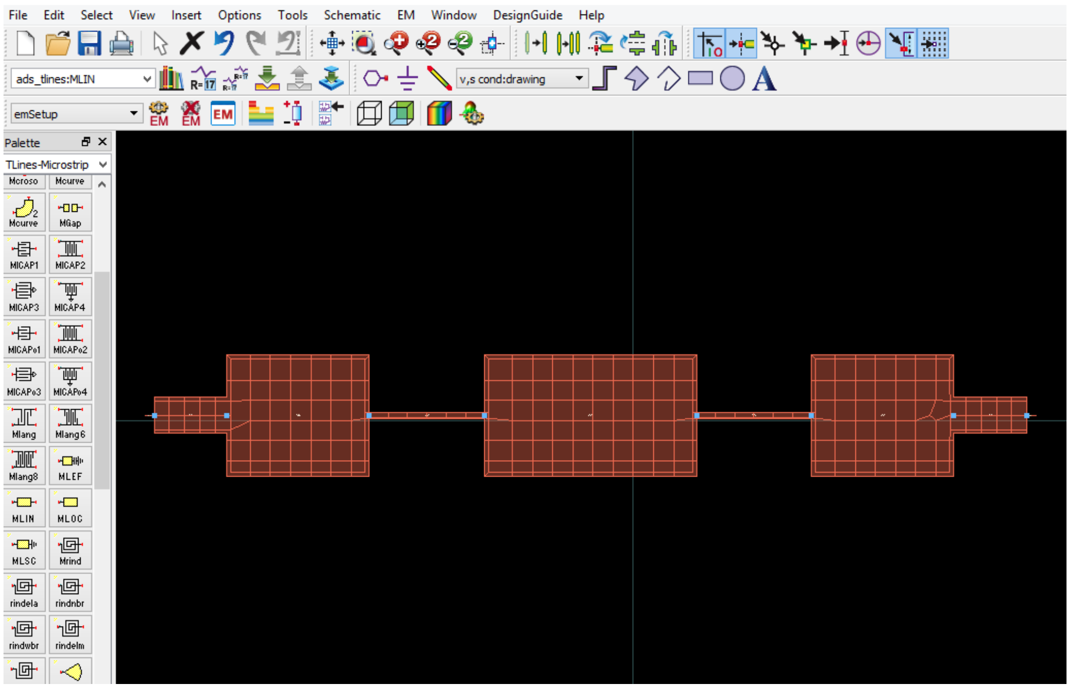


Fig: ADS Layout of the 1st filter

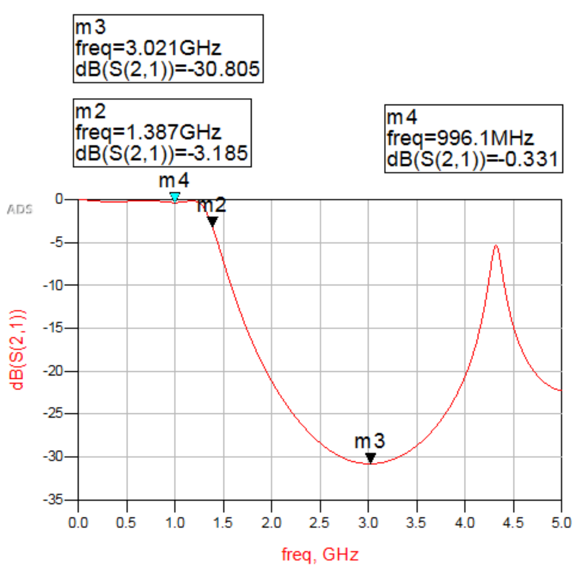


FIG: S_{21} Plot after EM simulation of the layout

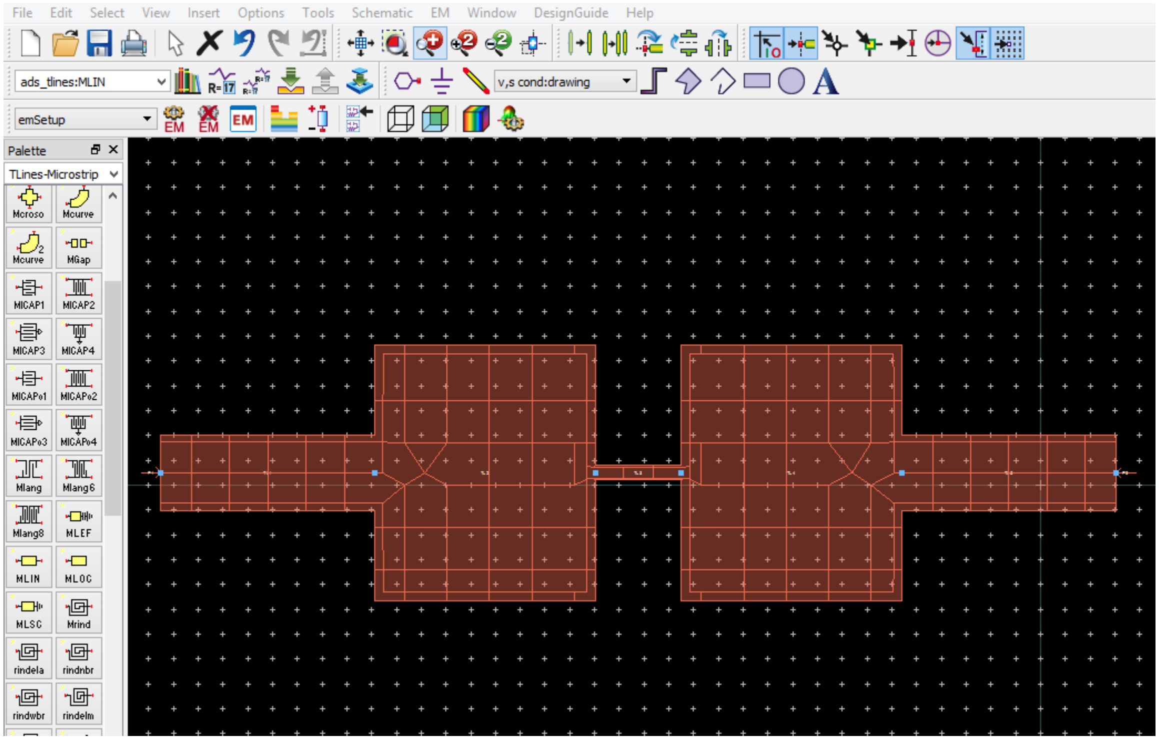


FIG: ADS layout of the 2^{nd} Filter

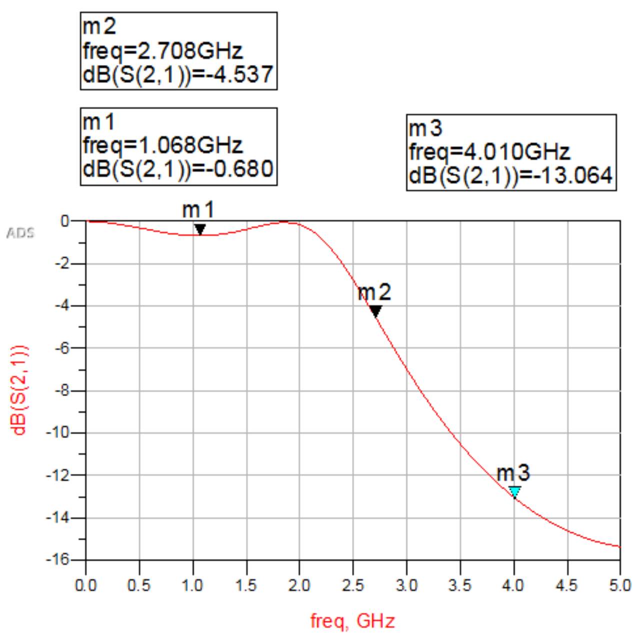


Fig: S_{21} Plot After EM simulation of the 2^{nd} Filter

CONCLUSION

Thus if the readers have followed through the entire page, it may be noted that writing the application program and generating the complete layout in GUI Python is pretty straight forward.It only required patience and a understanding of the underlying tasks performed by the program.

In the Checking the Correctness of the Generated Layout by the Application with ADS EM Simulation Tool Section before, I have only tried to show the readers that the layout generated by the Application is not erroneous and the same can be verified using any of the CAD EM simulation softwares. As we can see the cut off frequencies in the plots match with the desired cut off frequencies.Also the stopband attenuation is more than what is desired.Now one very important thing to note is, Stepped Impedence Technique of designing LPFs though is a celebrated technique,yet it has some inherent approximations.Because of this the cut off frequencies do not come exactly the same as it was designed for.So,in the final design before fabrication of the filter some optimizations may have to be done.

CONGRATULATIONS!! Now the readers are well equipped with all the knowledge required to write application softwares to generate layout from specification of passive microwave components.

REFERANCES

1.Microwave Engineering,David M.Pozar

2.Parallel Coupled Transmission line Resonator Filters,Seymour B Cohn,1958

3. Microwave Filters, Impedance-Matching Networks, and Coupling Structures (Artech Microwave Library)

by G. Matthaei (Author), E.M.T. Jones (Author), L. Young (Author)

DOWNLOADS

1.GOOGLE DRIVE LINK FOR THE INSTALLABLE WINDOWS APPLICATION

https://drive.google.com/file/d/13aR0KudIVJtKEdabFylcuDtqexkAHJBe/view?usp=sharing

2.GOOGLE DRIVE LINK FOR THE COMPLETE PYTHON CODE:

https://drive.google.com/file/d/1LEMDXpK0k-31c7g_T1tJpa2laC-5NVsr/view?usp=sharing

3.Download link for Python

https://www.python.org/downloads/

4.Download link for NSIS

https://nsis.sourceforge.io/Download

5.PyCharm download link

https://www.jetbrains.com/pycharm/download/

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