RF CAD LABORATORY BASED PROJECT ON CHEBYSHEV MULTISECTION IMPEDANCE MATCHING

Submitted By

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PROBLEM STATEMENT

Designing of a 5-section Chebyshev matching transformer to match 50 Ω line to 30 Ω Load. Maximum permissible SWR over passband is 1.25. Find resulting Bandwidth along with a comparison of input SWR vs. Frequency plot.

ACKNOWLEDGEMENT

It is difficult to acknowledge the precious debt of knowledge and learning. But we can only repay it through our gratitude. I, Asish Nayak, a M.tech student in RF and Microwave Engineering , would like to convey my heartfelt gratitude to my professor ***Dr. M.V Kartikeyan*** *, for blessing us with his immense knowledge of Microwave Engineering and being a constant source of inspiration for me.*

I would also like to thank Mr. ***Mr. Sai Haranadh(PhD Scholar, IIT Tirupati)*** *for his valuable instruction and support through this project by clarifying my doubts and guiding me with his novel ideas.*

Regards,

Asish Nayak

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INTRODUCTION

The Concept of Impedance Matching immersed from the idea of minimizing the Return loss and maximizing the power transmitted from an emitter into a medium. This concept is a turning point in Microwave Engineering without which there might be breakdown of circuits of transmitting antenna.

The power transmitted from Antenna is carried through the Transmission Line and some power is dissipated due to resistance of conducting lines. When this power hits the point of impedance Mismatch, then some power gets reflected back. This reflected power also gets dissipated into mediums as heat by Transmission line and if this reflected power somehow manages to reach near antenna, then there's a possibility of high dissipation of power at antenna side due to its internal resistance which might breakdown the circuits connected to antenna. Transmission line can also be damaged if both reflected and transmitted power dissipating in the for of heat into medium exceeds the power handling capacity of the Transmission line.

With the help of the impedance matching concept, we can't prevent the problem that is being mentioned above from happening. There exists many types of impedance matching techniques such as ***Single Stub Tuning, Double Stub Tuning, Quarter wave Transformer.***

This Project mainly involves the concepts of Quarter wave Transformer and theory of multi-section impedance matching. In this project, I have designed a ***5-section Chebyshev Impedance matching Transformer*** *to match a line of 50Ω to a load of 30Ω and maximum permissible SWR (standing wave ratio) is 1.25.*

The software that has been used in this project is ***Ansys Electronics Desktop Student Version.*** *The whole circuit is designed on a patch of* ***FR4 Epoxy*** *substrate of dielectric constant 4.4 and height 1.6mm. The concept of Microstrip line is used for designing of Transmission line. The circuit is designed keeping a center frequency of 5 GHz and after the simulation* **S_{11} (reflection coefficient of port 1)** *and* **SWR (standing wave ratio)** *plots are plotted, where it can be observed that the* **S_{11}** *will be very close approximate to 0 near 5GHz frequency and* **SWR** *will be very close approximate to 1 near 5GHz frequency.*

THEORY

Microstrip line Theory

The concept of Microstrip line stands out when it comes to designing of Transmission lines based on compactness. It can be fabricated by photolithographic processes and is easily miniaturized and integrated with both passive and active microwave devices. Following figures shows the structure of a microstrip line and formation of Electric and Magnetic Field patterns around it.

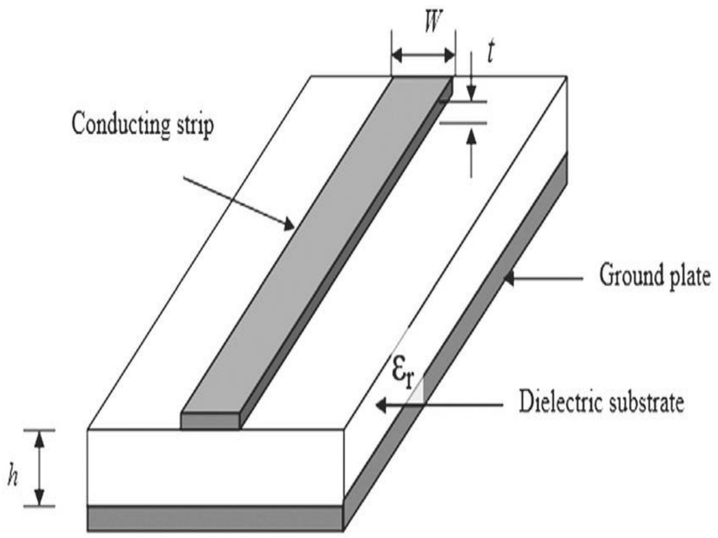


FIGURE-1

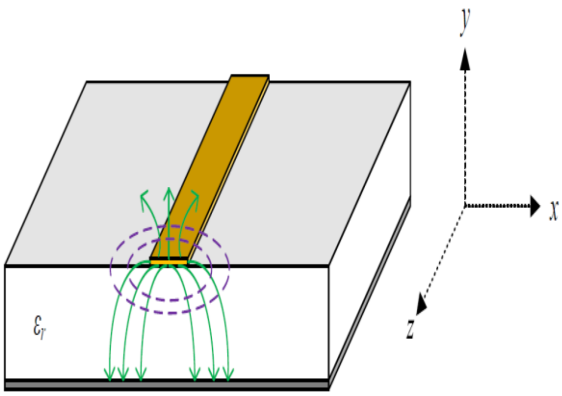


FIGURE-2

h- *height of substrate (FR4 Epoxy)*

t- *thickness of conductor*

l- *length of microstrip line*

$\boldsymbol{\varepsilon_r}$- *relative permittivity of substrate*

w- *width of microstrip line*

One can see from figure-2 that the electric field lines are radiating into two different dielectrics, that is, one into air and another into FR4 Epoxy. Hence, the *term Effective permittivity will come into play here. Following is the relation that satisfies the effective permittivity.*

$$\mathbf{1 < \epsilon_e < \epsilon_r}$$

For designing of Transmission line with various Characteristic Impedances , we will simply need to calculate the design parameters **(w,h,l)** *using the formulae of Microstrip line.*

Calculation of ***Effective Permittivity*** *will be done using following formula,*

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}$$

Calculation of ***Characteristic Impedance*** *will be done using following formula,*

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\epsilon_e}} \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & \text{for } W/d \leq 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_e}\left[W/d + 1.393 + 0.667 \ln\left(W/d + 1.444\right)\right]} & \text{for } W/d \geq 1. \end{cases}$$

Calculation of ***W/h*** *will be done using following formula,*

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & \text{for } W/d < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \dfrac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B - 1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] & \text{for } W/d > 2, \end{cases}$$

*Calculation of **A** and **B** will be done using following formula,*

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}.$$

One can use above equations to calculate design parameters of microstrip transmission line for different characteristic impedances.

Multi-section Impedance Matching theory

*The only advantage of multi-section over single section is that we can get very less reflection coefficient over multiple frequency range. There are two types of Multi-section impedance matching techniques, that is**, Binomial Multi-section impedance matching** and **Chebyshev Multi-section impedance matching.***

The overall reflection Coefficient at input side of N-section Quarter-wave transformer is:

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 e^{-2j\theta} + \Gamma_2 e^{-4j\theta} + \cdots + \Gamma_N e^{-2jN\theta}$$

Since the problem statement was to design a Chebyshev transformer to match a 50Ω line to 30Ω load, hence our main concern will be about Chebyshev Impedance matching technique.

Chebyshev Multi-section Matching Transformer

The overall reflection coefficient at input side can also be reduced to following equation:

$$\Gamma(\theta) = 2e^{-jN\theta}[\Gamma_0 \cos N\theta + \Gamma_1 \cos(N-2)\theta + \cdots + \Gamma_n \cos(N-2n)\theta + \cdots]$$

The above equation can be compared a Chebyshev polynomial of N^{th} order, that is,

$$\begin{aligned}\Gamma(\theta) &= 2e^{-jN\theta}[\Gamma_0 \cos N\theta + \Gamma_1 \cos(N-2)\theta + \cdots + \Gamma_n \cos(N-2n)\theta + \cdots \\ &= Ae^{-jN\theta} T_N(\sec\theta_m \cos\theta),\end{aligned}$$

From above comparison we will get following results:

Value of A: $$A = \frac{Z_L - Z_0}{Z_L + Z_0} \frac{1}{T_N(\sec\theta_m)}$$

Value of θ_m: $$\sec\theta_m = \cosh\left[\frac{1}{N}\cosh^{-1}\left(\frac{1}{\Gamma_m}\left|\frac{Z_L - Z_0}{Z_L + Z_0}\right|\right)\right]$$

Value of f_m: $$f_m = \frac{2\theta_m f_0}{\pi}$$

Using above formulae, we can get range of frequencies within which our circuit will show the Characteristics of Chebyshev polynomial.

THEORETICAL CALCULATIONS

Since our problem statement was to design a 5-Section impedance matching Transformer with a maximum permissible SWR of 1.25, hence we will perform all our calculation keeping in mind that maximum reflection coefficient should be 0.11.

$$\Gamma_m = \frac{\mathrm{SWR} - 1}{\mathrm{SWR} + 1} = 0.11$$

Our assumed Design center frequency is 5 GHz.

Our source impedance, $Z_o = 50\Omega$

Our load impedance, $Z_L = 30\Omega$

Value of A using given formulae, $A = \Gamma_m = 0.11$

Value of maximum electrical length, $\theta_1 = \theta_m = 16.6936°$

$$\theta_2 = \pi - \theta_m = 163.30°$$

Hence, frequency sweep range for above electrical lengths:

$$F_m 1 = 1.854GHz$$

$$F_m 2 = 18.144GHz$$

Upon comparing Overall reflection with Chebyshev Polynomial:

$$\Gamma_o = 0.5Asec^5\theta_m = \Gamma_5 = 0.0682$$

$$\Gamma_1 = 2.25A(sec^5\theta_m - sec^3\theta_m) = \Gamma_4 = 0.0281$$

$$\Gamma_2 = 0.5A\left(10sec^5\theta_m - 15sec_m^\theta + 5sec\theta_m\right) = \Gamma_3 = 0.03$$

Using above equations and relations, we will get characteristic impedance values of 5-sections.

$$Z_1 = 43.62\Omega$$

$$Z_2 = 41.23\Omega$$

$$Z_3 = 38.79\Omega$$

$$Z_4 = 36.49\Omega$$

$$Z_5 = 34.49\Omega$$

Using above impedances of each section, respective width of microstrip line for each section can be designed using formulae mentioned in the theory of Microstrip Line.

$$W_1 = 3.8153526319042mm$$

$$W_2 = 4.1615406824767mm$$

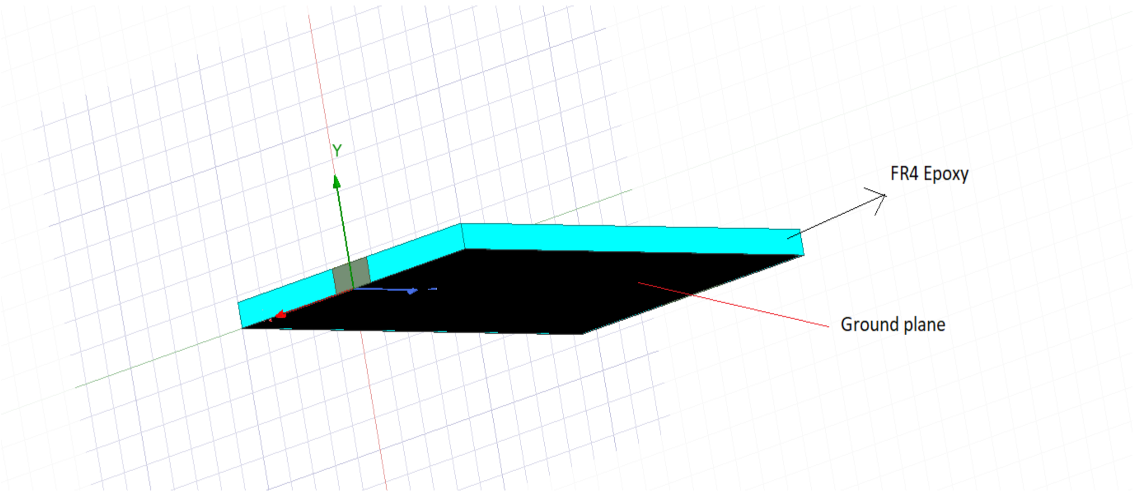
$$W_3 = 4.5613605402284mm$$

$$W_4 = 4.9896804384855mm$$

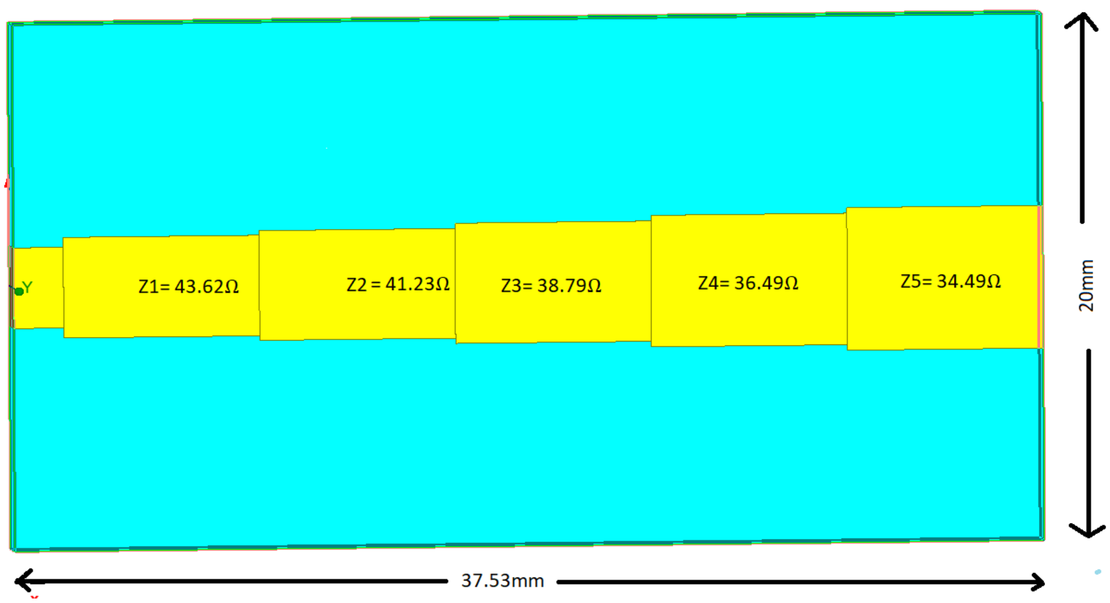
$$W_5 = 5.410767070023mm$$

IMPLEMENTATION OF DESIGN USING HFSS

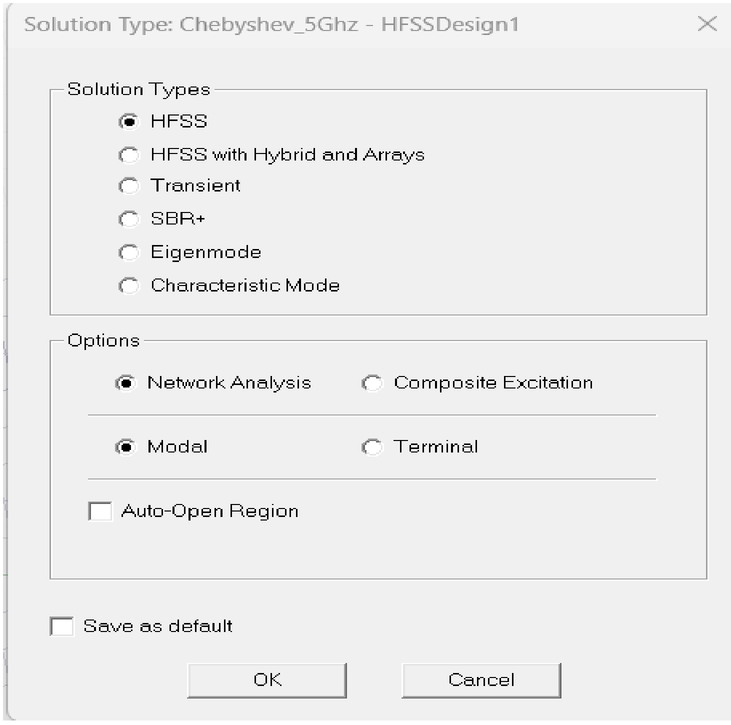
After completion of all possible calculation for the given problem statement, the results are implemented for the design of Chebyshev 5-section transformer, using Ansys HFSS. The FR4 Epoxy substrate is drawn first and then the Ground plane.



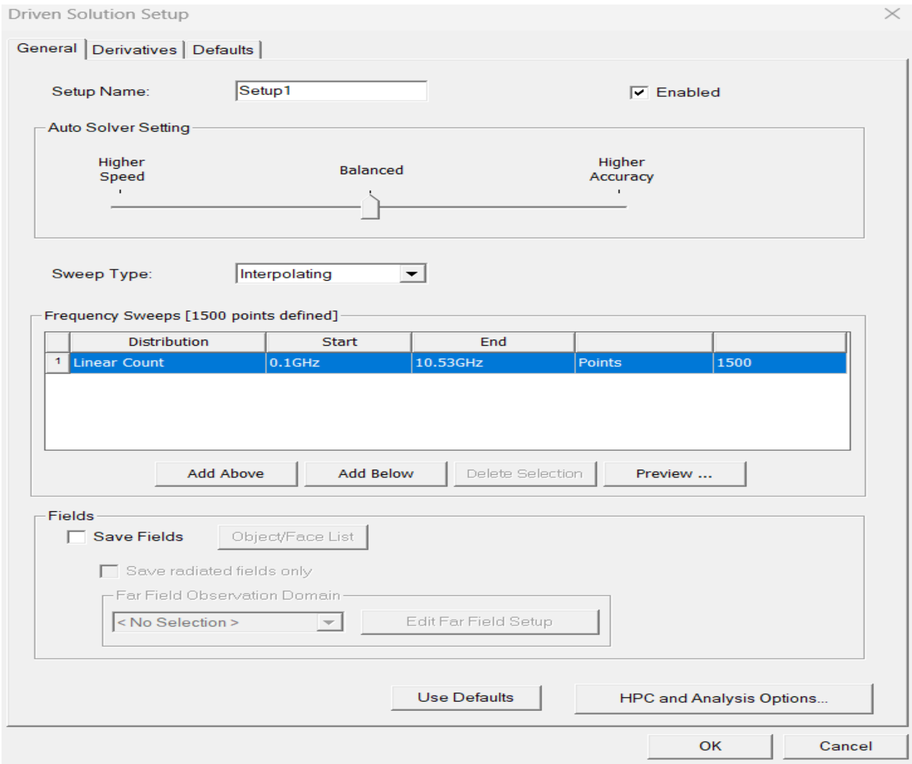
After that, transmission line of source impedance and all 5-section impedances are designed using microstrip line based on their respective width and length.



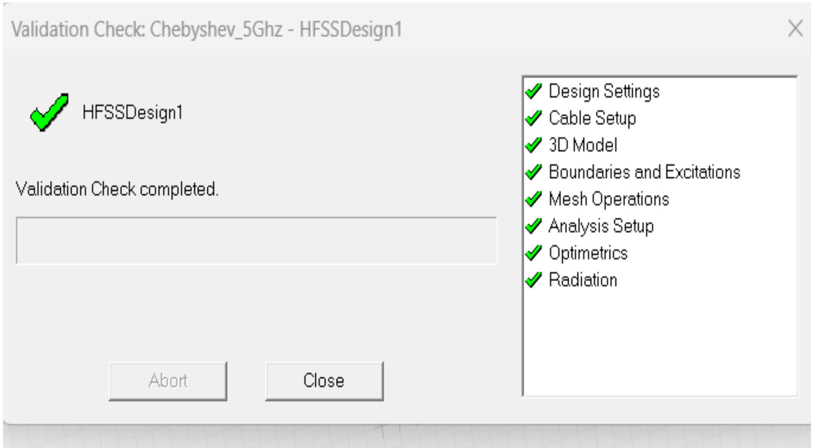
Then, radiation box is drawn to restrict the computational area for faster simulation and lumped excitation port is assigned at source Transmission line. After that, solution setup is driven modal for getting results based on modes.



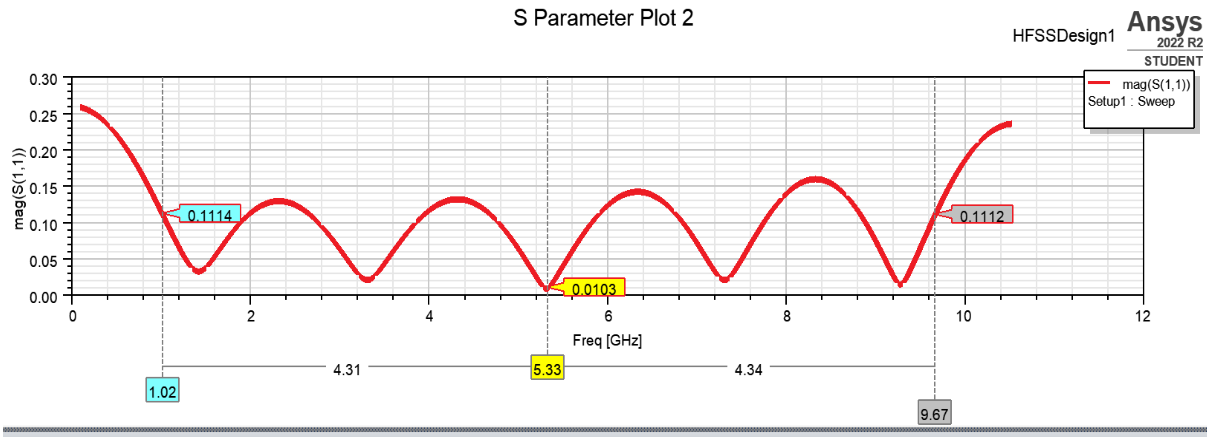
After setting the solution setup, frequency sweep from 0.1GHz to 10.53GHz is done by setting up the "analysis setup".



After that a check for circuit design validation is done and corresponding result rectangular plots are plotted.



*The Reflection coefficient **S_{11}** magnitude plot vs frequency is shown below:*

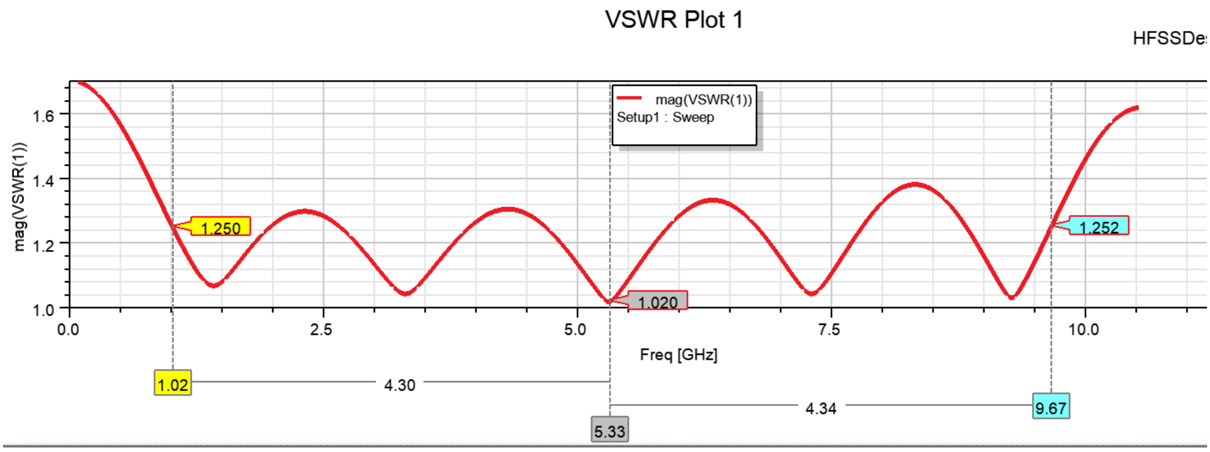


As we can see, there is a slight delay in frequency at which we get $S_{11} = \Gamma_m$ *. Practically, there exists some delay compared to ideal circuit.*

From above graph, $$\frac{\triangle f}{f_o} = 1.62$$

Which means that the practical bandwidth is 162% of ideal bandwidth.

*Following is the **SWR** vs frequency plot:*



CONCLUSION AND REFERENCES

Hence, a 5-section impedance matching transformer for matching a 50Ω line to a 30Ω load is designed with maximum permissible SWR of 1.25. While going through this project, the concept of Chebyshev Multi-section impedance Matching is learnt. From the above plots, it is clear that the results obtained are very close approximate to the ideal ones.

Following are the references used in this project:

1. *David M. Pozar, "Microwave Engineering", John Wiley, 2000.*