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Band Pass Filter and Low Noise Amplifier Design using Advanced Design System (ADS)

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Abstract— The paper presents the design of a lumped model of Low pass Filter (LPF) for 4.8 GHz and High pass filter(HPF) for 4.6 GHz using software tool ADS and then finally cascading the LPF and HPF to develop a Band pass filter(BPF), for passing frequencies between 4.6 GHz to 4.8 GHz whose response is analyzed after simulation. It also describes the design of a HEMT based Low noise amplifier (LNA) using the software ADS, on which a stability check and performance analysis is made on the chosen model for the design of LNA. Once LNA design is ready, then it is cascaded with the BPF to produce an amplified output with the least minimum noise figure.

Index Terms— high pass filter, low pass filter, Filter Design, Low noise amplifier, LNA, Advanced design system, HEMT.

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1 Introduction

Low Pass Filter (LPF) is used to block the high frequency components and pass only the low frequency signals. In LPF, signals with frequencies higher than the cut off frequency are attenuated. High Pass Filters (HPF) is just the opposite of LPF as it blocks low frequency components and passes high frequency signals. Cascading the LPF and the HPF, a Band Pass Filter (BPF) can be obtained that passes frequencies within a certain range and attenuates or rejects frequencies outside that range. The Low Noise Amplifier (LNA) is a special type of electronic amplifier used in communication systems which amplifies very weak signals captured by an antenna. This is frequently used in microwave applications or systems such as GPS.

2 Cut-off frequencies for the bandwidth 0.2 GHz (4.6 GHz to 4.8 GHz):

Bandwidth (BW) = 0.2GHz
And

f_{p1} = 4.6GHz
f_{p2} = 4.8GHz

Now we determine the stop band frequencies f_{s1} and f_{s2} for BW 0.2GHz for cut-off frequencies between 4.6GHz to 4.8GHz as follows:

$f_{s1} = f_{p1} - 0.2$GHz
So f_{s1} = 4.6GHz – 0.2GHz
Therefore,
f_{s1} = 4.4GHz
Similarly,
$f_{s2} = f_{p2} + 0.2$GHz
f_{s2} = 4.8GHz + 0.2GHz
f_{s2} = 5 GHz

3 Design calculations for the desired specification:

i. Low Pass Filter (LPF) design for 4.8GHz
$R_0 = 50\Omega$
Cut off frequency, f_c = 4.8GHz
$W_c = 2\pi f_c$
= 2*3.14*4.8GHz
= 30.163*10^9

$L = 2R_0/W_c$
= 2*50/30.163*10^9
= 3.315nH ……(1)

$C = 2/W_cR_0$
= 2/30.163*10^9
= 1.326pF ……(2)

ii. High Pass Filter design (HPF) for 4.6GHz
$R_0 = 50\Omega$
Cut off frequency, f_c = 4.6GHz
$W_c = 2\pi f_c$
= 2*3.14*4.6GHz
= 28.90*10^9

$L = R_0/2W_c$
= 50/2*28.90*10^9
= 0.8650nH ……(3)

$C = 1/2W_cR_0$
= 1/2*28.90*10^9*50
= 0.346pF …….(4)

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4 Methodology in Simulating Lumped Model Based Band Pass Filter Using ADS:

- Open ADS and then create a new project, after creating a schematic layout window opens.
- At the left hand side, top of the screen, Drop down by clicking and select Lumped components, and then all the lumped components are displayed at the left hand side palette.
- LPF and HPF are designed by selecting the components from the palette and placing it on the schematic.
- Once the components are placed and connected respectively, then calculate the Inductance (L) and Capacitance (C) values that needs to be assigned to the inductors and capacitors.
- The values of L and C depends on the type of filter we are designing i.e. LPF or HPF.
- Once calculated, these values are assigned to their respective components. Then click and open the drop down box and select S-parameters. After this, select terminal impedance from the palette and connect this to the source and load impedance of the circuit. Then select the S-parameter Engine, and place it on the layout. Make sure to connect the ground.
- Then double click on the S-parameter Engine and assign the start, stop and step frequency values such that we obtain the desired response.
- And then finally we simulate and a simulation window pops up, in this we select the graph from the palette present on the left hand side of the screen. Then we have to select the response we desire to see i.e. S (2, 1), which is gain and S (1, 1) is the return loss. Then a graph pops up and we can see and analyze the response shown in the graph.
- So the HPF and LPF is designed separately using the above procedure and then the successfully designed HPF and LPF is cascaded to develop a band pass filter (BPF), whose frequency response is analyzed after simulation.

5 Design, Model, Simulate and Verify the Designed Band Pass Filter (BPF) Using ADS:

i. Low Pass Filter (LPF):

- DESIGN:

L = 3.315nH ……From eqn (1)
L/2 = 1.657nH
C = 1.326pF ……From eqn (2)

- MODEL:

The LPF circuit in the Fig (1a) is modeled using the ADS software.

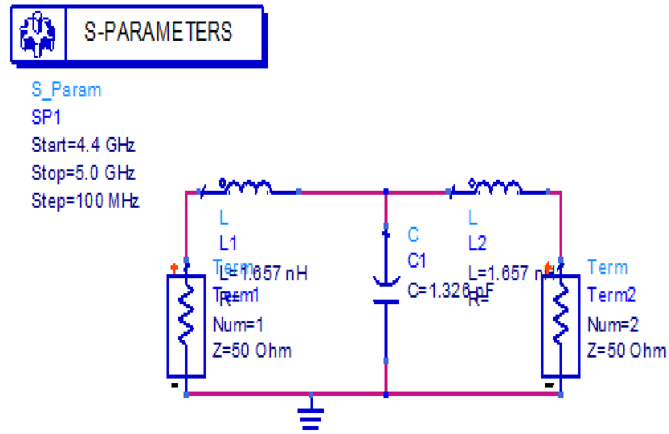

Fig 1a Low Pass Filter (LPF)

- SIMULATION AND VERIFICATION :

The parameter S (2, 1) is the Gain Response and S (1, 1) is the return loss.

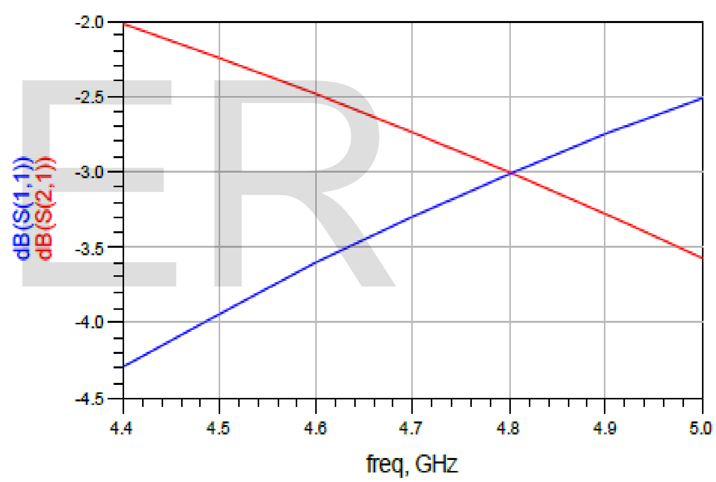

Fig 1b Low Pass Response

The Fig (1b) verifies the Low pass filter designed for 4.8GHz, Since we can see that the gain response and the return loss is intersecting exactly at 4.8GHz.

ii. High Pass Filter (HPF):

- DESIGN:

C = 0.346pF …..From eqn (4)
2C = 0.692pF
L = 0.8650nH ……From eqn (3)

- MODEL:

The HPF circuit is modeled as shown in the Fig (2a) using the ADS software.

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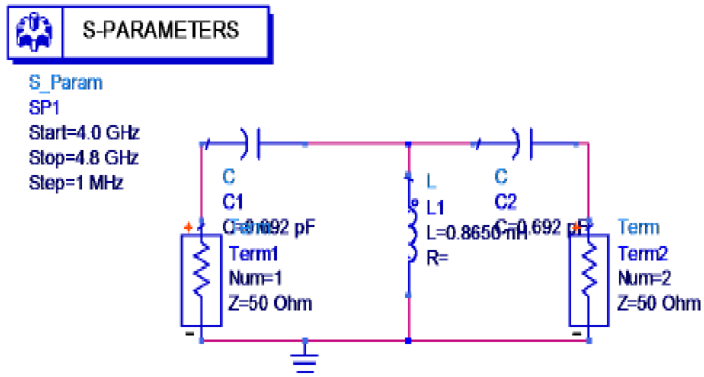

Fig 2a High Pass Filter

- SIMULATION AND VERIFICATION:

The parameter S (2, 1) is the Gain Response and S (1, 1) is the return loss.

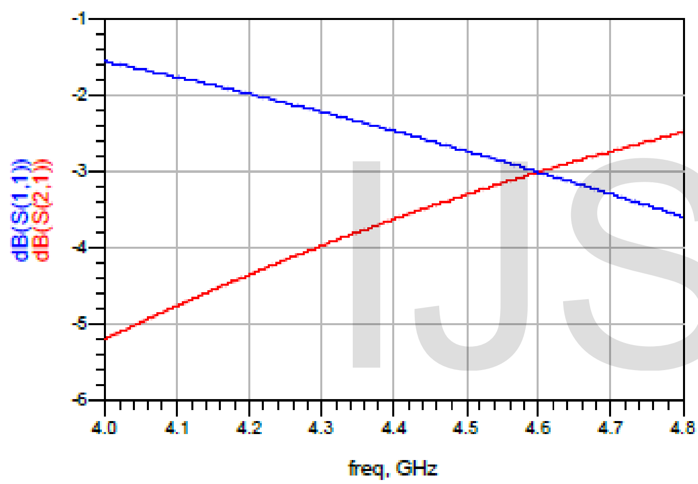

Fig 2b High Pass Response

The Fig (2b) verifies the High pass filter designed for 4.6GHz, since we can see that the gain response and the return loss is intersecting exactly at 4.6GHz.

iii. Band Pass Filter (BPF):

- DESIGN:

The designed LPF and HPF are cascaded in series together in order to design a Band Pass Filter and then it is modeled and simulated using the ADS software.

- MODEL:

The Band pass filter is modeled by cascading the model of LPF and HPF using the software ADS, and it is shown in Fig (3a),

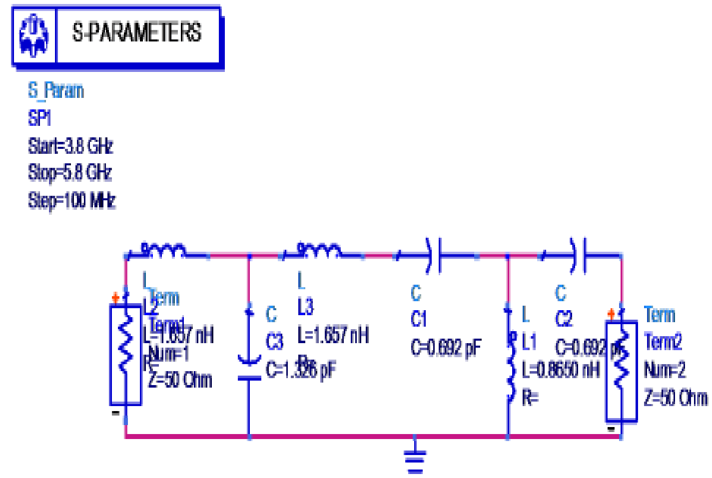

Fig 3a Band Pass Filter (BPF)

- SIMULATION AND VERIFICATION:

The parameters S (2, 1) is the Gain Response and S(1,1) is the return loss.

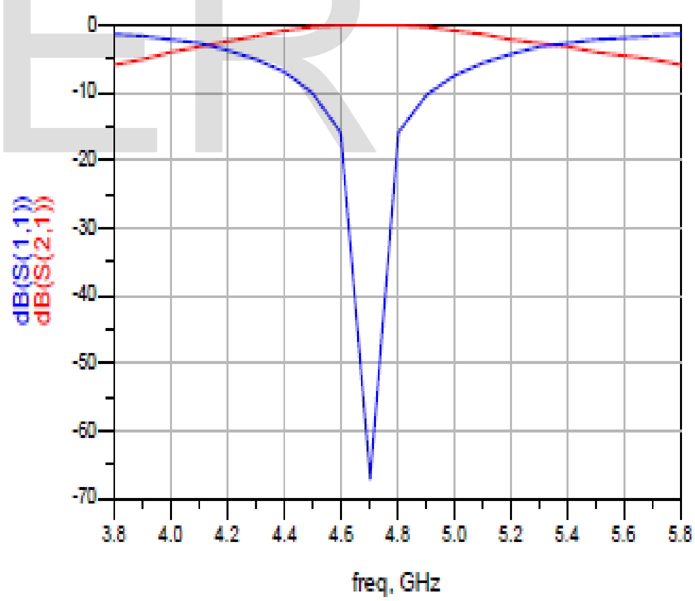

Fig 3b Band Pass Response

The Graph in Fig (3b) verifies the Band pass filter designed to pass 4.7GHz, since we can see the Fig (3b), that the only frequency returning S (1, 1) is 4.7GHz between 4.6GHz to 4.8GHz.

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6 Set up to Perform the Harmonic Analysis for the Designed Band Pass Filter:

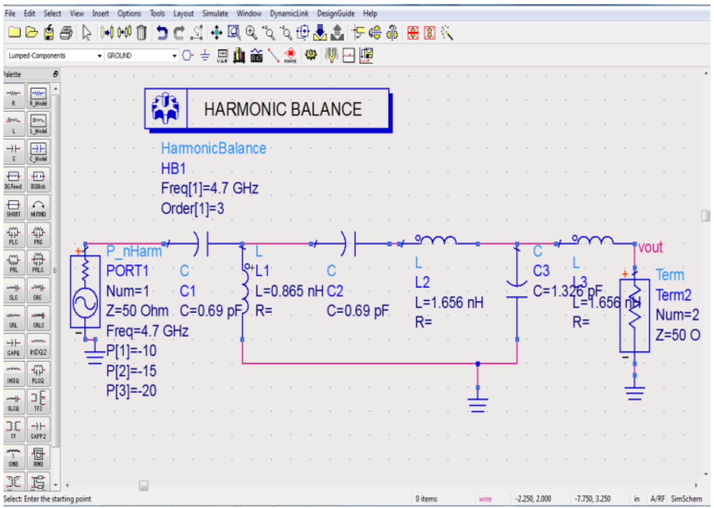

Fig 4a Harmonic Set up

The Fig (4a) shows the set up to perform a harmonic analysis of a particular frequency. Since we have designed a BPF to pass a frequency of 4.7 GHz, so we perform a harmonic analysis on this frequency by determining the first three harmonics. In the Fig (4) set up, we use the designed BPF, and p_n harm is connected at the source to obtain the harmonics and the set up is terminated by a terminal impedance of 50Ω.

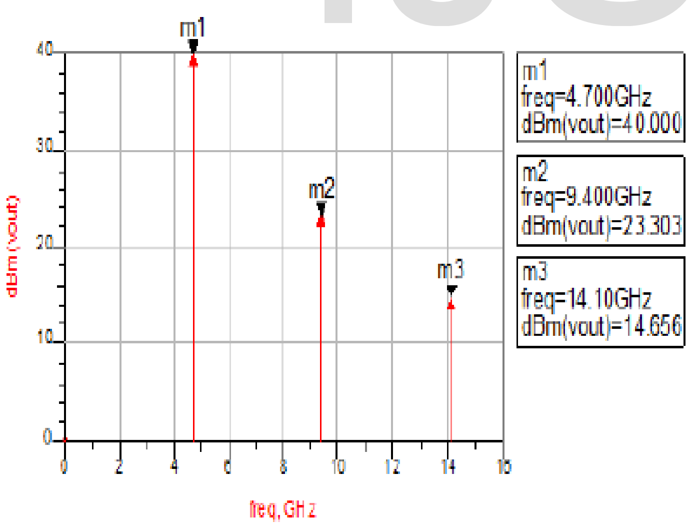

Fig 4b Harmonic Response

The Fig (4b) shows the harmonics of frequency 4.7 GHz. And m1, m2 and m3 are the marker indicating the plots where m1 is considered as the fundamental harmonic followed by m2 and m3. The harmonics generated depends on the form,

N*freq.

Where,

N = order or number of harmonics.

And freq = frequency

7 Design of LNA and Stability Analysis of the Chosen Model:

The stability of a High Electron Mobility Transistor (HEMT) depends on the Stability factor (K), and it is exhibited as follows,

- If K>1, it means the Hemt is stable.
- If K<1, it means the Hemt is unstable or oscillating.

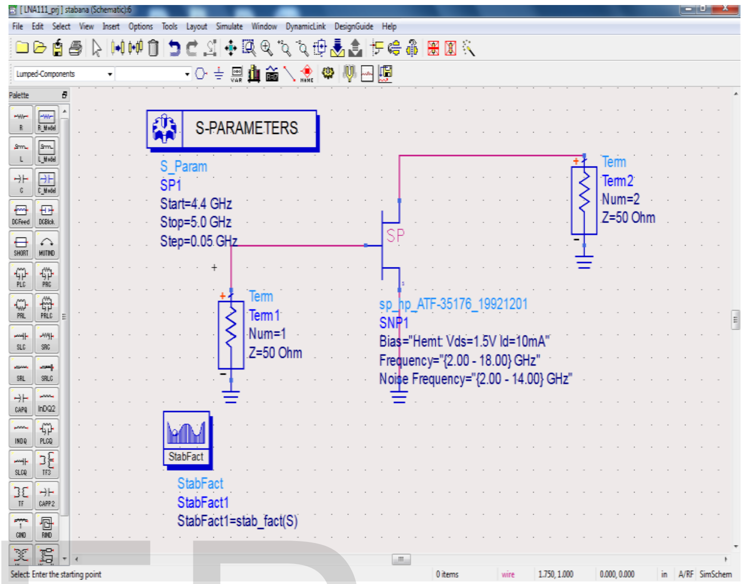

Fig 5a Stability Analysis (A)

Therefore it is necessary to analyze the values of "K" to check the stability of the HEMT. The HEMT model shown in Fig (5a) is ATF-35176_19921201 and we do a stability check on this chosen HEMT based LNA

Table 1 Unstable K

Frequency	S(1,1)	S(2,1)	Stabfact1(K)
4.400 GHz	0.904 / -6…	3.970 / 1…	0.365
4.500 GHz	0.900 / -6…	3.960 / 1…	0.374
4.600GHz	0.896 / -6…	3.950 / 1…	0.384
4.700GHz	0.892 / -7…	3.940 / 1…	0.393
4.800GHz	0.888 / -7…	3.930 / 1…	0.401
4.900GHz	0.884 / -7…	3.920 / 1…	0.410
5.000GHz	0.880 / -7…	3.910 / 1…	0.419

.

From the Table 1, it is seen that the values of "K" are less than 1 i.e. K<1, Therefore the above HEMT is not stable. Since it is not stable, now it is necessary to make the above chosen model stable using the method of sopt, In which we use an optimum load, such as a resistor which is connected at the source of the HEMT as shown in Fig (5b), in order to obtain stability.

The chosen resistance should be such that it provides stability as well as adequate gain, in this case R1 = 18 Ohm as shown in Fig (5b). In the Table.2, it is seen that the value of K is greater than 1 i.e. K>1. Therefore we obtained the stability of the chosen model.

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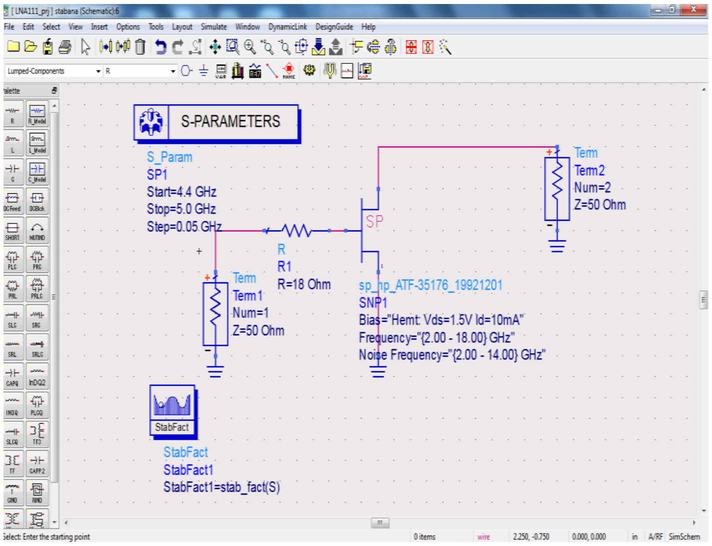

Fig 5b Stability Analysis (B)

Table 2 Stable K

Frequency	S(1,1)	S(2,1)	Stabfact1(K)
4.400GHz	0.738 / -6…	3.530 / 1…	1.025
4.500GHz	0.728 / -6…	3.506 / 1…	1.045
4.600GHz	0.719 / -6…	3.484 / 1…	1.069
4.700GHz	0.709 / -6…	3.461 / 1…	1.093
4.900GHz	0.691 / -6…	3.416 / 9…	1.138
5.000GHz	0.681 / -7…	3.394 / 9…	1.160

The Table 3 shows the noise figure values at port 1 and port 2. Noise is the disturbance present along with the signal and it is measured in terms of signal to noise ratio. We can see the noise figure's nf (1) and nf (2) for the above design is negligible and does not distort the signal.

Table 3 Noise Figure

Frequency	nf(1)	nf (1)
4.40GHz	19.371	2.115
4.45GHz	19.374	2.117
4.50GHz	19.377	2.118
4.55GHz	19.379	2.120
4.60GHz	19.380	2.121
4.65GHz	19.381	2.122
4.70GHz	19.381	2.124
4.75Ghz	19.380	2.125
4.80GHz	19.379	2.127
4.85GHz	19.378	2.128
4.90GHz	19.376	2.130
4.95GHz	19.373	2.131
5.00GHz	19.370	2.133

8 Minimum Noise Figure and Maximum Gain Circles for the Chosen LNA Design:

i. Maximum Gain:

The Fig (6a) shows the design of LNA, in which the display template element is chosen to display the stability and noise gain circles.

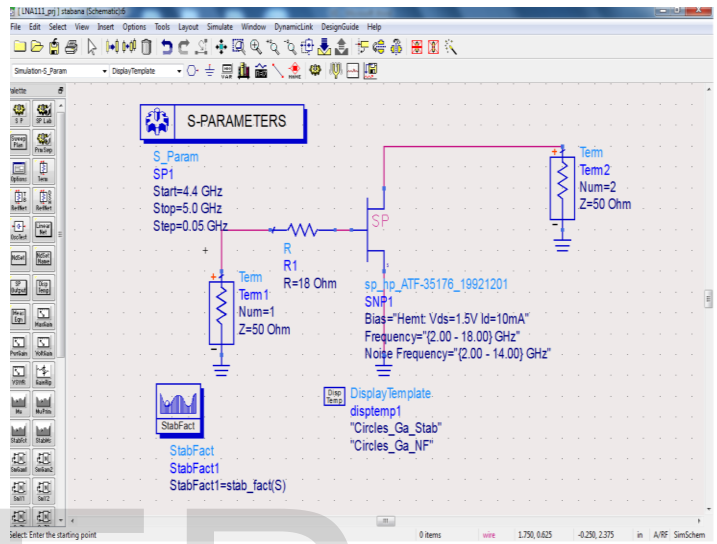

Fig 6a Low Noise Amplifier (LNA)

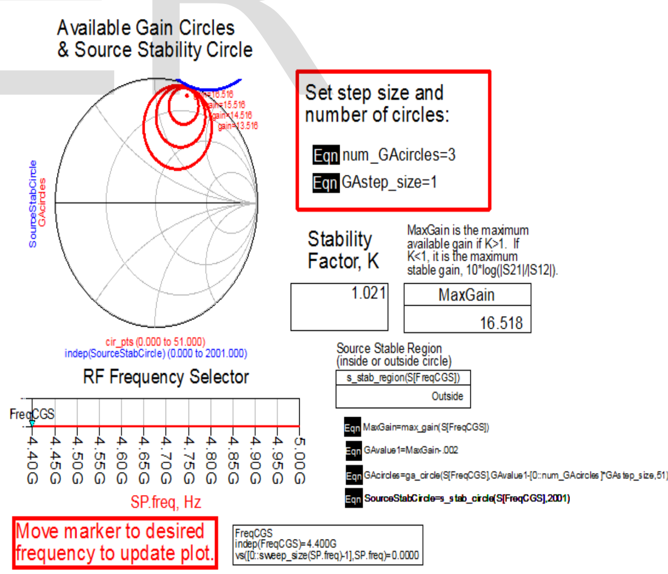

Fig 6b Maximum Gain

The above Fig (6b) shows the Maximum gain circles in the smith chart, and the value of the maximum gain and stability factor K at different frequencies between 4.4GHz to 5.00GHz. In the above Fig (6b), there is a Radio Frequency (RF) selector scale and a marker on it., the marker is at 4.4 GHz, and this marker is moved on the scale to specific frequencies in steps of 0.05 GHz, And the corresponding values of K and MaxGain are noted down and analyzed. The Table 4 below shows the values of K and Maximum Gain for different frequencies.

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Table 4 Maximum Gain Values

Frequency	Stability Factor (K)	Maximum Gain
4.40GHz	1.021	16.518
4.45GHz	1.033	16.244
4.50GHz	1.045	16.031
4.55GHz	1.057	15.807
4.60GHz	1.069	15.621
4.65GHz	1.081	15.448
4.70GHz	1.093	15.286
4.75Ghz	1.104	15.133
4.80GHz	1.116	15.987
4.85GHz	1.127	14.848
4.90GHz	1.138	14.715
4.95GHz	1.149	14.587
5.00GHz	1.160	14.464

ii. Minimum Noise Figures:

The Fig (7) shows the smith charts with plots of gain circles and noise circles. These plots vary as the marker on the RF frequency selector is changed to different frequencies. Therefore varying the frequency, we note the corresponding minimum noise figure. The Table 5 shows the values of minimum noise figures at different frequencies.

Table 5 Minimum Noise Figure

Frequency	Minimum Noise Figure, dB
4.40GHz	1.102
4.45GHz	1.114
4.50GHz	1.126
4.55GHz	1.139
4.60GHz	1.151
4.65GHz	1.163
4.70GHz	1.174
4.75Ghz	1.186
4.80GHz	1.198
4.85GHz	1.210
4.90GHz	1.221
4.95GHz	1.233
5.00GHz	1.244

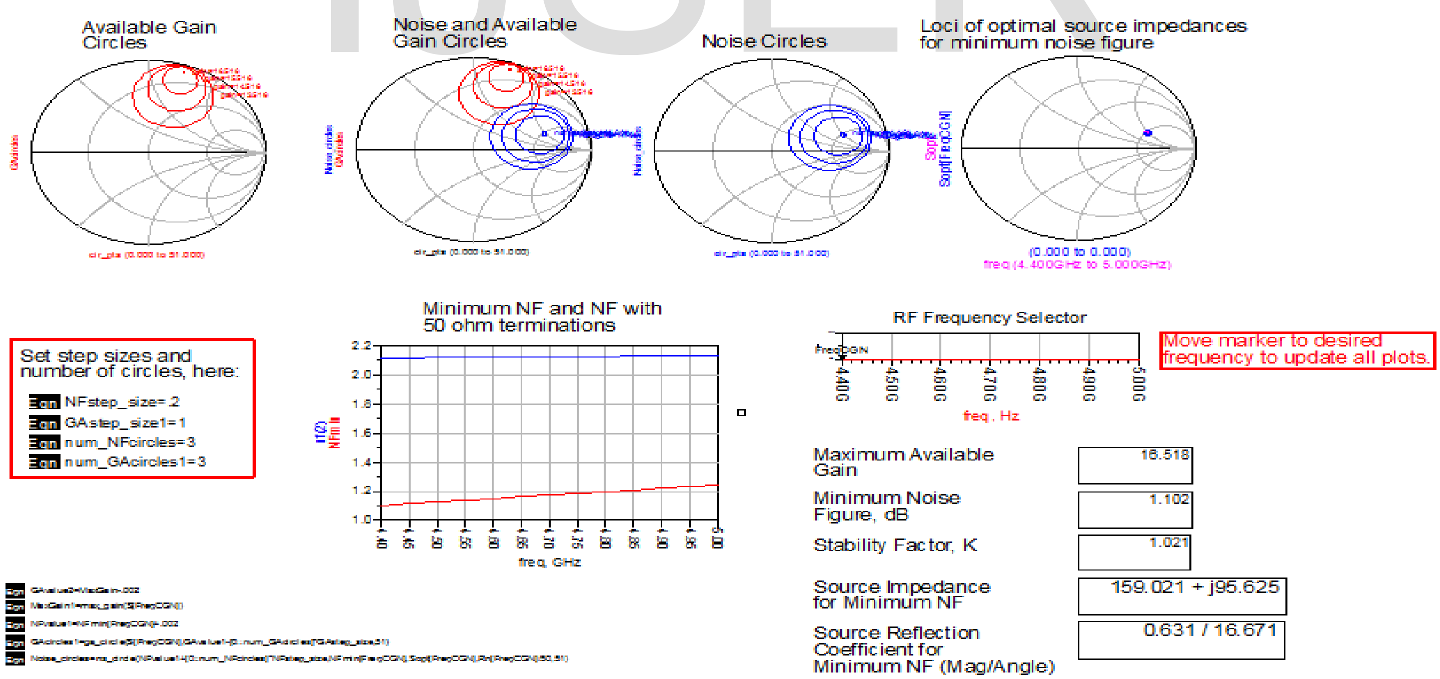

Fig 7 Gain and Noise Cirles

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9 Cascading the Designed BPF with LNA and Simulate the Response of the Cascaded System:

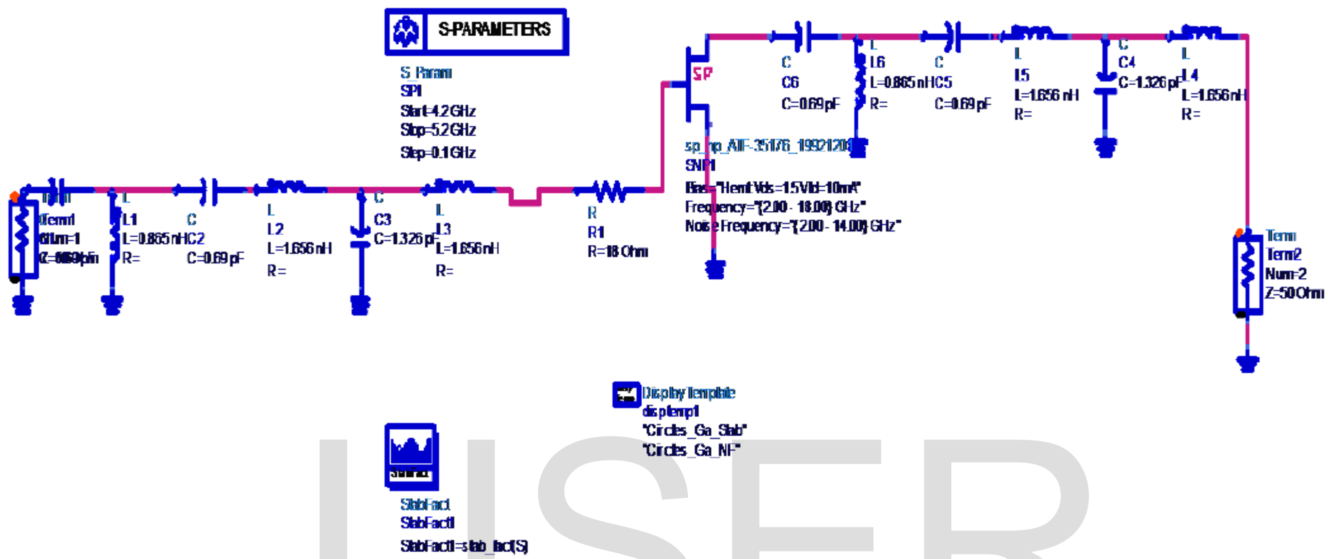

Fig 8a Cascading BPF and LNA

In section 5, we designed Band pass filter by cascading the low pass filter and the high pass filter. This Band Pass filter is cascaded with the designed Low noise amplifier and the response is analyzed after simulation. The Fig (8a) shows the cascading of the Band pass filter and the LNA. The BPF is connected at the source and load terminals of the LNA.The graph in Fig (8b) shows the gain response and the return loss. Since the design is developed, now this design is tuned to obtain a maximally flat and stable response. The process of tuning exhibited as we proceed further.

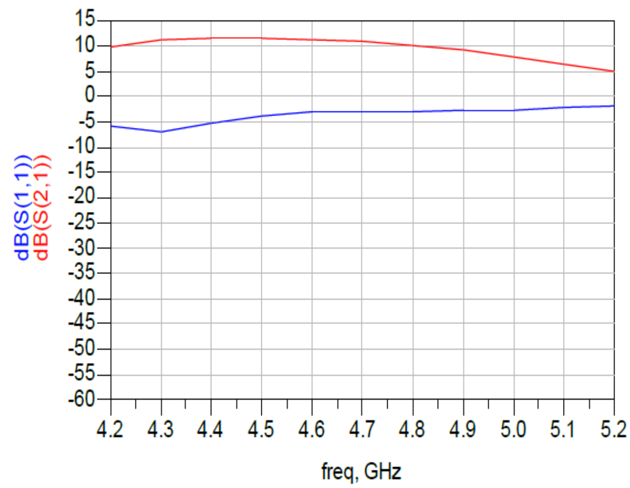

Fig 8b Cascaded Response

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10 Fine Tune the LNA Source and Load for Optimum S (1,1) and S (2,1) Parameters:

The Table 6 shows the best possible values of gain S (2,1) that can be achieved along with stability for the different values of the components L7, C7 and C8. The above results analysed closely and the best possible values of L7, C7 and C8 are selected which gives maximum stability with adequate gain. From the Above values, we shall consider the values of L7, C7 and C8 which provides a gain of 10.928 dB.

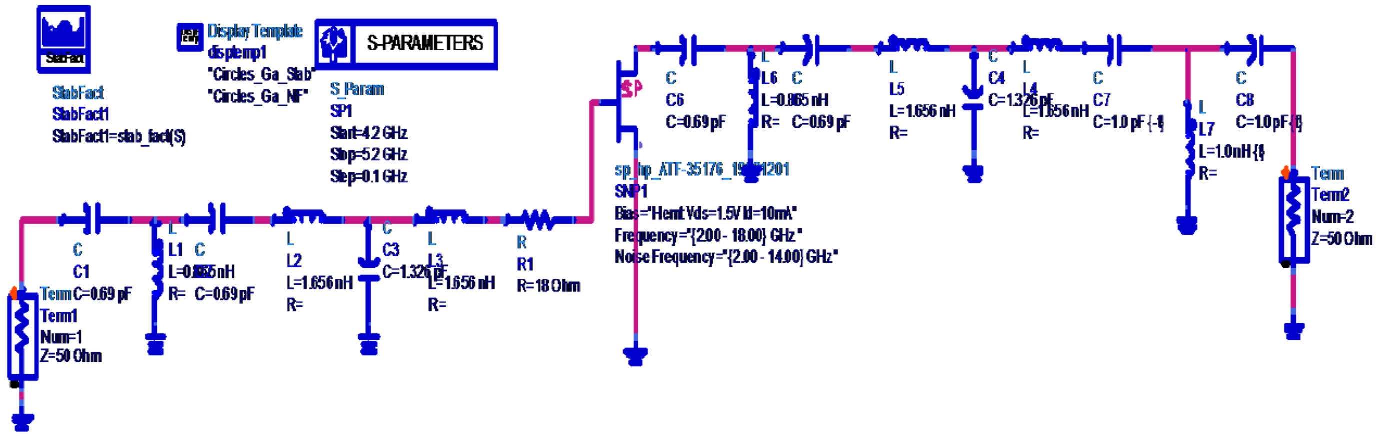

Fig 9a Fine Tuning

Fine Tuning is a process in which, we connect passive components such as L and C to the cascaded circuit and then we vary the parameters of these components, in order to get the most suitable response of the S (2, 1) and S (1, 1) parameters.In the Fig (9a), the components (capacitance) C7, C8 and (Inductance) L7 parameters at the termination end are varied and simultaneously the variation in S (2, 1) and S (1, 1) response parameters is analyzed and the chosen values of C8, C7 and L7 will be the ones which provide stability along with the desired gain response.

Table 6 Fined Tuned Parameters

L7.L (nH)	C7.C (pF)	C8.C (pF)	S (2,1) Gain
1.505	1.25	1.75	10.200 dB
1.805	1.97	1.94	10.928 dB
1.805	1.97	1.625	11.165 dB
1.745	0.725	0.77	10.771 dB

The graph in Fig (9b), shows the Gain response S (2,1) of 10.928 dB achieved by components L7, C7 and C8 having values of 1.805nH, 1.97pF and 1.94pF respectively, and also provides better stability with adequate gain compared to the other values of L7, C7 and C8.

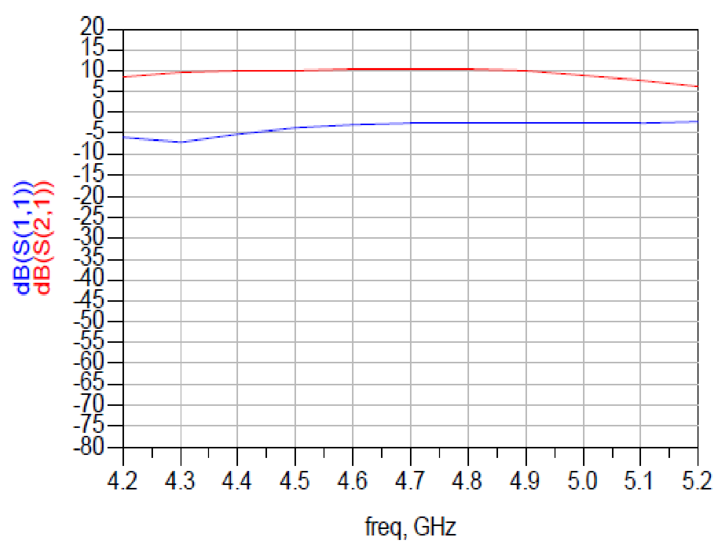

Fig 9b Tuned Response

Note that a maximum gain of 11.165 dB can be achieved, but the design may not provide the desired stability, whereas the others provide good stability but insufficient gain such as 10.771 dB and 10.200 dB. Therefore we prefer to achieve a gain of 10.928 dB with good stability.

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11 Conclusion:

The designed LPF blocks high frequency components and passes frequencies below 4.8GHz, while the HPF blocks low frequency components and passes frequencies above 4.6GHz, thus the cascaded LPF and HPF will pass frequencies only between 4.6GHz and 4.8GHz making it a BPF. From the harmonic setup and analysis, it's concluded that the fundamental harmonic with maximum amplitude is at 4.7GHz followed by the attenuated harmonics at 9.4 GHz and 14.10GHz. The chosen HEMT model for LNA design becomes stable with a resistance load 18 Ohm connected at the source. Maximum gain value is at 4.4GHz of 16.518 with a stability factor of 1.021. The cascaded response of LNA and BPF is tunned for different values of L7 (nH), C7 (pF) and C8 (pF) to obtain maximum gain with stability, therefore the selected tunned parameters or values of L7, C7 and C8 are the ones that provides a gain of 10.928 db or 11.165 db.

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