RF/ Microwave Circuits Final Design Project

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Objective:

To design a 20±1 dB parallel line 3-section coupler with a center frequency of 3 GHz and a bandwidth of 4 GHz between 1 GHz and 5 GHz, while meeting the following specifications: Coupling at 3 GHz at 20±1 dB, Directivity at design frequency 15±2 dB, insertion loss at design frequency 1.5 dB maximum.

Abstract:

The directivity in the microstrip directional couplers will get degraded due parasitic effects of junctions and inhomogeneous dielectric, without proper modeling of these parasitic effects, directivity enhancement becomes extremely difficult especially for weak coupling levels [5]. In this paper the Inductively compensated directional paper is implemented. Design of a 20 dB 3 section coupler with center frequency of 3 GHz. The simulation was first carried out for the uncompensated coupler. The length, width and spacing of each section was calculated. This paper fills the void by presenting a best way to the design of microstrip directional couplers with ideal match or high directivity.

Introduction:

Directional couplers are four-port circuits where one port is isolated from the input port. Directional couplers are passive reciprocal networks, which you can read more about on our page on basic network theory. All four ports are (ideally) matched, and the circuit is (ideally) lossless. Directional couplers can be realized in microstrip, strip line, coax and waveguide[6].

Microstrip directional couplers with conventional parallel-coupled lines are widely used in baluns, filters, and various microwave integrated circuits. However, their directivity deteriorates with frequency, which is resulted from the difference of the even-mode and odd-mode phase velocities. Also, a microstrip transmission line has an inhomogeneous dielectric—partly dielectric substrate, partly air. For this reason, odd and even, odd phase velocities are unequal. This inequality manifests itself in the coupler’s poor directivity. The directivity performance becomes worse as the coupling is decreased or as the dielectric permittivity is increased.

Various compensation techniques have been reported, which include adding a different dielectric overlay on the top of coupled lines and wiggling the edges of coupled lines. The compensation is also effective by adding reactive lumped elements to the coupled lines. Examples are the insertion of capacitors at the ends or the center of coupled lines and the insertion of inductors between the collinear ports of coupled lines. There are several methods of improving the directivity of such couplers, i.e., serrating the gap between the conductors, adding lumped capacitors at each end of the coupler and selecting two or more different permittivity and their thickness for the multilevel substrate. The method we will be using in our project is adding a shunt inductance and/or capacitance to increase the directivity as well as the other parameters and try to bring them within the acceptable range. [1][2]

Design procedure:

Given substrate properties

- H=20 mil
- Er=2.2
- Mr=1
- T=37um
- TanD=0.0009

Coupler design in schematic window

Uncompensated-

- The substrate was added with given properties.
- Microstrip was selected from TLines from the Palette list and added **Mclin** to the schematic window.
- Each coupler was sent to Linecalc. Coupler 1 & 3 had the same properties.
- We then entered parameters like design frequency (f_c), Z_o, electrical length of transmission line and coupling factor in dB.
- Once synthesized, we got the values of width, spacing and length of coupled transmission lines (W, S, and L respectively).
- These values were then put in the respective couplers of the Mclin component and the circuit was simulated as shown.
- The width of the bends was put as the same width of transmission line.
- The frequency was set as 0-5GHz with 500 steps in between. The simulation was done and the graphs were plotted. (Shown below)

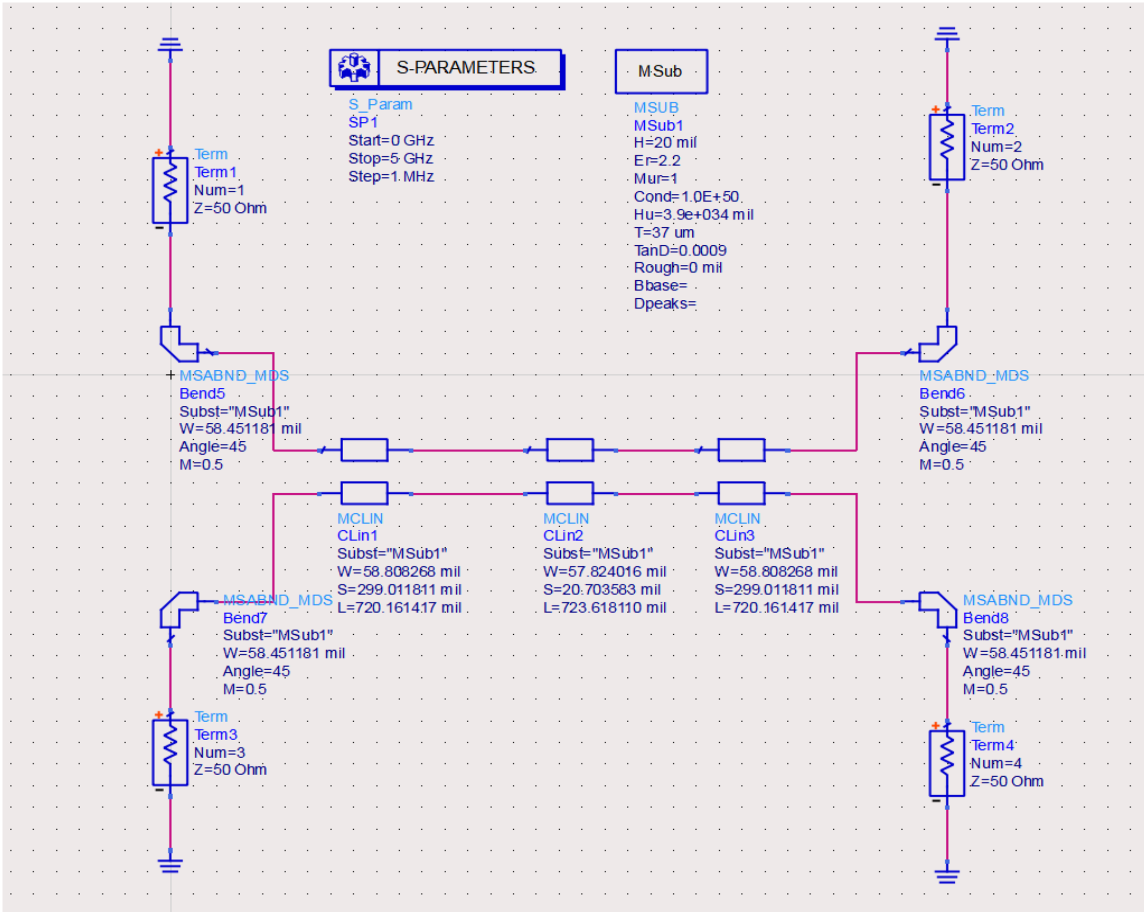

Figure 1 Schematic for Uncompensated design

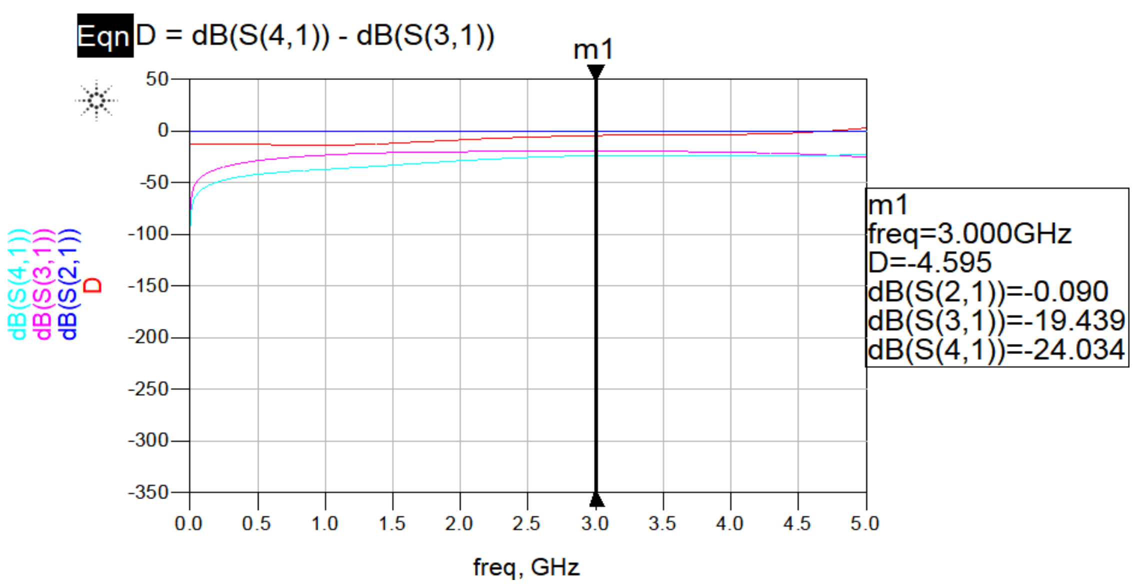

Figure 2Waveforms of Uncompensated design simulation

Coupler design in schematic window

Compensated-

- In the uncompensated simulation graphs the values of the parameters were checked at center frequency i.e. 3GHz.
- The deviation from the desired values were observed.
- We then tried to achieve the desired values of the parameters (Insertion loss, Coupling and directivity) by adding inductors in shunt and trying different combinations to tune the circuit within our desired values.
- We achieved one such result at inductor values of 2.5nH and 3nH.
- The schematic of the compensated design and the graphs from simulation are shown below.

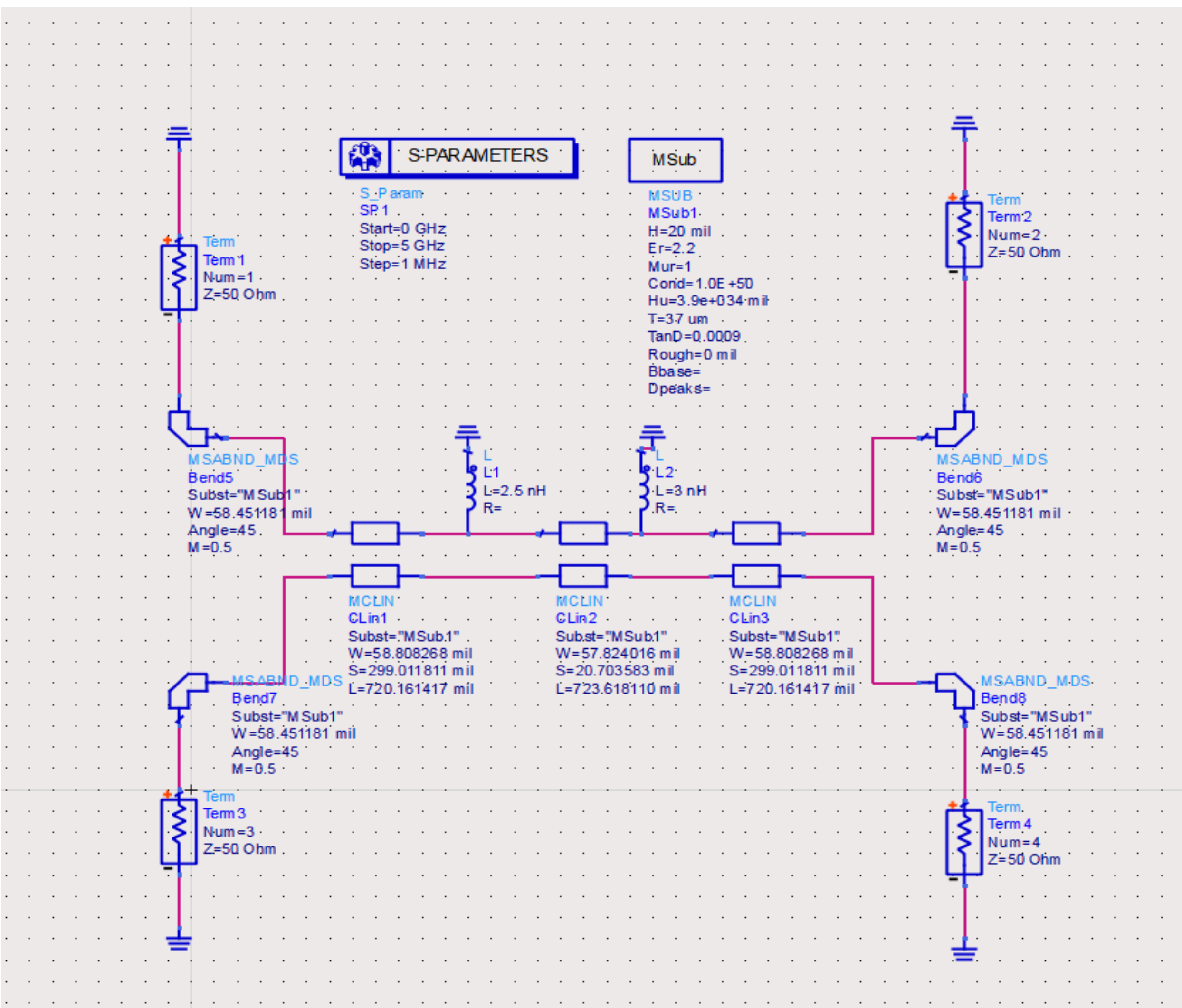

Figure 3 Compensated design schematic

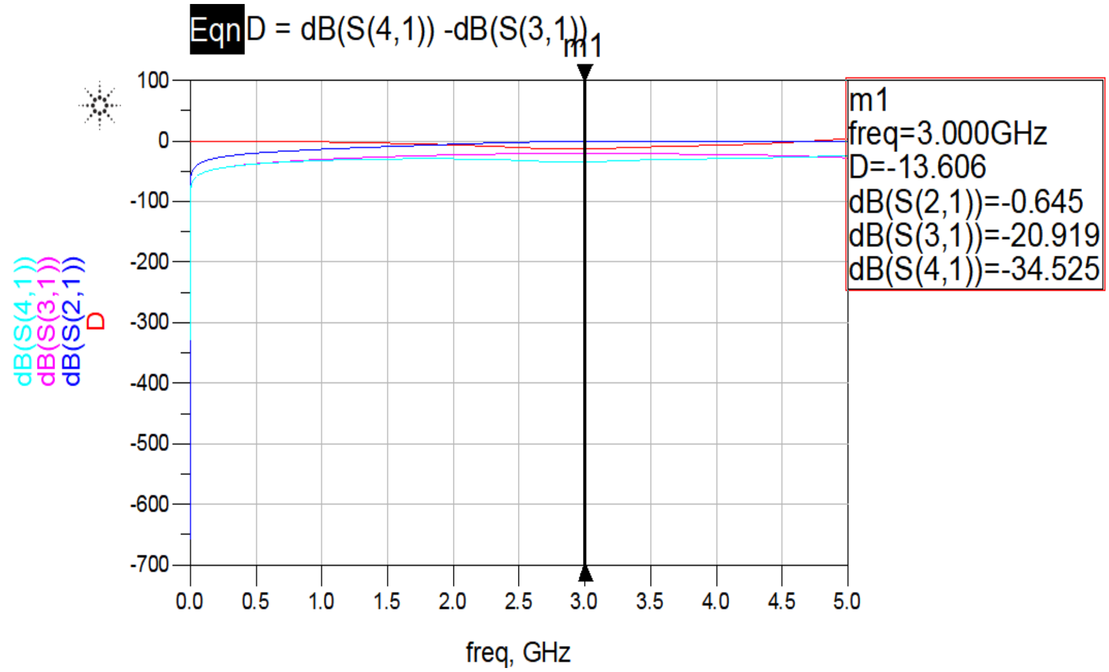

Figure 4 Graphs of compensated design simulation

EM simulation

- After the simulation for the compensated design was carried out, the simulation in EM mode was done.
- The layout was created first by going to EM, then Generate/Update layout
- The substrate properties for EM simulation were set, generating a new default substrate "Substrate 1"
- In new substrate window, new dielectric 'Dielectric_1' was added and its properties were changed.

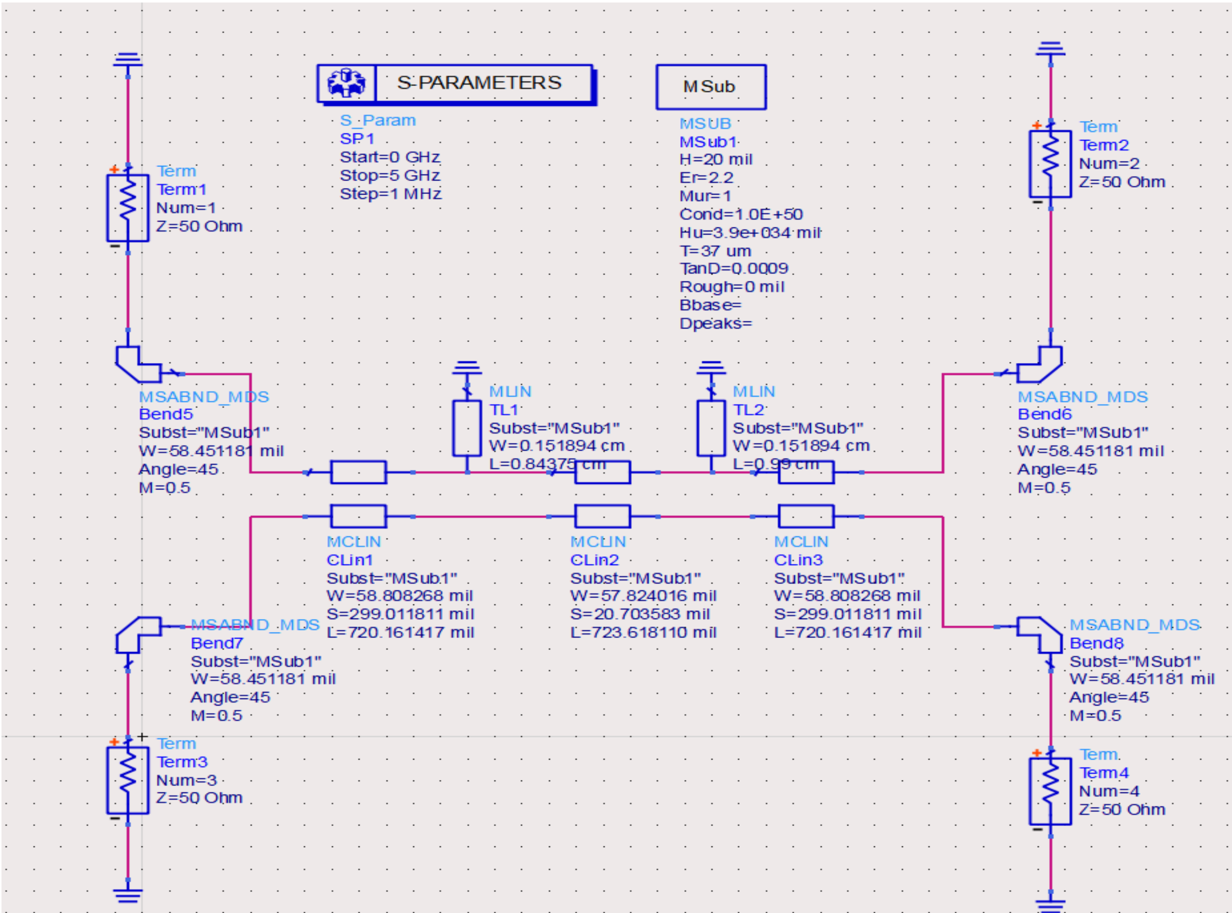

Figure 5 Schematic for EM simulation

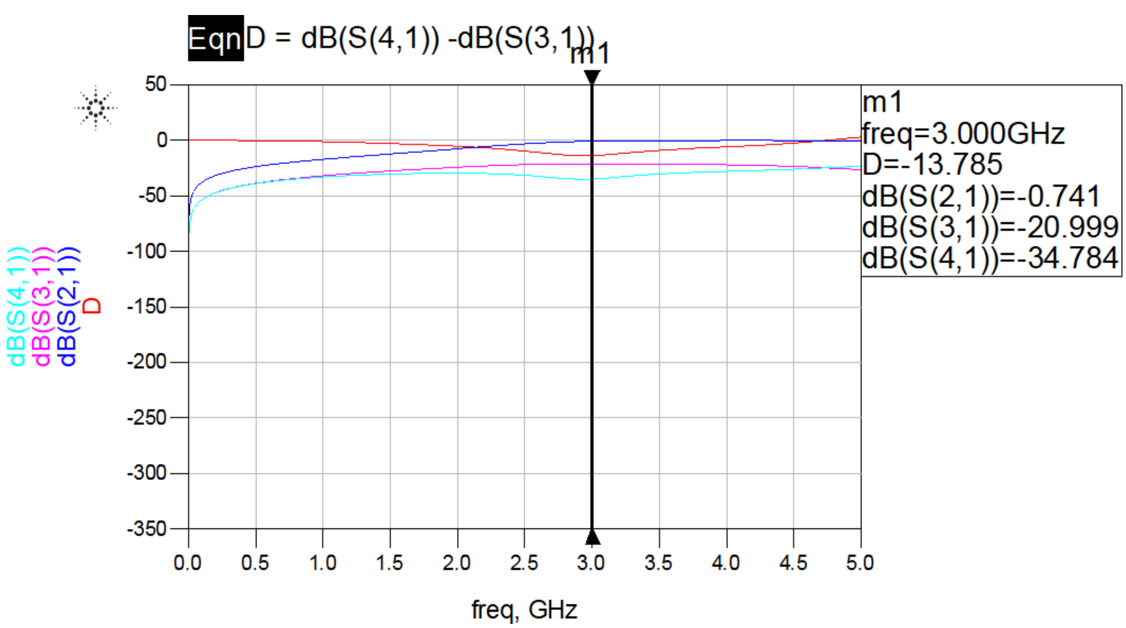

Figure 6 Simulation graphs for new design

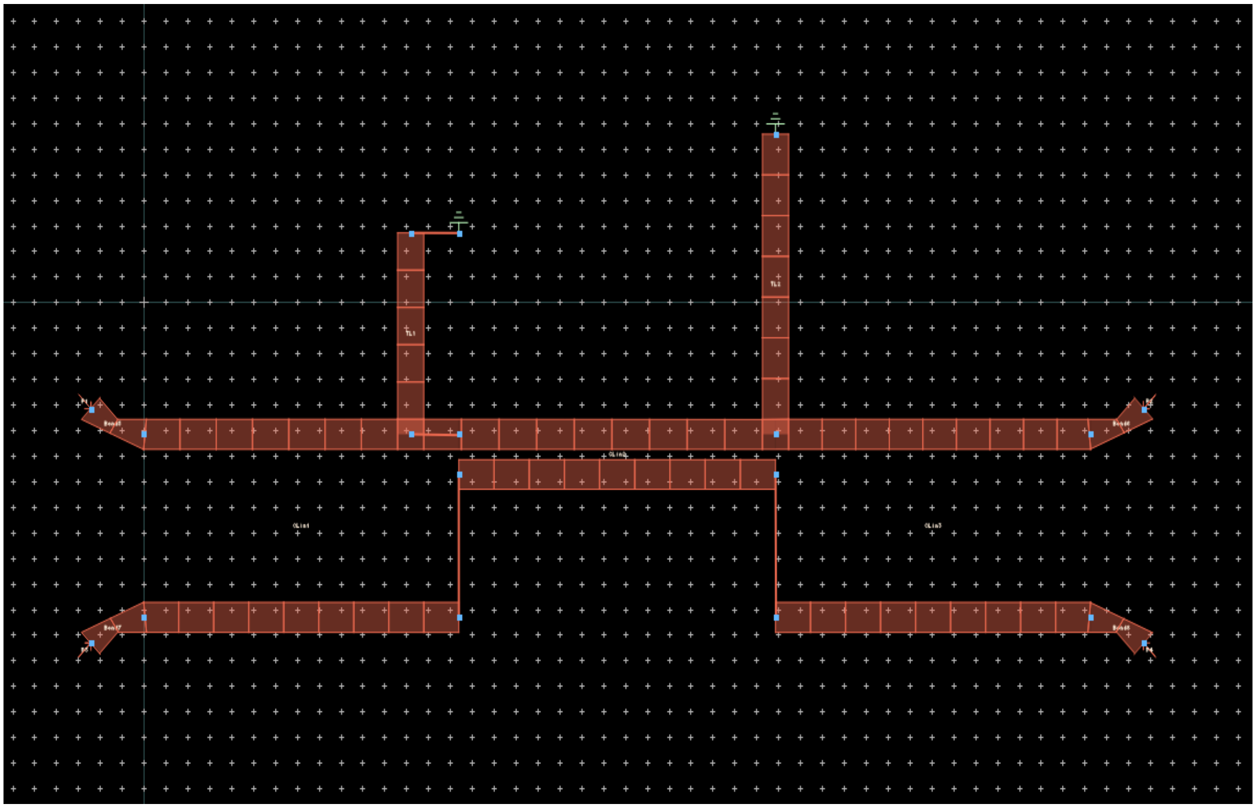

Figure 7 EM schematic model

Once we run the simulation for EM mode, we observed that there were quite disparities from our desired specification. Hence, we tried changing the length of the inductor in the schematic till we got a value of directivity in the desired range. The lengths at which we observed this result were 0.84375 cm and 0.99 cm

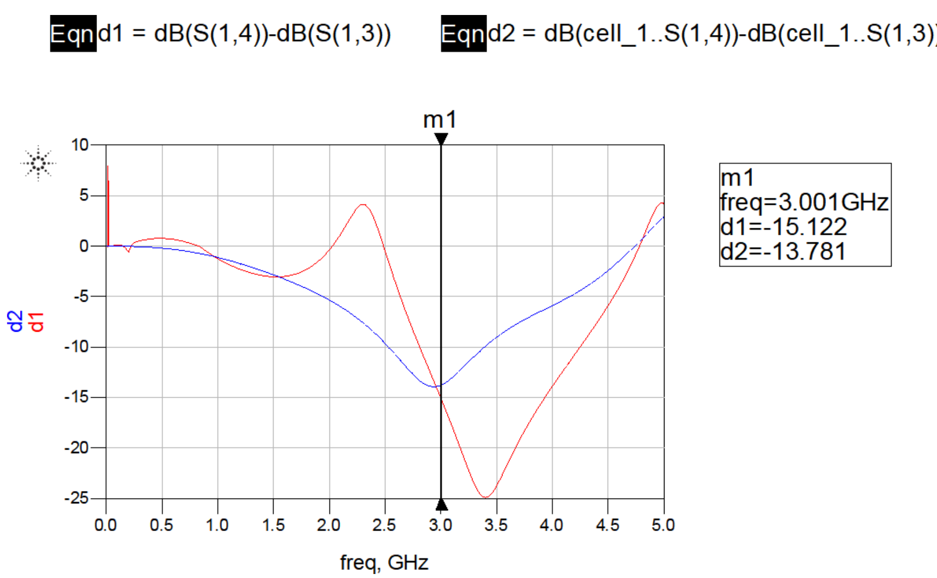

Figure 8 Graphs for EM Mode simulation

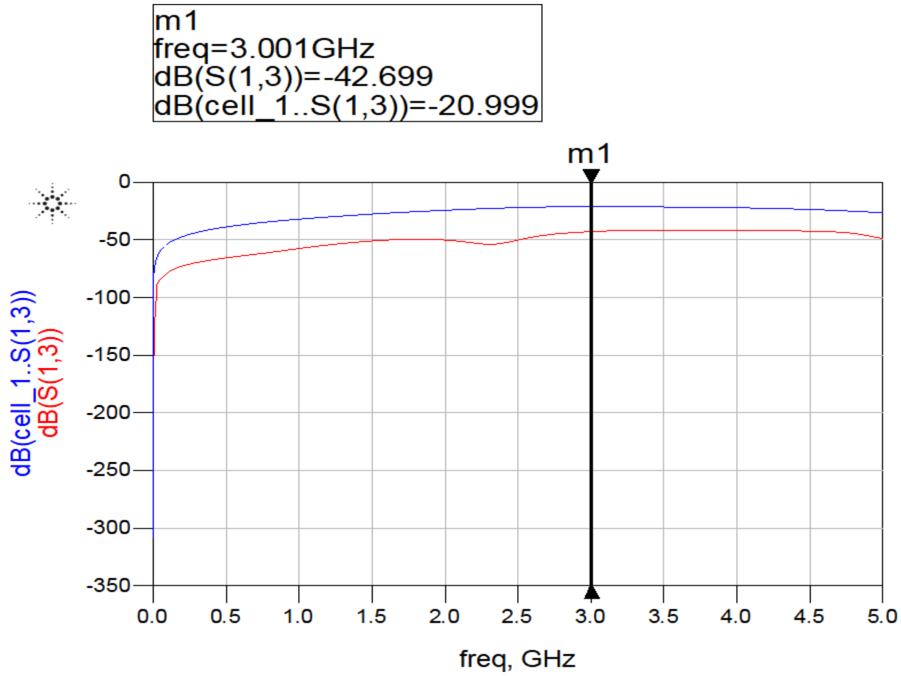

Figure 9 Graphs for EM Mode simulation

Conclusion

A new directional coupler with high Directivity is achieved by using two shunt inductor, compared to uncompensated directional coupler which was having very low directivity is now improved using shunt inductors, As you can see, there is a slight difference in the EM simulations vs ADS schematic simulation. The EM simulation will be closer to real board, as it uses fewer approximations. Now in order to get coupling from EM simulations to 20 dB, in our schematic we achieved the desired value by changing the value of the length of the inductor (a transmission line was used because EM mode does not recognize an inductor directly). [3]

References

[1] Sheng-Fuh Chang, Jia-Liang Chen, Yng-Huey Jeng, and Chain-Tin Wu "*New High-Directivity Coupler Design With Coupled Spurlines",* IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 14, NO. 2, FEBRUARY 2004

[2] Michael Dydyk, Senior Member, IEEE "*Microstrip Directional Couplers with Ideal Performance via Single-Element Compensation"* IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 47, NO. 6, JUNE 1999

[3] Dr. Uttam Singisetti, "Single Section coupler design example", State University of New York, Fall 2021

[4] Ravee Phromloungsri, Mitchai Chongcheawchamnan, Member, IEEE, and Ian D. Robertson, Senior Member, IEEE "*Inductively Compensated Parallel Coupled Microstrip Lines and Their Applications*" IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 54, NO. 9, SEPTEMBER 2006

[5] Seungku Lee and Yongshik Lee, Member, IEEE, '*A Design Method for Microstrip Directional Couplers Loaded With Shunt Inductors for Directivity Enhancement',* IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 58, NO. 4, APRIL 2010

[6] https://www.microwaves101.com/encyclopedias/directional-couplers