EDISON

Electromagnetic Design of
flexIble SensOrs

FNP Team-Tech

Report 1.
Analysis of Software Calibration Ports in InventSim Simulator Using De-embedding Techniques

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Contents

1 Introduction

The aim of the report is showing the calibrations techniques and the results of numerical experiments.

The problem of discontinuity (changes in propagation parameters) occurs during simulation using lump port, because it is nonphysically excitation. A lumped port is model consisting of two terminals: signal and ground (impress voltage or current source). Our goal is to find the error box (expressing discontinuities)[1], for the DUT (circuit network), which will be example the microstrip line with stub. Error box, in the following part we will be called the matrix of a single port.

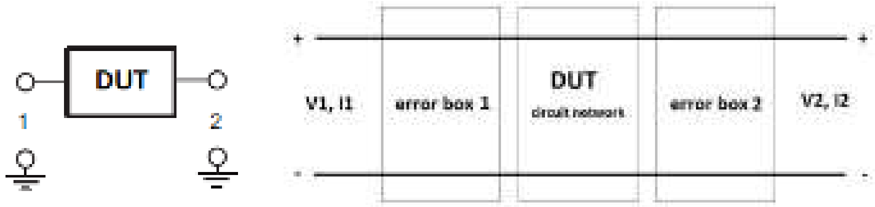
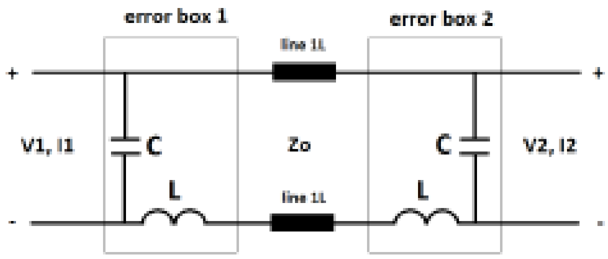


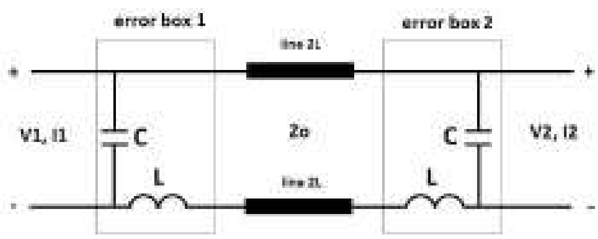
Figure 1: The general scheme of the system and the idea of calibration.

1.1 Procedure of the calibration

In this document has focused on the method double delay[2]. Double delay calibration is de-embedding techniques and is directly inspired by the physical TRL (Thru, Reflect, Line) calibration algorithm, using a three standards with precisely known characteristics.

- In this case, standard that we know precisely is cascaded two identical lines (our DUT).





- This scheme assumes the port discontinuity as a shunt capacitor and makes use of two transmission line standards with lengths L and 2L to calibrate the error boxes.

1.2 Simulation parameters

Simulations were performed for a single microstrip line (by the length L and 2L) in IventSim with (general wave port and lumped port), by testing several configurations. Also Simulations were performed in commercial software ADS.

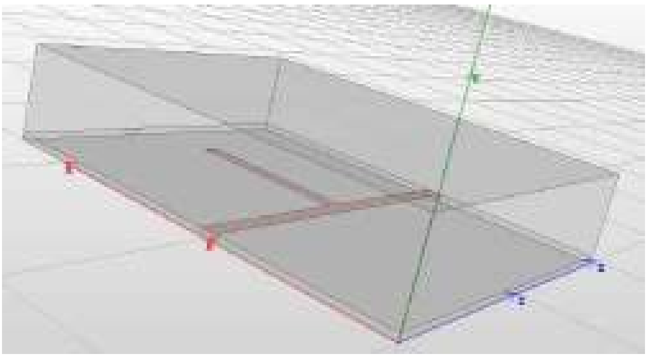


Figure 2: The process of calibration of the lumped port will be made for example DUT a microstrip line with stub.

For test simulations were assumed substrate which is available in department for the purpose of physical realization, and measurement. Structure parameters:

- substrate : laminat ISOLA I-TERAMT 3.45 0300 XHB
- thickness of the substrate : $0.762mm$
- permeability : 3.45
- width strip : $1.72mm$ (50Ω)
- electric length line : $90degrees$ (on frequency $2.5GHz$), $\mathbf{L} = 18.19mm$

Simulation was made in the frequency range from $0.1GHz$ do $5.1GHz$ for the line parameters described above. Two variants were used for the test: line 50Ω (width $1.72mm$) and line $\approx 31.5\Omega$ (width $2 \cdot 1.72mm$).

1.2.1 ADS and Momentum

In the ADS simulator was made circuit analysis. In the Momentum was made wave simulations without and with TML (Thru, Match, Line) port calibration.

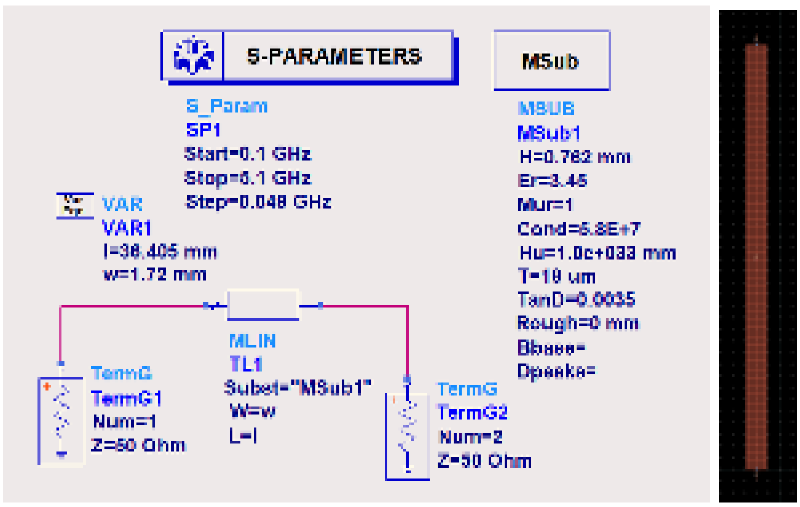


Figure 3: Line scheme in ADS and layout drawn in Momentum.

1.2.2 InventSim

Four configurations of the microstrip line were made in InventSim simulator:

- general wave port („**wave**”)

- lump port (which we will calibrate)
  - lump port on the side wall („**lump**”)
  - lump port on the side wall internal line (extended substrate) („**lump in**”)
  - lump port between the inside stripe and the side wall (PEC) outside („**lump PEC**”)

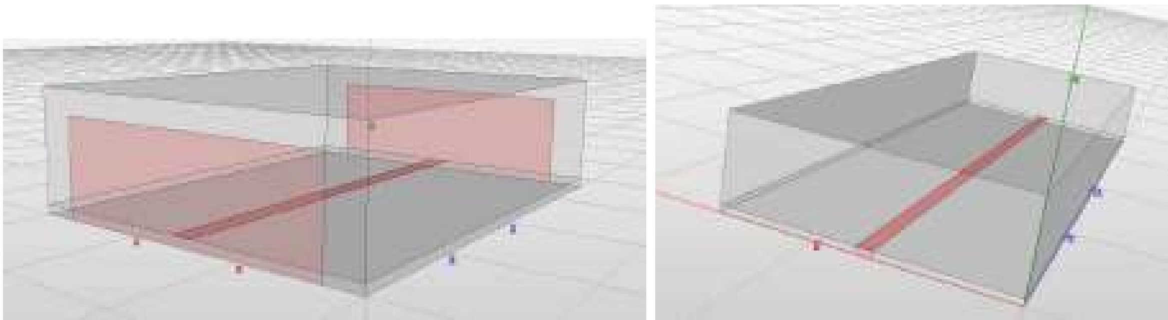


Figure 4: On the left line with length **L** of the („**wave**”) port, on the right line with length **2L** of the („**lump**”) port.

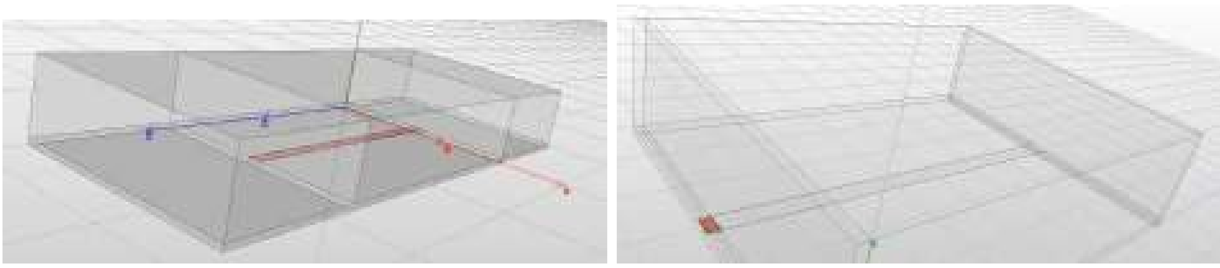


Figure 5: On the left line with length **L** of the („**lump in**”) port, on the right line with length **2L** of the („**lump PEC**”) port.

Figure 6: The idea of the definition lumped port on the side wall. In this case it is small rectangular area between the strip with conductor and the groundplane.

Figure 7: This structure consists of two box objects representing the dielectric substrate layer and air above and a 2D rectangular object that is a PEC strip. In the port plane sets perfect magnetic conductor boundary condition.

2 Simulation Results - before calibration

In this section the simulation results for the microstrip line will be presented.

2.1 Line 50 Ω

2.1.1 ADS and Momentum

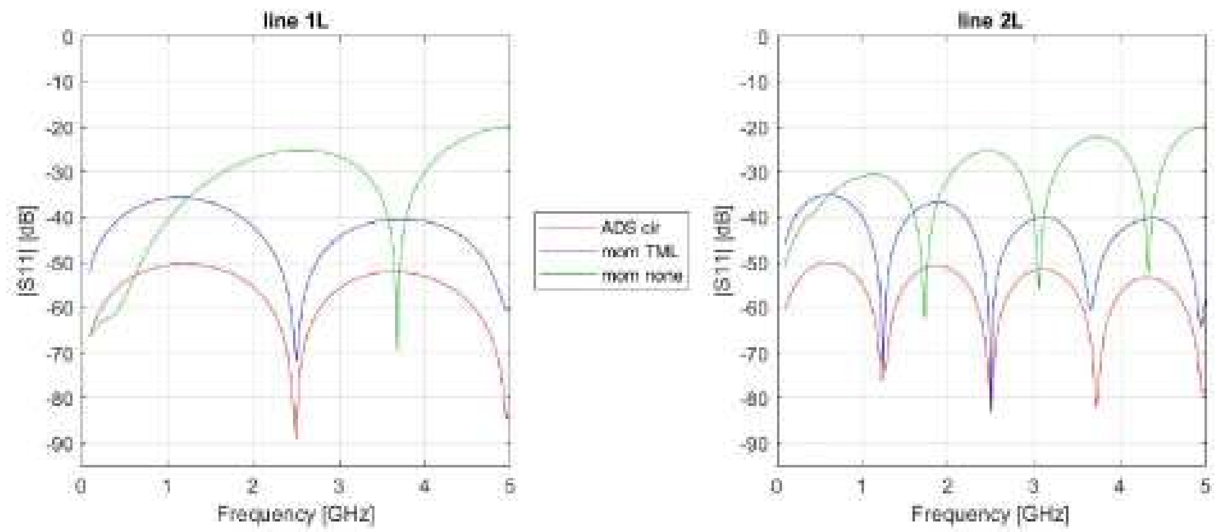


Figure 8: Obtained characteristics of the S_{11} module for the line length **L** and length **2L**.

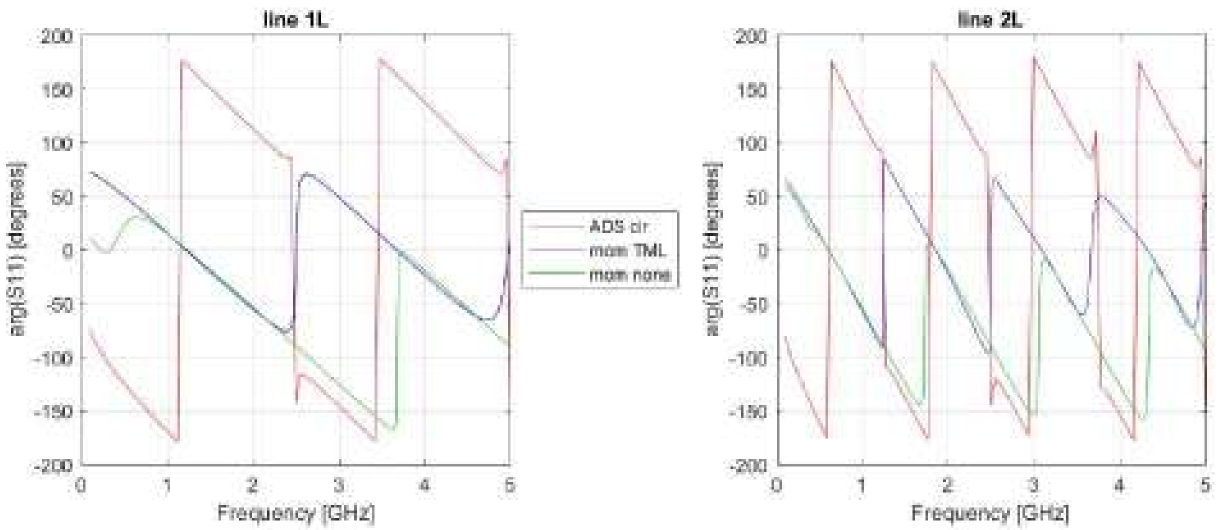


Figure 9: Obtained characteristics of the S_{11} phase for the line length **L** and length **2L**.

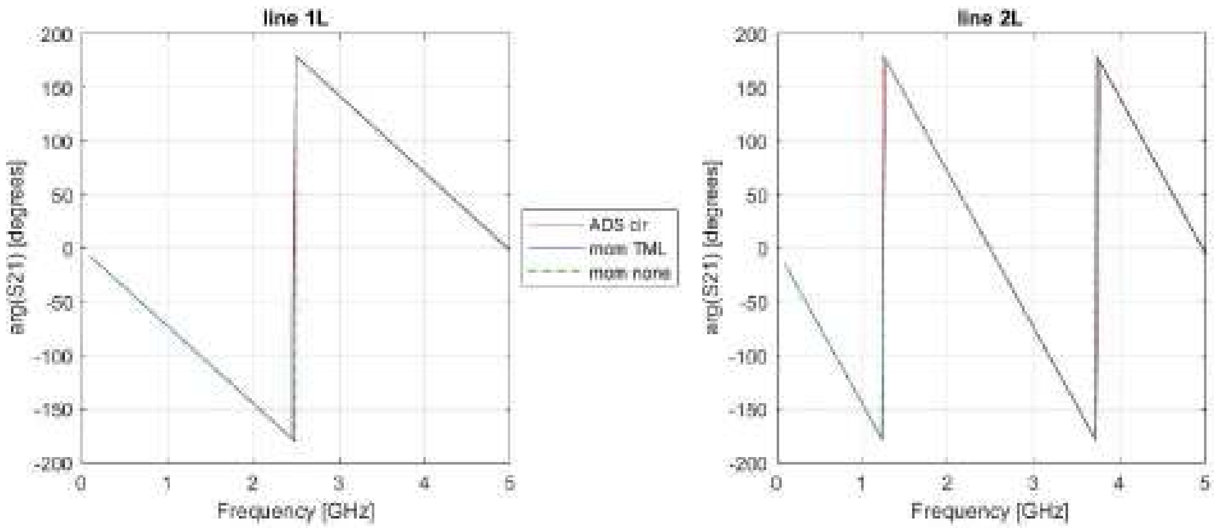


Figure 10: Obtained characteristics of the S_{21} phase for the line length **L** and length**2L**.

2.1.2 IventSim

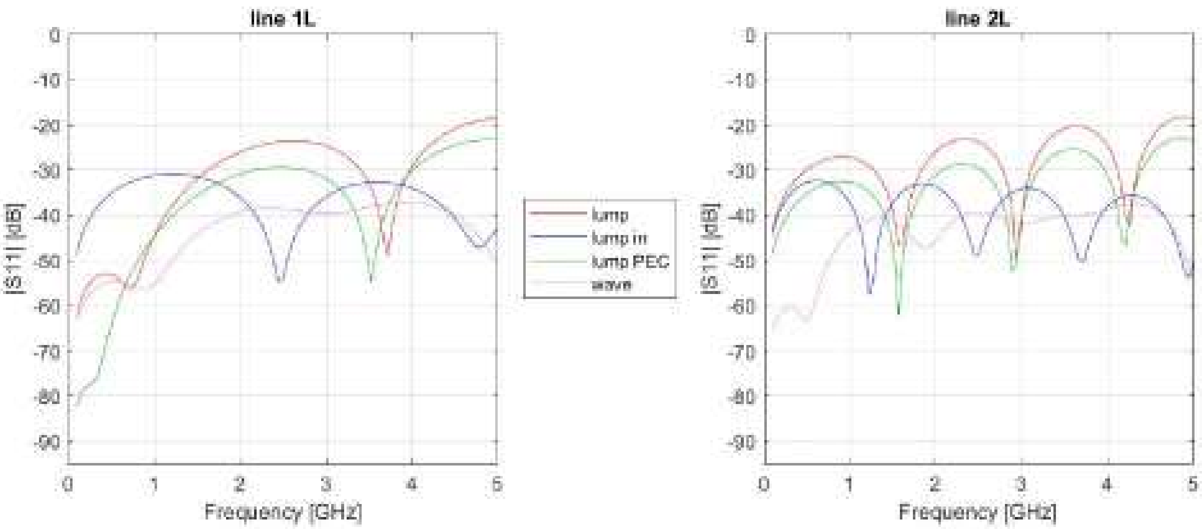


Figure 11: Obtained characteristics of the S_{11} module for the line length **L** and length **2L**.

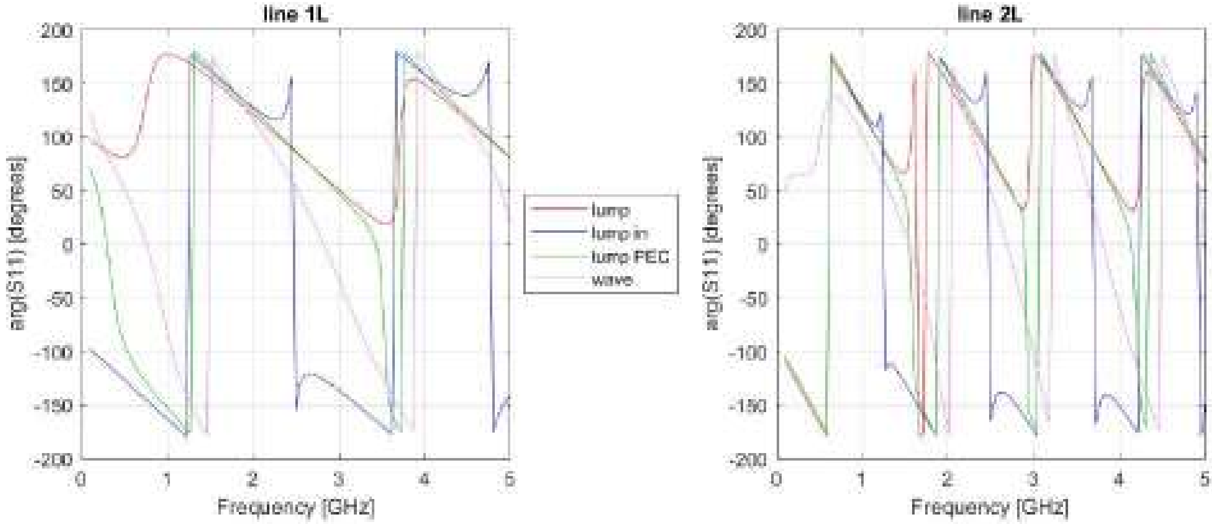


Figure 12: Obtained characteristics of the S_{11} phase for the line length **L** and length **2L**.

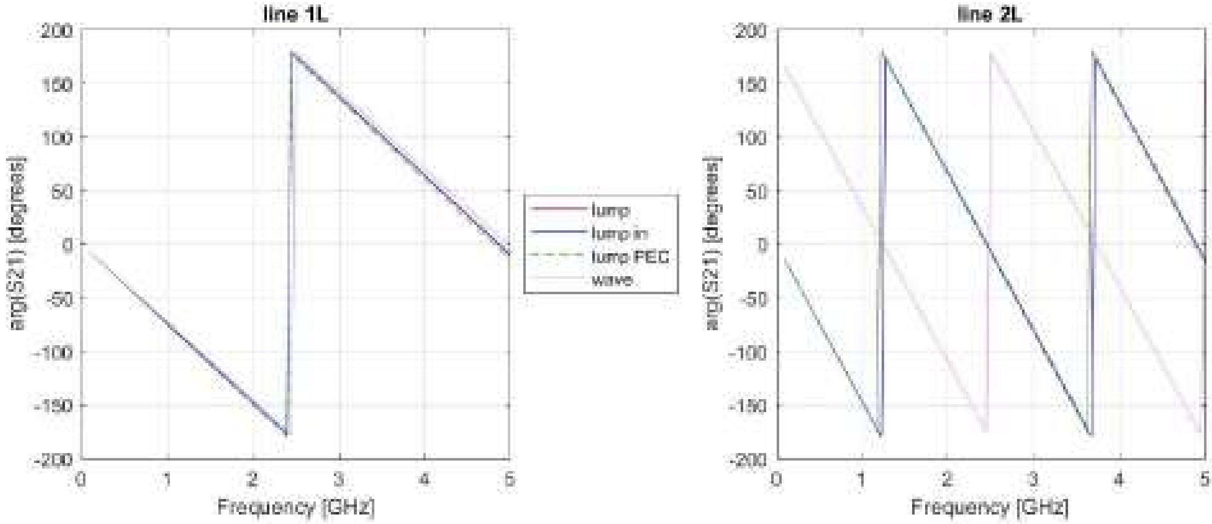


Figure 13: Obtained characteristics of the S_{21} phase for the line length **L** and length**2L**.

2.1.3 Comparison of simulation results with ADS, Momentum and InventSim

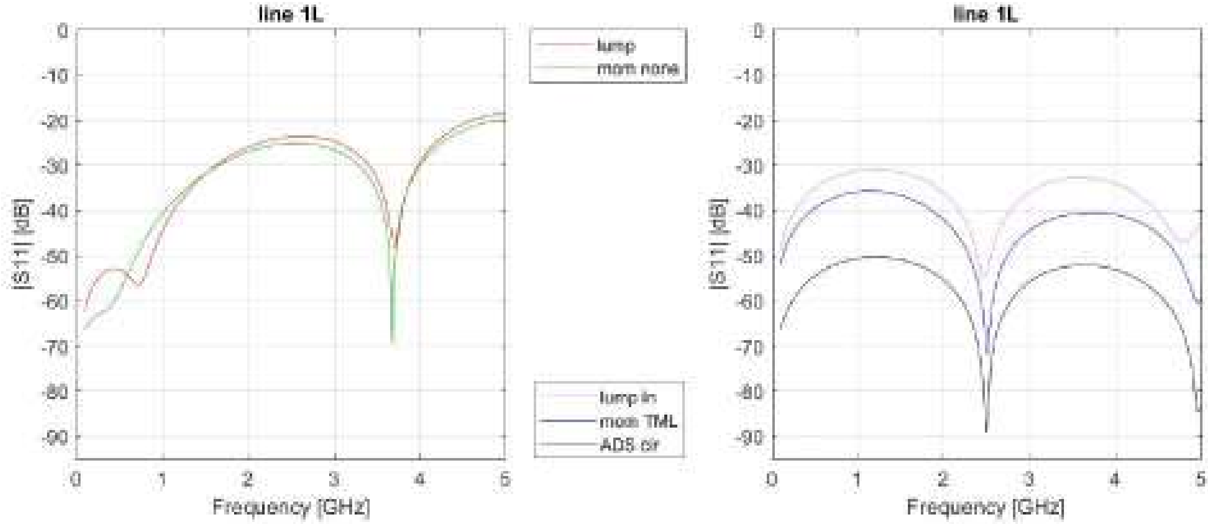


Figure 14: On the common chart obtained the results of the S_{11} module for a line of length **L**.

As we can see, circuit simulation gave best match so it will be our reference during calibration. The shape of the obtained characteristics for the internal lump port is surprising. By adding an additional substrate and extending the computational field, we received relatively good match.

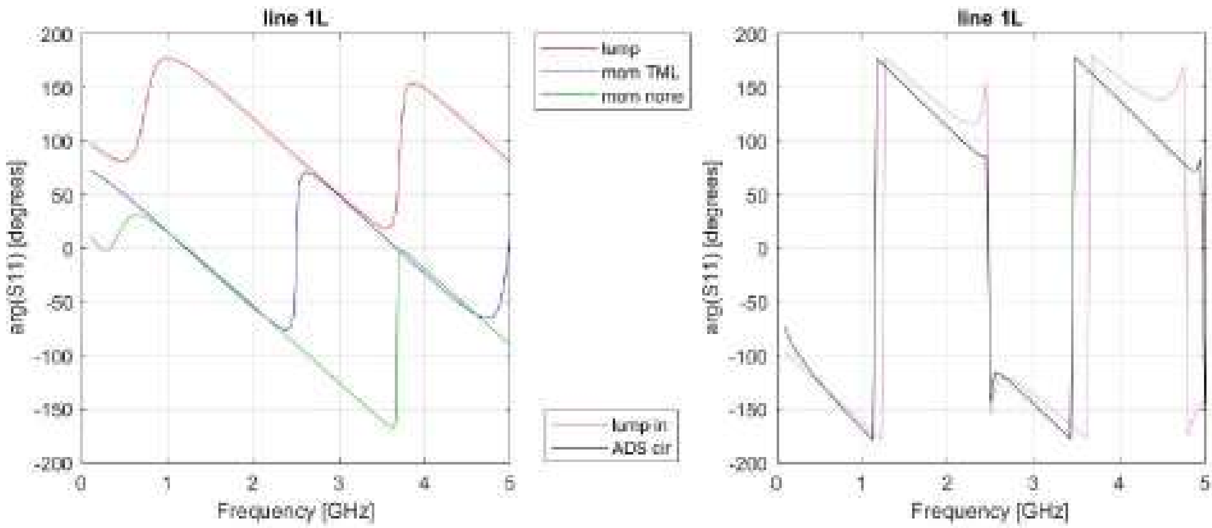


Figure 15: On the common chart, obtained the results of the S_{11} phase for a line of length **L**.

2.2 Line $\approx$ 31.5 Ω, strip twice as wide

2.2.1 ADS and Momentum

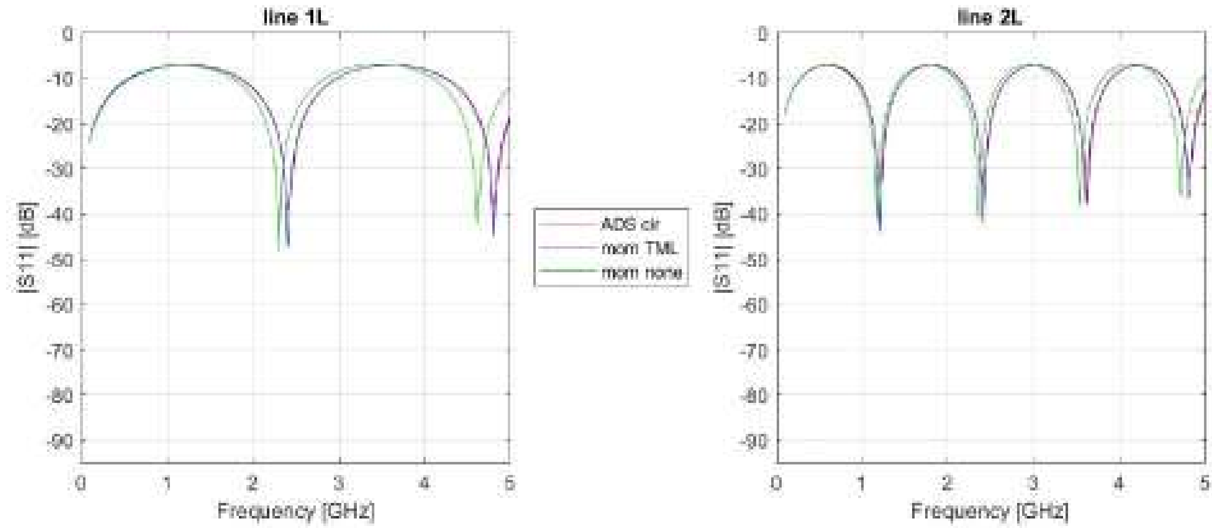


Figure 16: Obtained characteristics of the S_{11} module for the line length **L** and length **2L**.

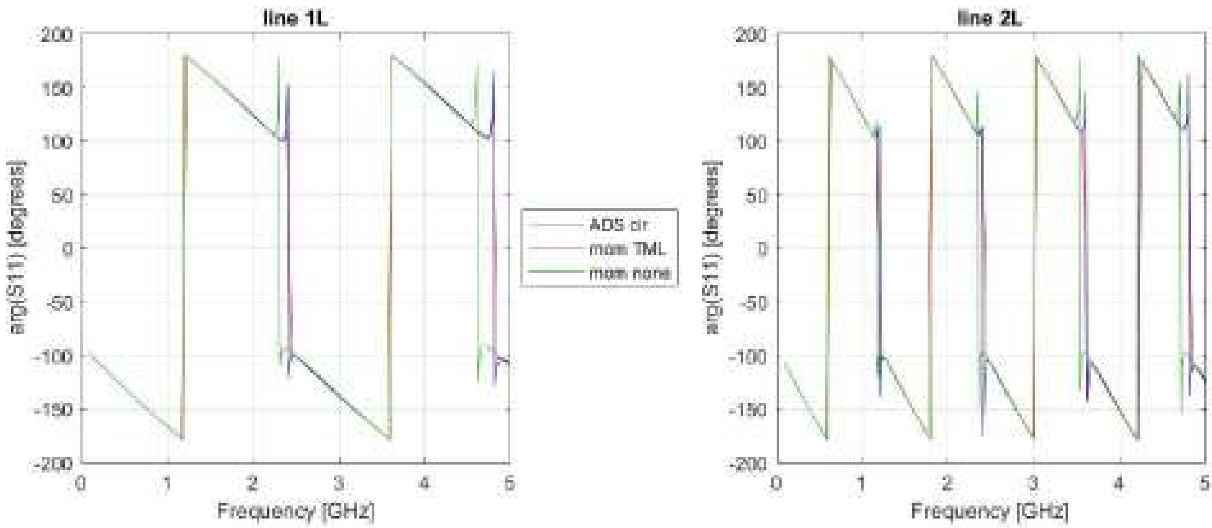


Figure 17: Obtained characteristics of the S_{11} phase for the line length **L** and length **2L**.

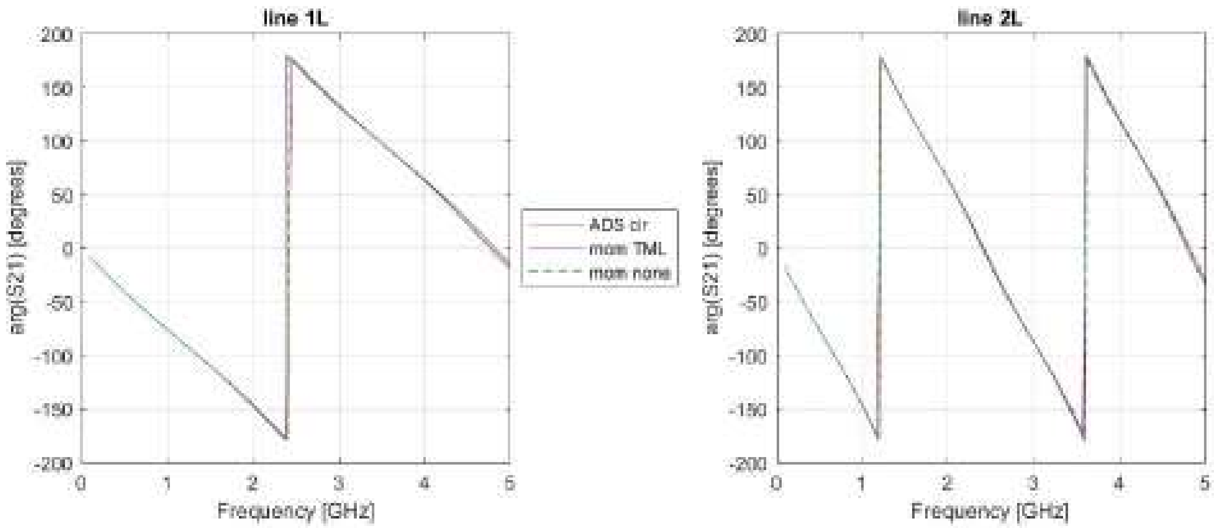


Figure 18: Obtained characteristics of the S_{21} phase for the line length **L** and length**2L**.

2.2.2 IventSim

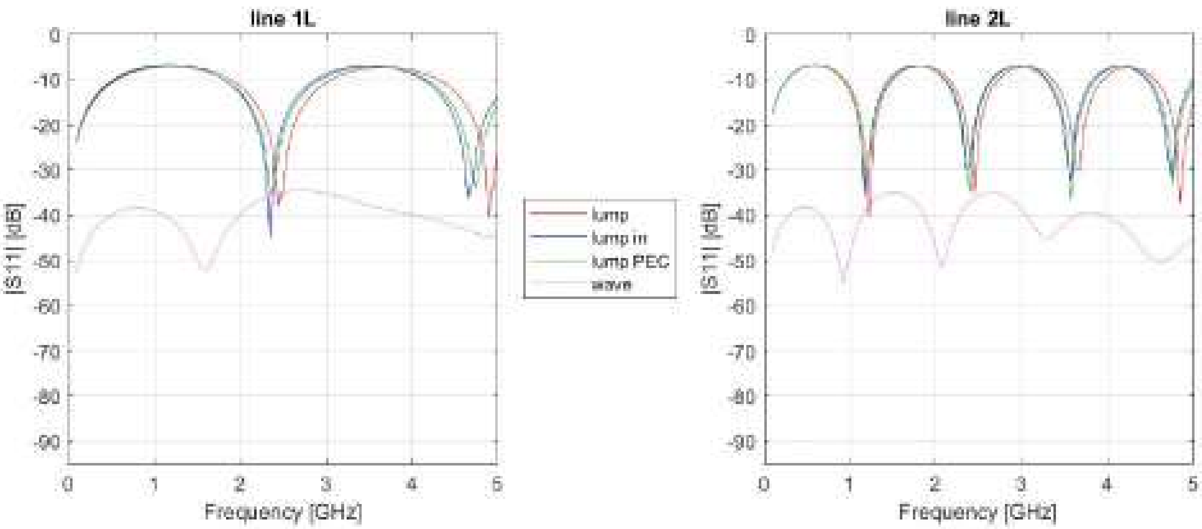


Figure 19: Obtained characteristics of the S_{11} module for the line length **L** and length **2L**.

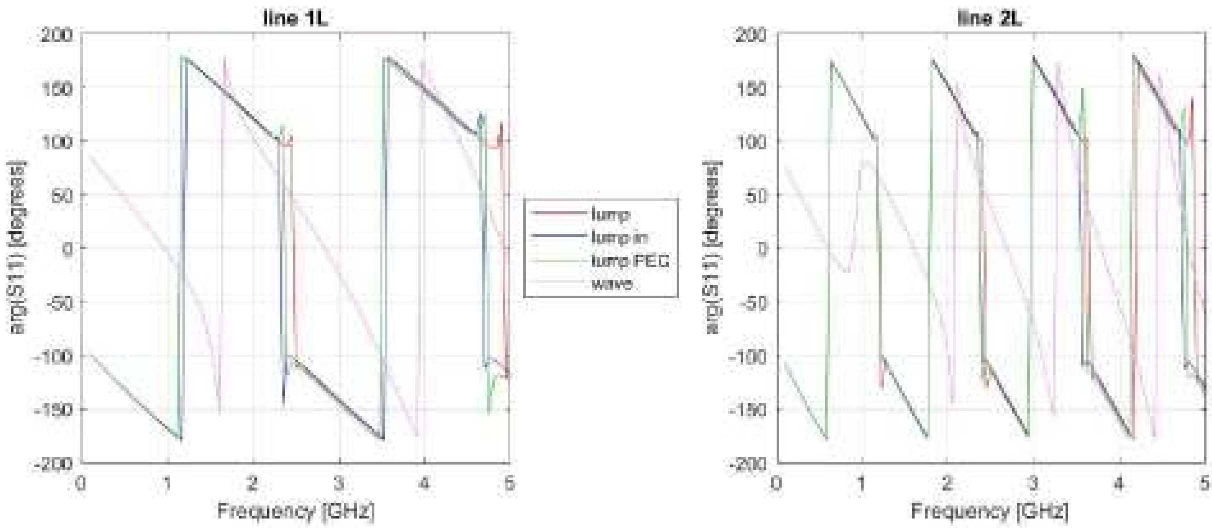


Figure 20: Obtained characteristics of the S_{11} phase for the line length **L** and length **2L**.

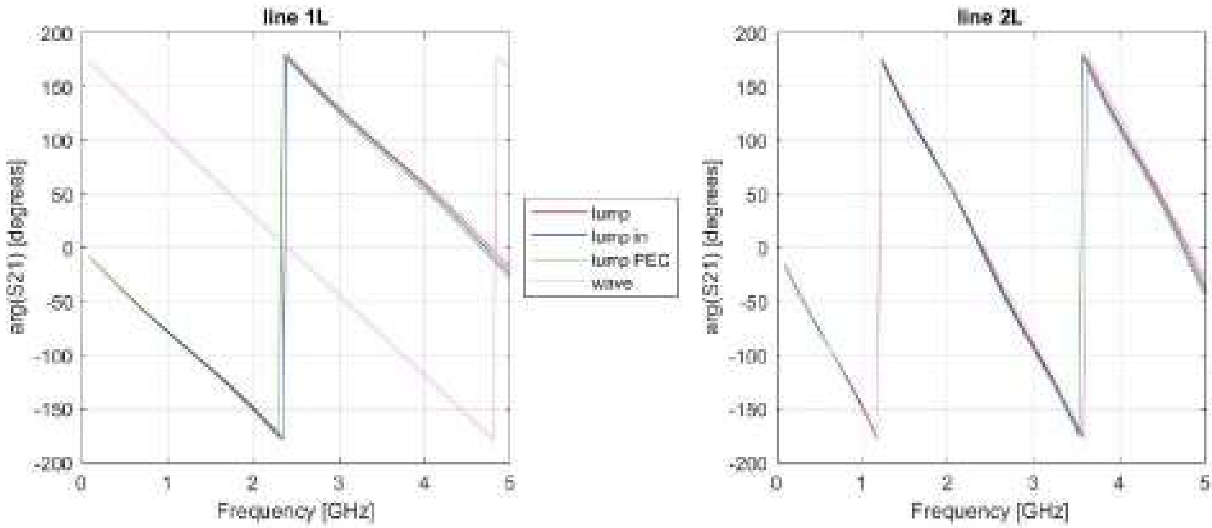


Figure 21: Obtained characteristics of the S_{21} phase for the line length **L** and length**2L**.

A match was obtained for the wave port. This is due to the fact that for a wave solution matrix S is normalized to impedance line, while in case of lump port matrix S is normalized to 50Ω (or other depending on the user defined), so as we can see that the line is not matched to the lump port.

3 De-embedding - implementation double delay method

The results of simulation obtained will be used during the calibration procedure. In the case of the ideal transmission line, the connection of two lines from the length **L** to the cascade is the same as the line with the length of **2L**. However, due to the discontinuity of the port to the line, some impedance or admittance was attached, which can be represented as follows:

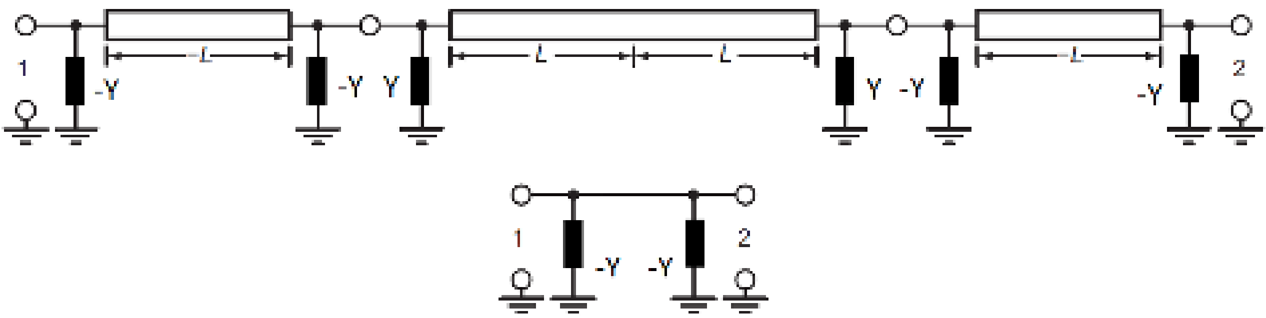


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Figure 22: It will pull out, the impedance responsible for the discontinuity can be obtained by adding a line with a negative length [3].

In the first place on the implementation this method, it should be changed matrix S (for line L,2L and DUT) on matrix ABCD. This is to conveniently combine the systems into a cascade. Next, analyzing circuit diagrams in the Figure 22, can be replaced with a matrix equation system in the form:

$$\begin{bmatrix} A_{2Port} & B_{2Port} \\ C_{2Port} & D_{2Port} \end{bmatrix}_{2Port}^{-1} = \begin{bmatrix} A_L & B_L \\ C_L & D_L \end{bmatrix}_{L}^{-1} \begin{bmatrix} A_{2L} & B_{2L} \\ C_{2L} & D_{2L} \end{bmatrix}_{2L} \begin{bmatrix} A_L & B_L \\ C_L & D_L \end{bmatrix}_{L}^{-1} \quad (1)$$

To get the value of „2Port" matrix (error box of responding characteristics discontinuity double port), we transform the equation:

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port}^{-1} \begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port}^{-1} = \begin{bmatrix} A_{2Port} & B_{2Port} \\ C_{2Port} & D_{2Port} \end{bmatrix}_{2Port}^{-1} \quad (2)$$

When we assume that in both ports I have an identical system of discontinuities, then the matrix for a single is square root of the „2Port" matrix. During the implementation, a Matlab function was used $X = sqrtm(A)$. If we have discontinuity characteristics for a single port, it should be used de-embedding. It is a technique to remove this discontinuity from DUT.

$$\begin{bmatrix} A_{de} & B_{de} \\ C_{de} & D_{de} \end{bmatrix}_{de} = \begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port}^{-1} \begin{bmatrix} A_{DUT} & B_{DUT} \\ C_{DUT} & D_{DUT} \end{bmatrix}_{DUT} \begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port}^{-1} \quad (3)$$

The resulting matrix called „de" should be transformed to matrix S in order to obtain the characteristics of the calibrated system.

3.1 Calibration results - test method

Our goal is to calibrate the port lump in InventSim. However, we first check the correctness of the implementation of the code written in Matlab's. For this purpose, tests were carried out using the results from the circuit simulation with ADS. The following subsections present two example tests (the others analogous have been included in the appendix).

To test the implemented method, we attach to the line (from the ADS circuit simulation) the known load (which will be responsible for the discontinuity of the port). In this way, we will be able to save them later in the form of an ABCD matrix and try to delete in the de-embedding process. The reference in this case will be the perimeter simulation with ADS.

3.1.1 ADS circuit analysis

Circuit simulation there is no port discontinuity, because the solution is described in the form of an analytical approached model. In this case calibration is not needed. The effect of the double-delay calibration is presented below.

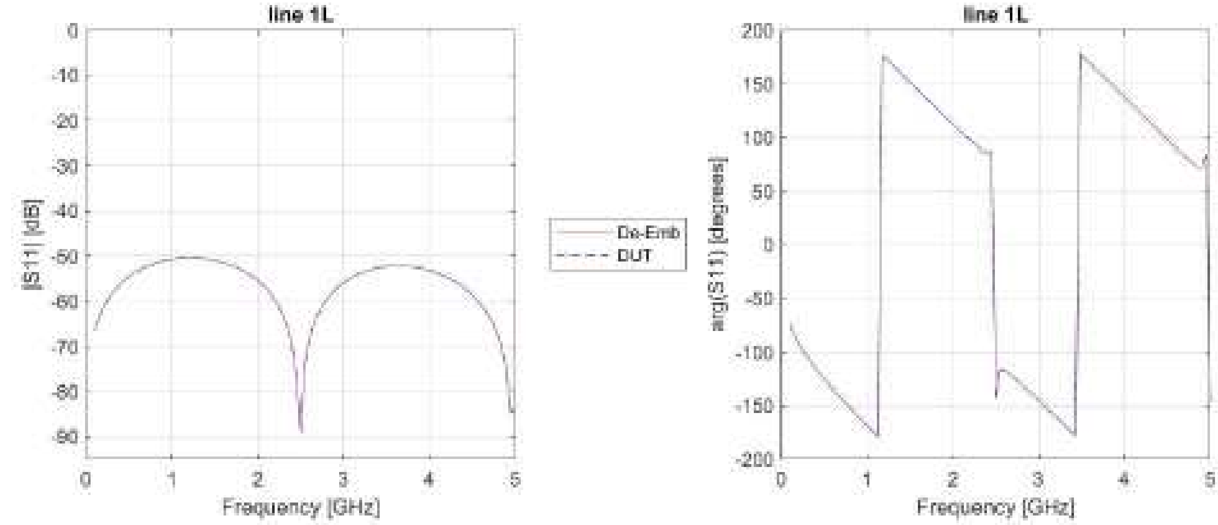


Figure 23: S_{11} reflectance characteristics before and after line length **L** calibration.

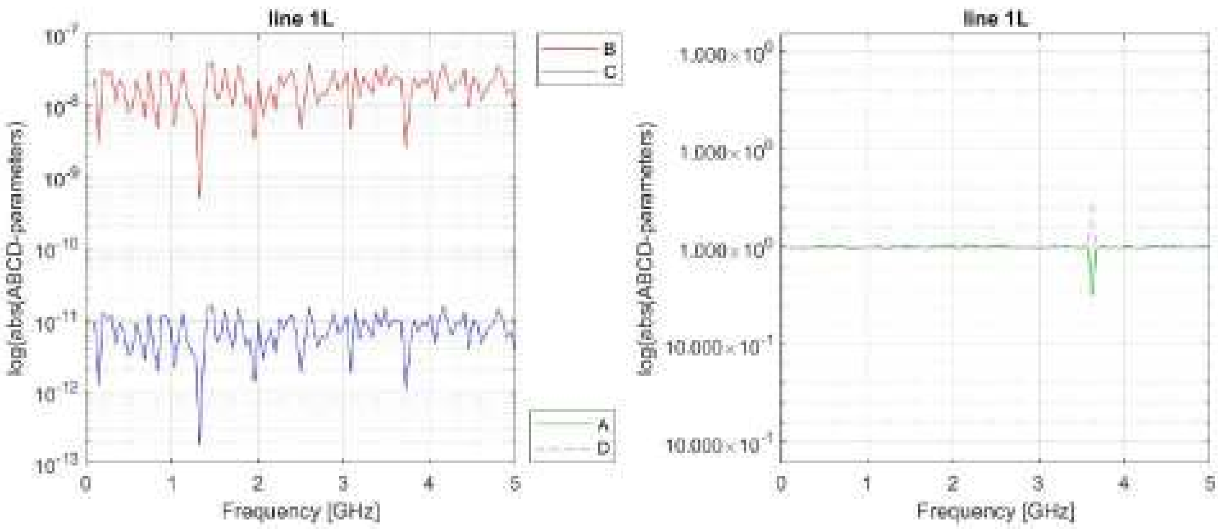


Figure 24: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{port} \approx \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{4}$$

This is confirmed by the „Port” matrix, where $Y_{Shunt} = 0$ and $Z_{Series} = 0$. In this case, the calibration process does not change the characteristics of the system.

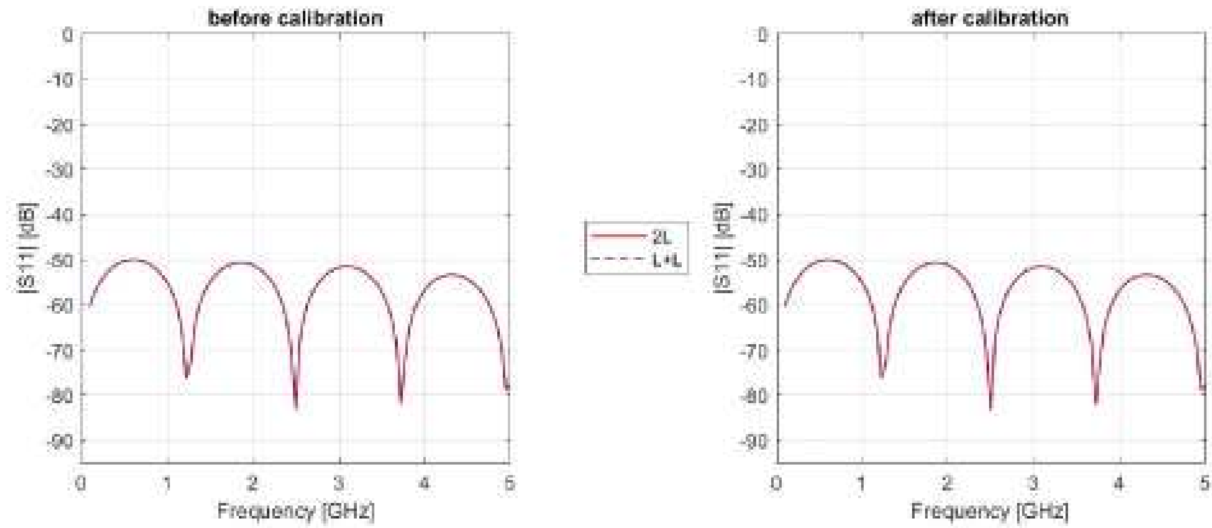


Figure 25: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

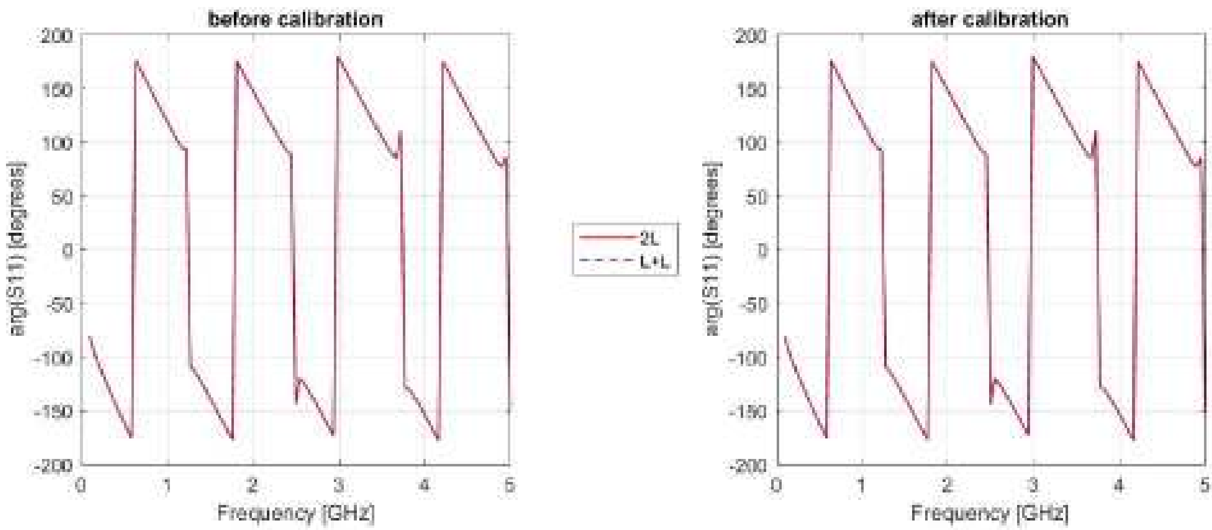


Figure 26: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

3.1.2 ADS circuit analysis with a single load attached

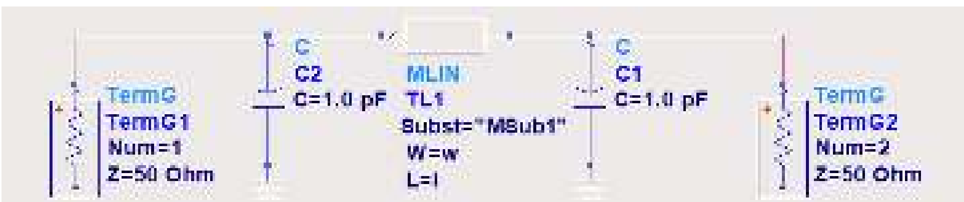


Figure 27: DUT - line with length **L**, 50Ω and shunt capacity equal $1pF$.

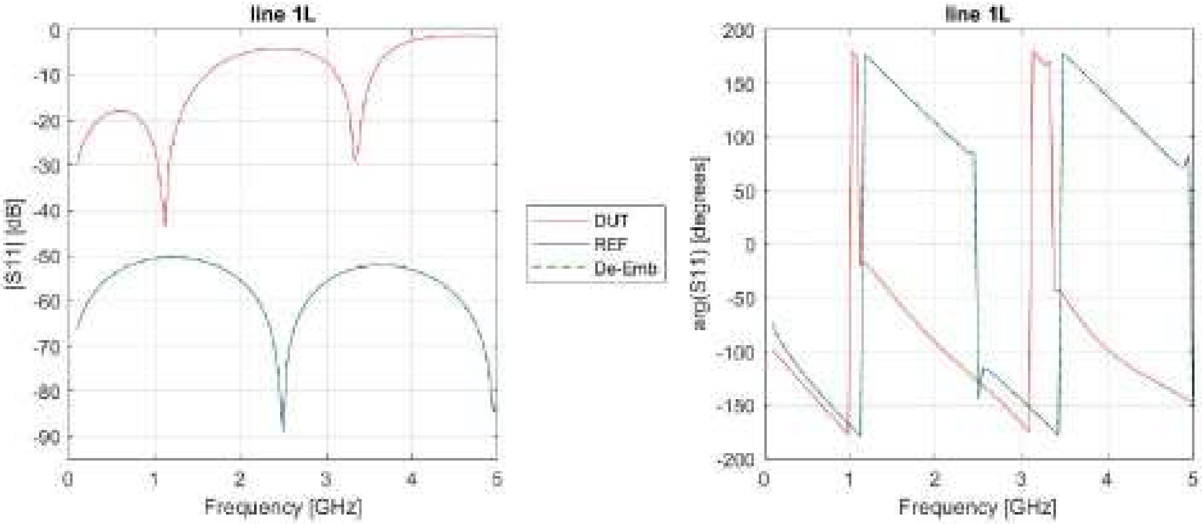


Figure 28: S_{11} reflectance characteristics before and after line length **L** calibration.

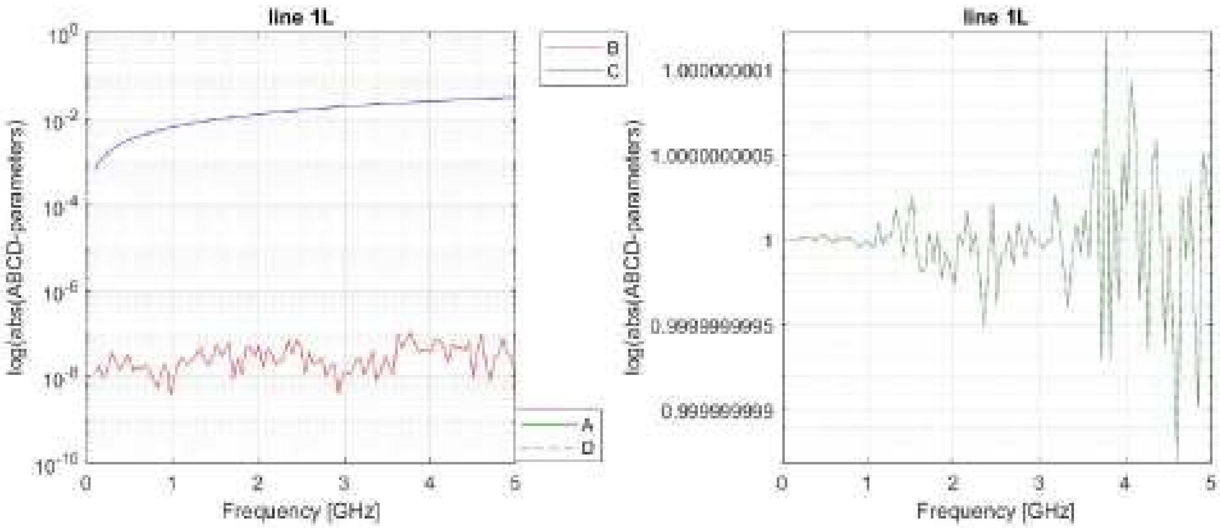


Figure 29: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port} \approx \begin{bmatrix} 1 & 0 \\ j\omega C_{1,2} & 1 \end{bmatrix}_{Shunt} \tag{5}$$

Analysing the above results, $C_{Port} = j\omega C_{1,2}$, where $C_{1,2} = 1pF$ calibration was successful and we managed to extract the added capacity and get the characteristics of the line itself.

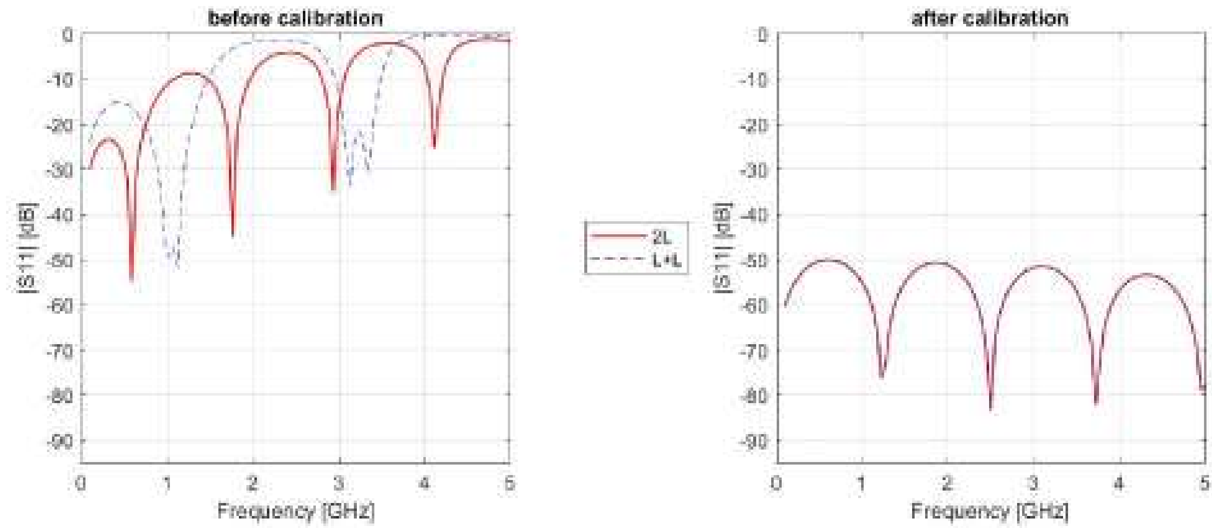


Figure 30: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

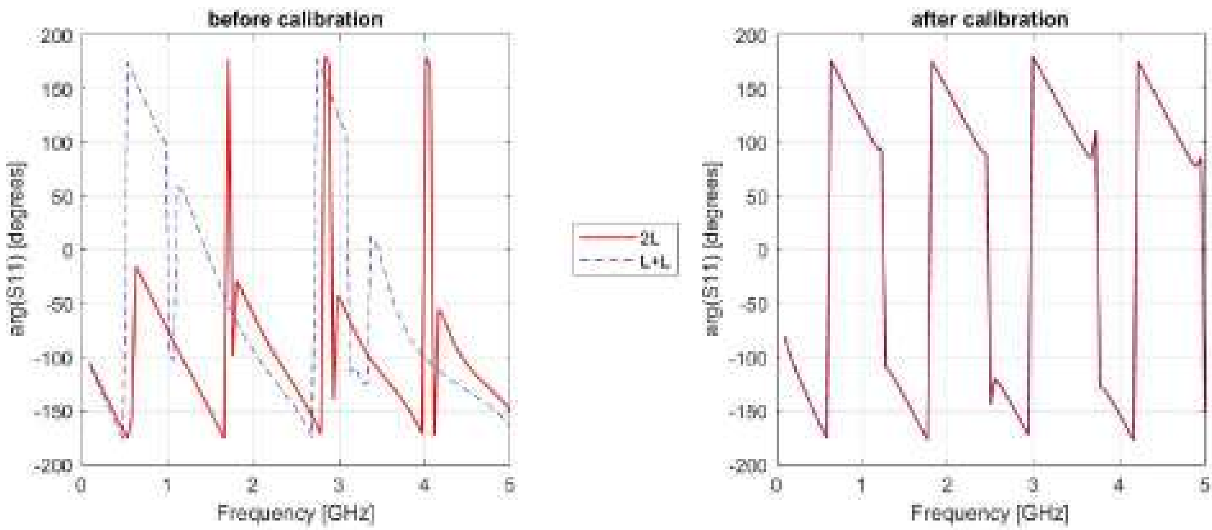


Figure 31: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

3.1.3 ADS circuit analysis with a double load attached

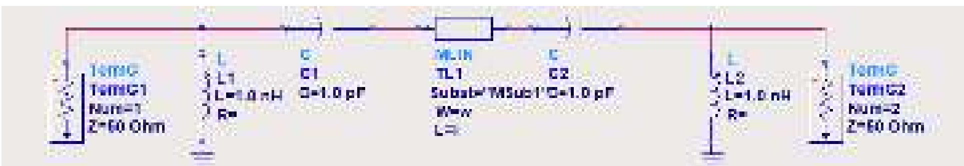


Figure 32: DUT - line with length **L**, 50Ω and shunt inductance equal 1nH and seriers capacity equal $1pF$.

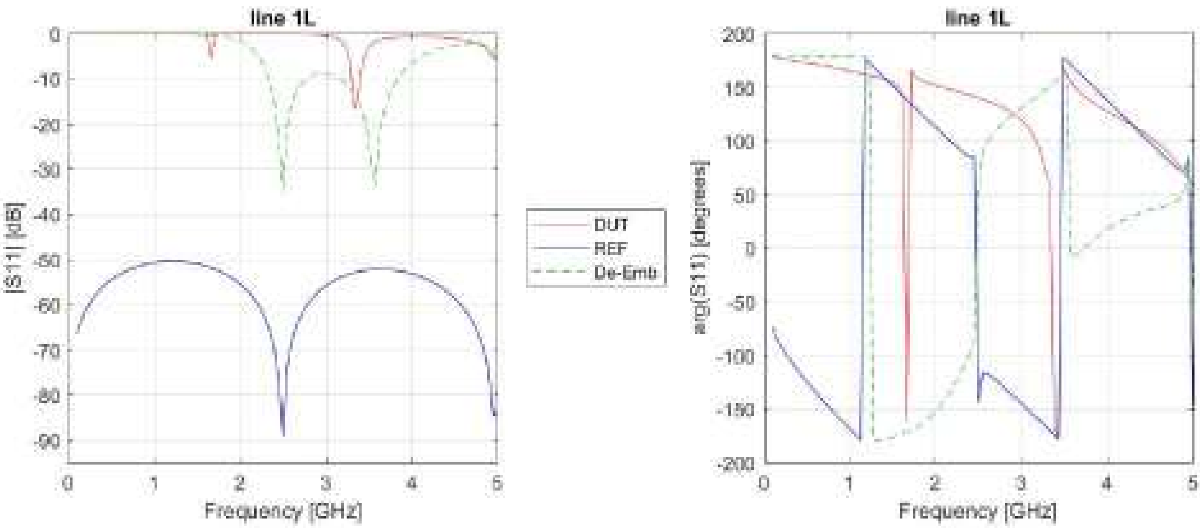


Figure 33: S_{11} reflectance characteristics before and after line length **L** calibration.

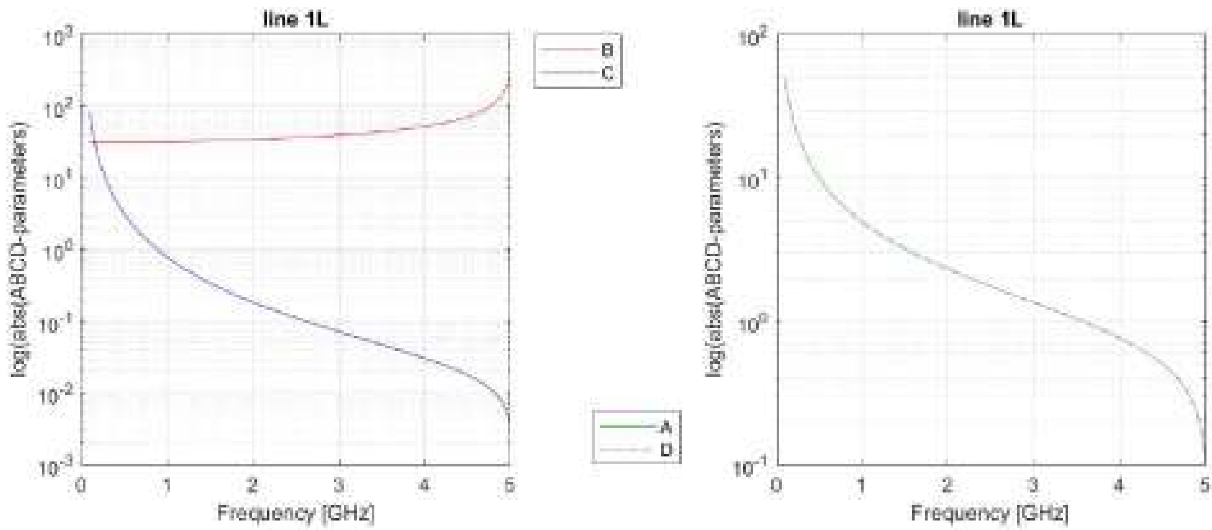
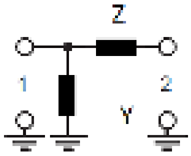


Figure 34: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

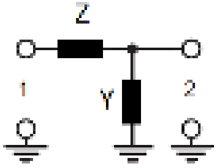
Analysing the above results, calibration was not successful. The obtained matrix is difficult to define clearly in the frequency function. One does not appear on the diagonal.

The obtained results show that the assumption that in both ports I have an identical scheme in the form of an errorBox, in this case is not quite true.

Look at the Figure 3.1.3 you can see it can be seen that the added "discontinuity" consists of a series capacitor connected with a shunt inductance on the left side of the line. On the other side of the line we have a symmetrical system that combines shunt inductance with a series condenser. To present these schemes in the form of an ABCD matrix with the definition of two-port network we obtain:



$$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} = \begin{bmatrix} 1+ZY & Z \\ Y & 1 \end{bmatrix} = A$$



$$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & Z \\ Y & 1+YZ \end{bmatrix} = B$$

As you can see, the order of elements in the case of joining two elements is important. Having a dual port matrix to obtain a single port matrix, the equation system should be solved, looking for the value of Y, Z.

$$AB = \begin{bmatrix} 2YZ+1 & 2Z \\ 2Y(YZ+1) & 2YZ+1 \end{bmatrix} \text{ and } BA = \begin{bmatrix} 2YZ+1 & 2Z(YZ+1) \\ 2Y & 2YZ+1 \end{bmatrix}$$

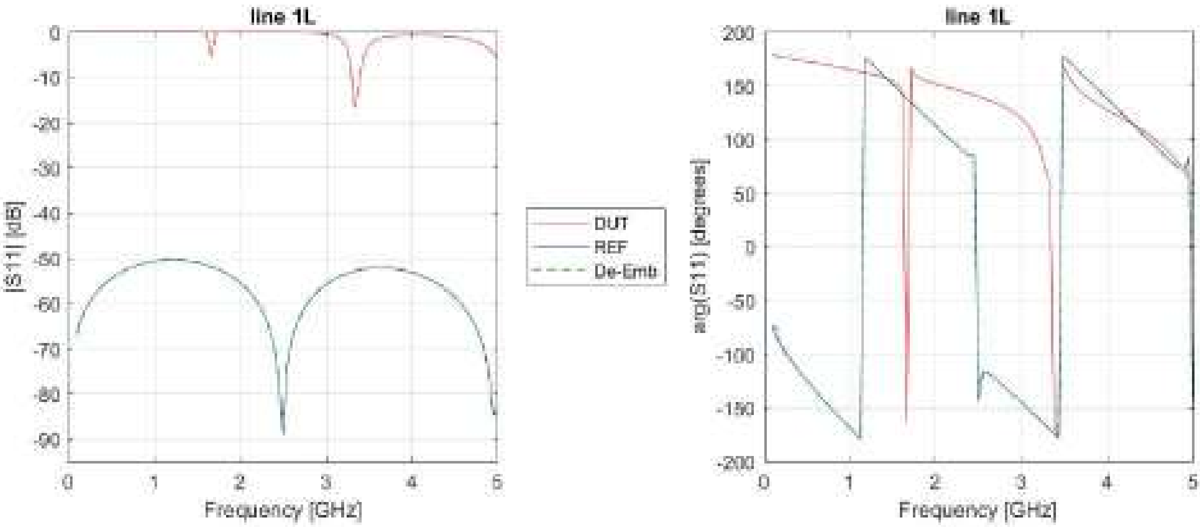


Figure 35: S_{11} reflectance characteristics before and after line length **L** calibration (double port double load attached predictive method).

Analyzing the above results, calibration was successful, because we have seen what ABCD matrix looks like in frequency function.

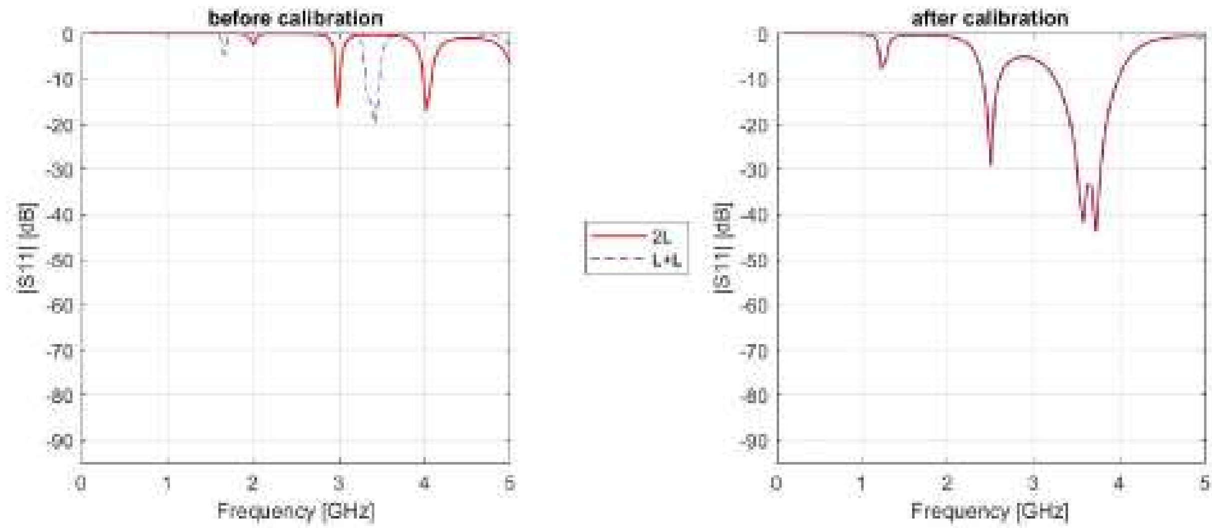


Figure 36: The test checking the characteristics of the S_{11} module before and after the calibration (square root of the matrix method), in the case of connecting the line **L** to the cascade and the line **2L**.

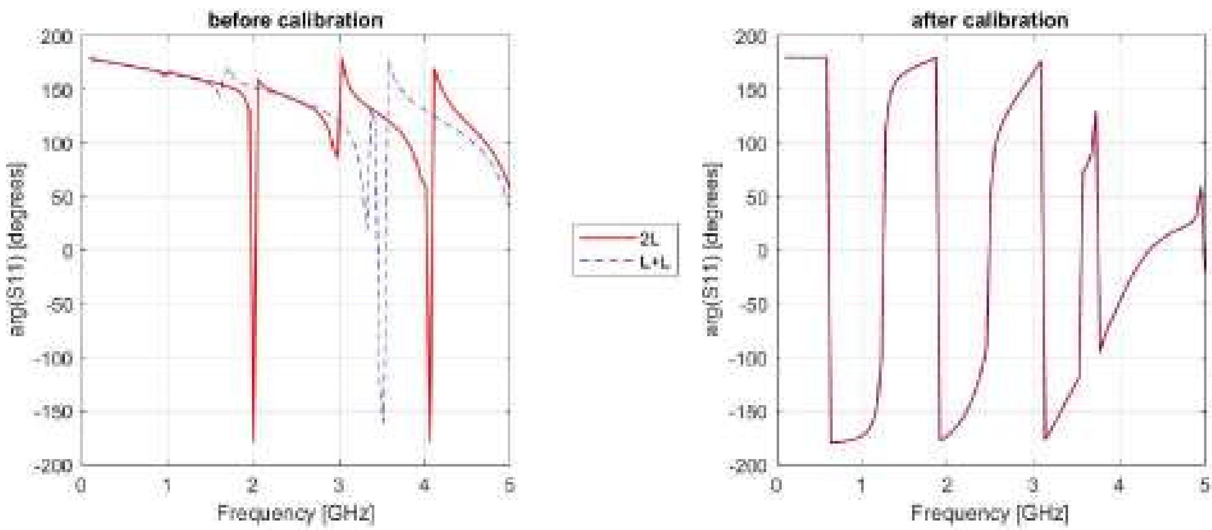


Figure 37: The test checking the characteristics of the S_{11} phase before and after the calibration (square root of the matrix method), in the case of connecting the line **L** to the cascade and the line **2L**.

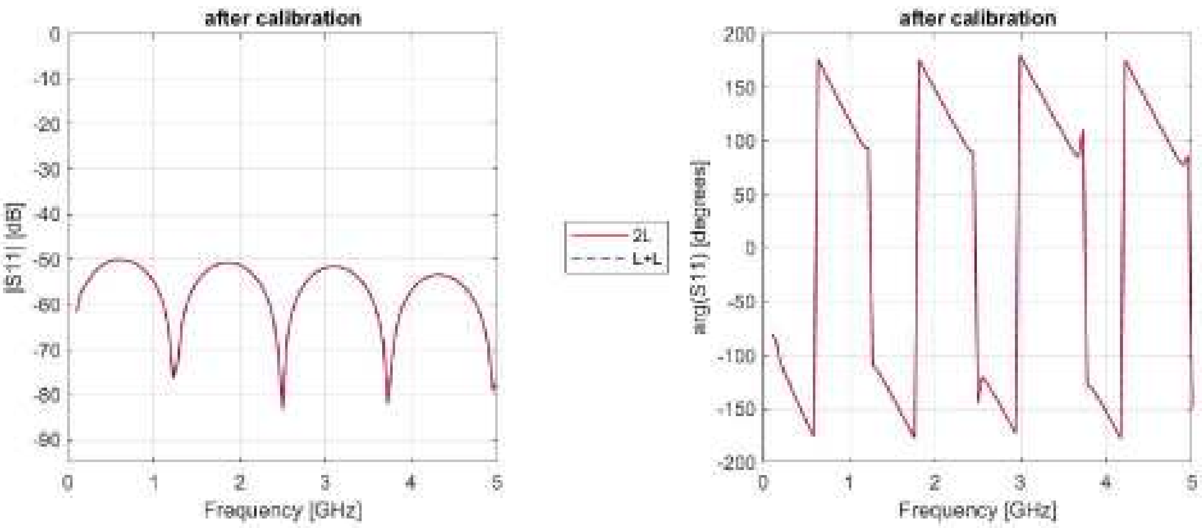


Figure 38: The test checking the characteristics of the S_{11} after the calibration (double port double load attached predictive method), in the case of connecting the line **L** to the cascade and the line **2L**.

As you can see after calibration with the **L,2L** method, we always get a convergence between line with length **L plus L** and line with length **2L** results. This is one of the forms confirming the correctness of the implementation method, but it does not confirm that the system is fully calibrated.

3.2 Calibration of the lump port in InventSim

In this section the calibration results for simulation the microstrip line in InventSim will be presented. Our DUT is microstrip line length L.

3.2.1 Lump port on the side wall

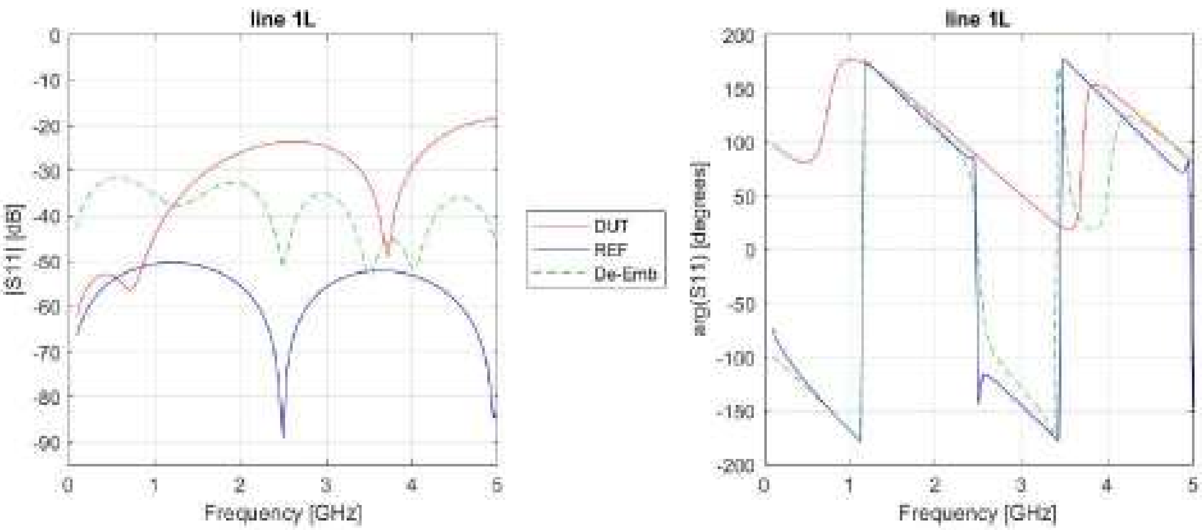


Figure 39: S_{11} reflectance characteristics before and after line length **L** calibration.

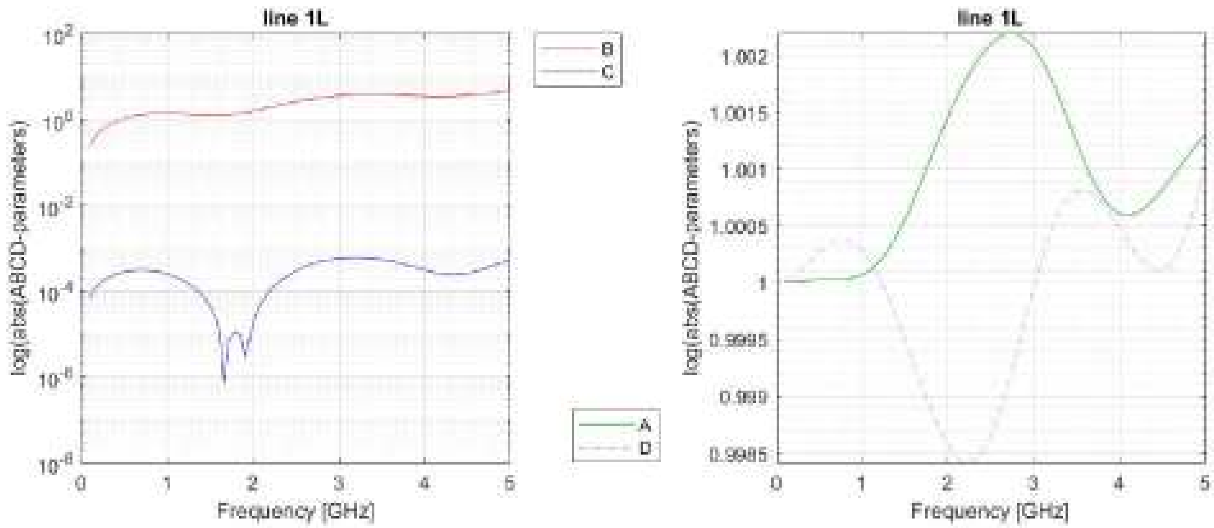


Figure 40: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

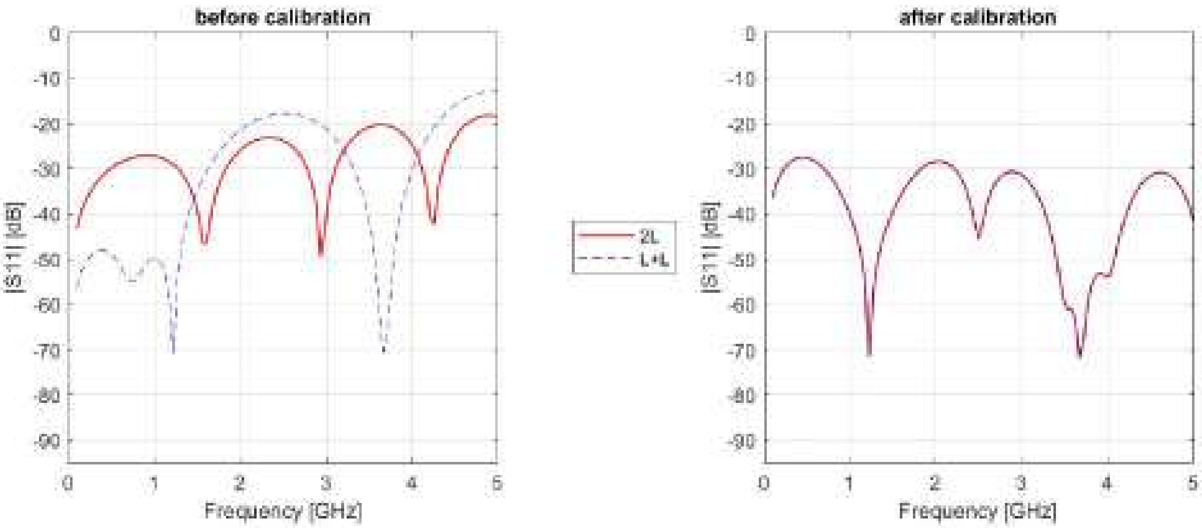


Figure 41: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

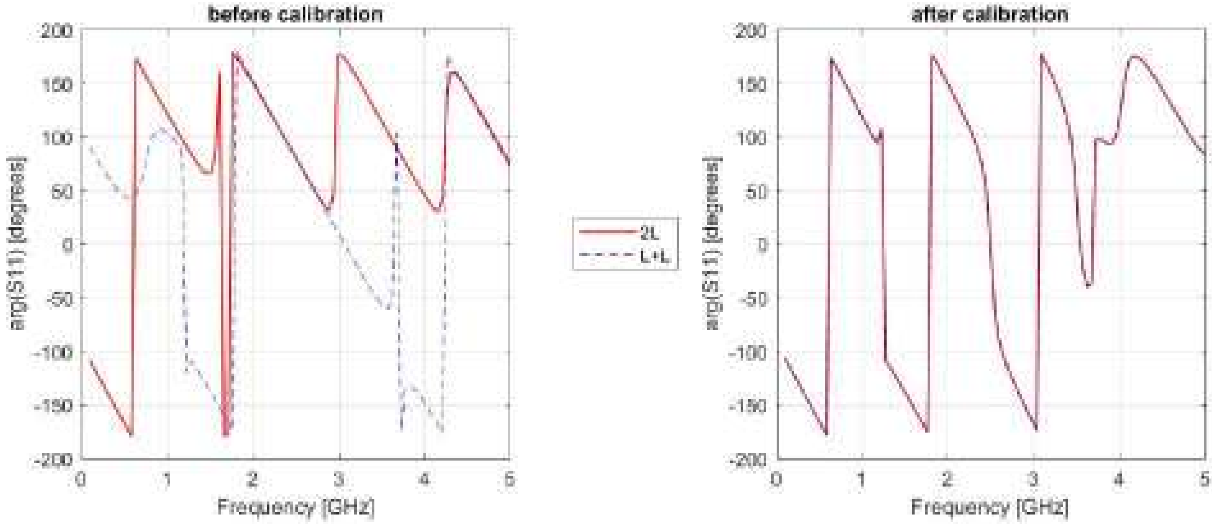


Figure 42: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

3.2.2 Lump port on the side wall internal line

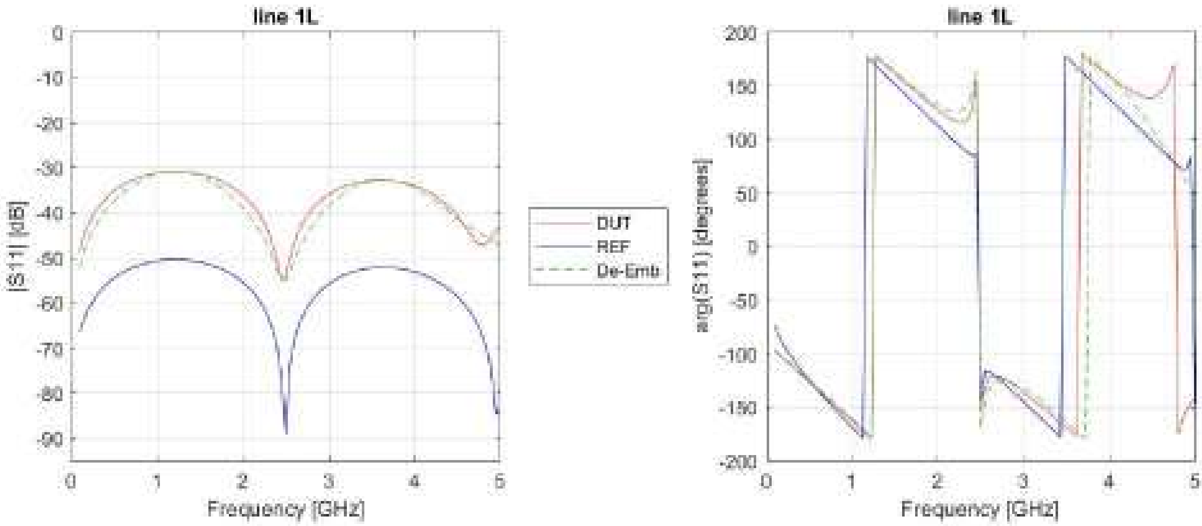


Figure 43: S_{11} reflectance characteristics before and after line length **L** calibration.

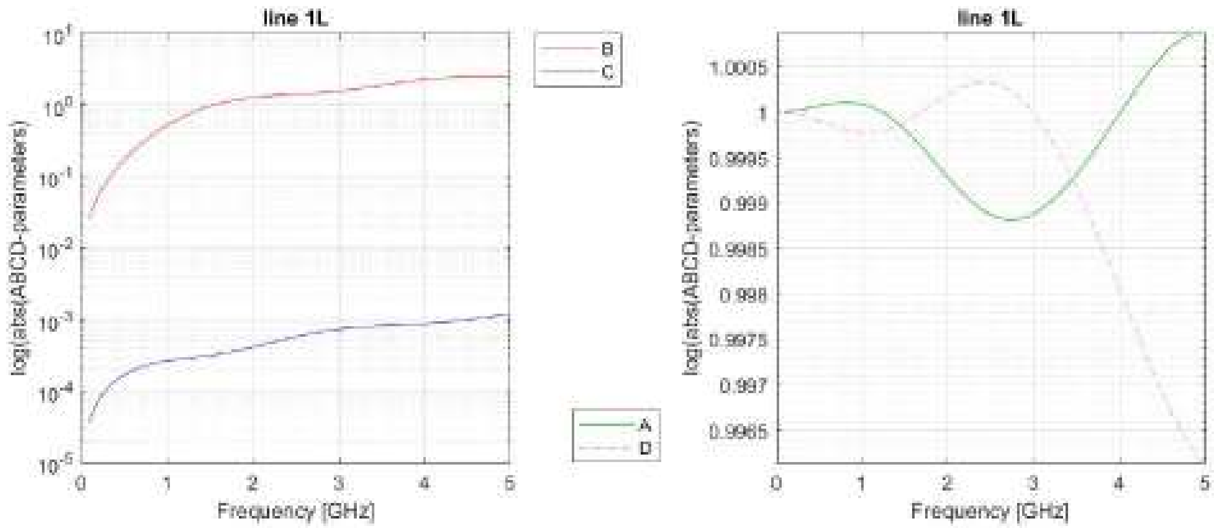


Figure 44: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

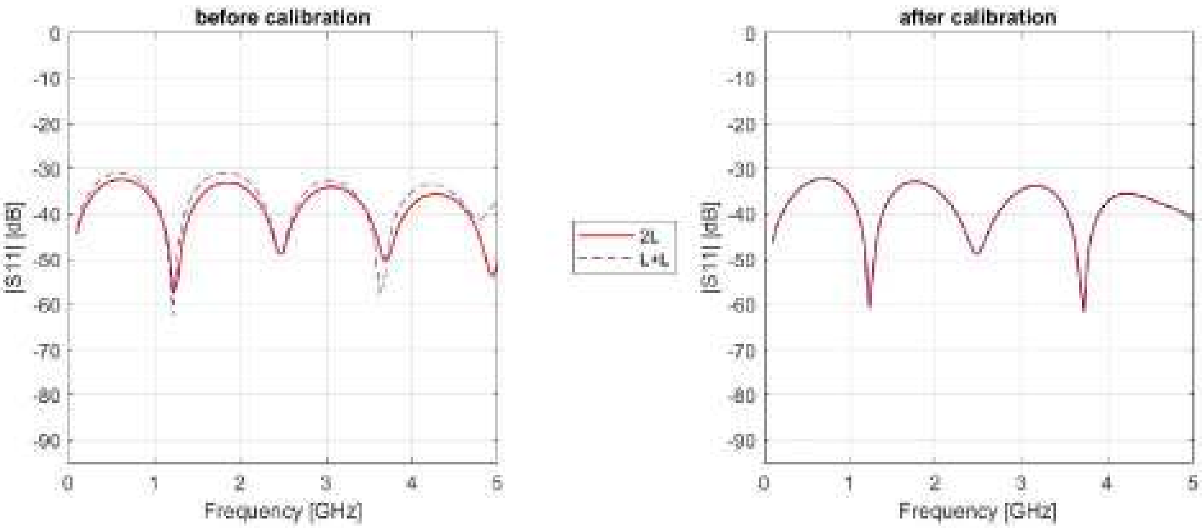


Figure 45: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

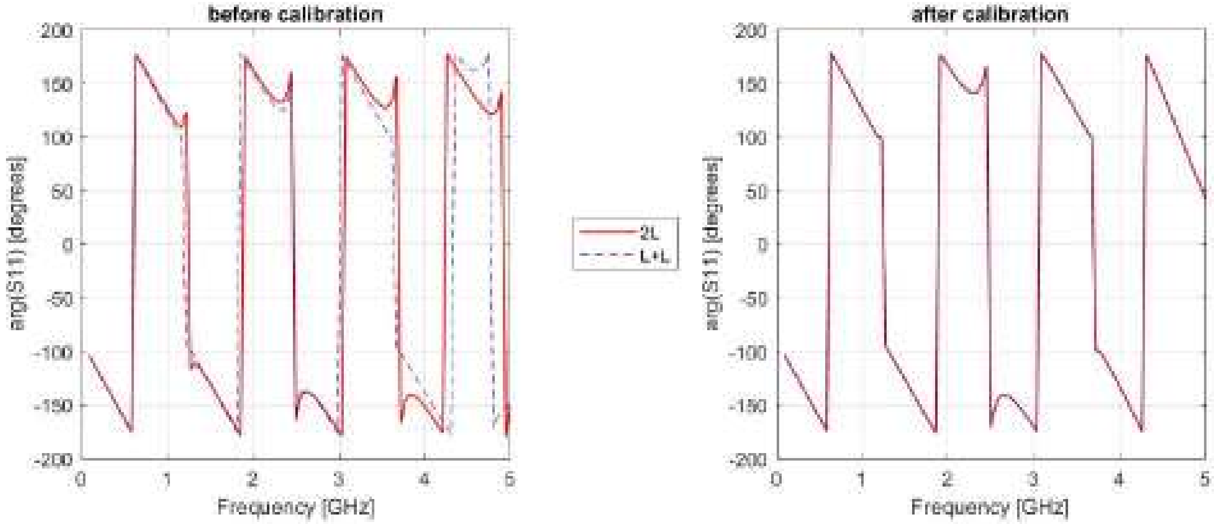


Figure 46: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

3.2.3 Lump port between the inside stripe and the side wall (PEC) outside

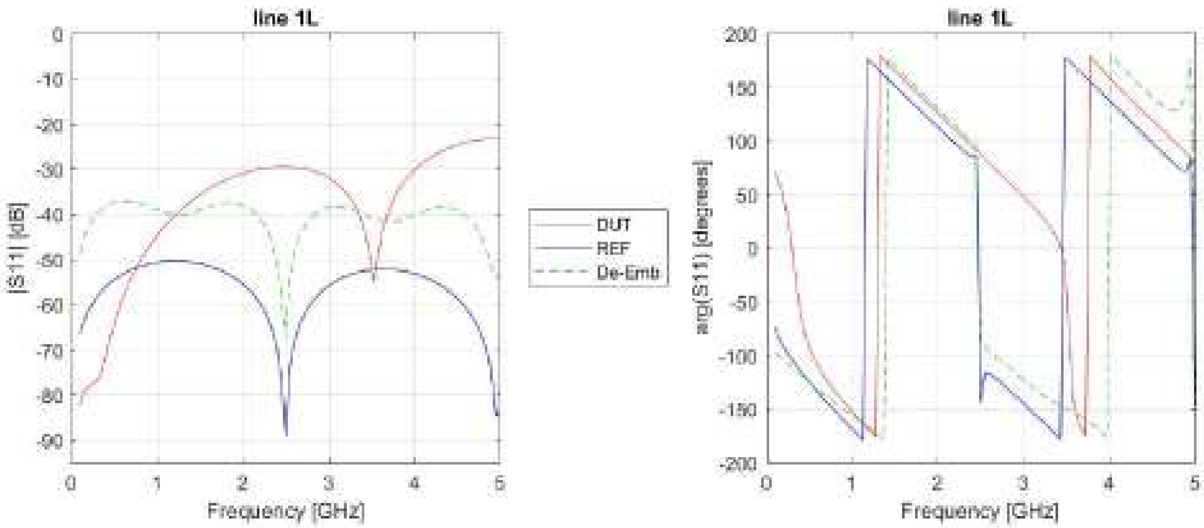


Figure 47: S_{11} reflectance characteristics before and after line length **L** calibration.

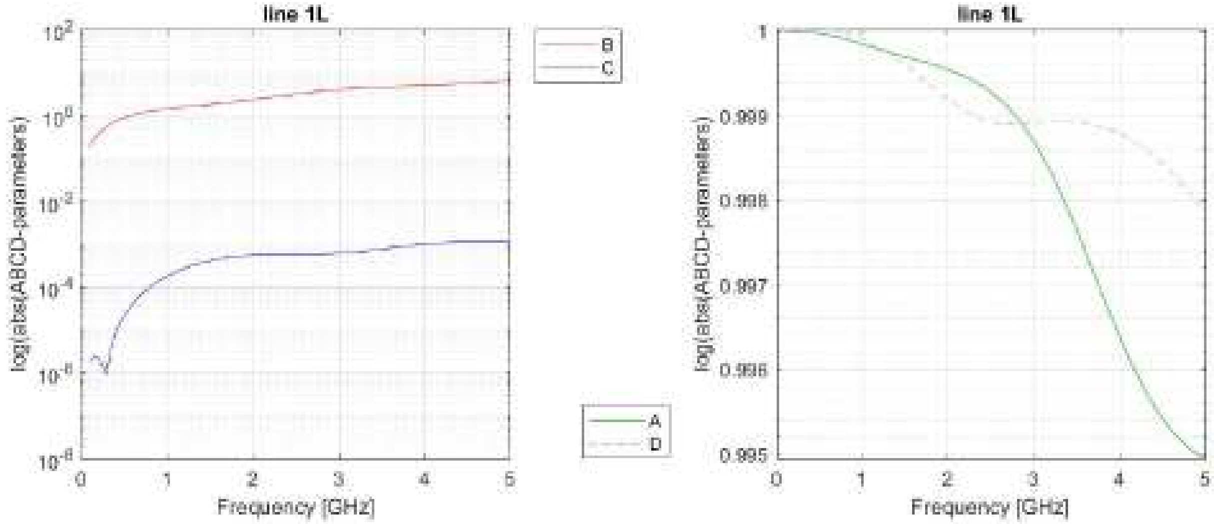


Figure 48: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

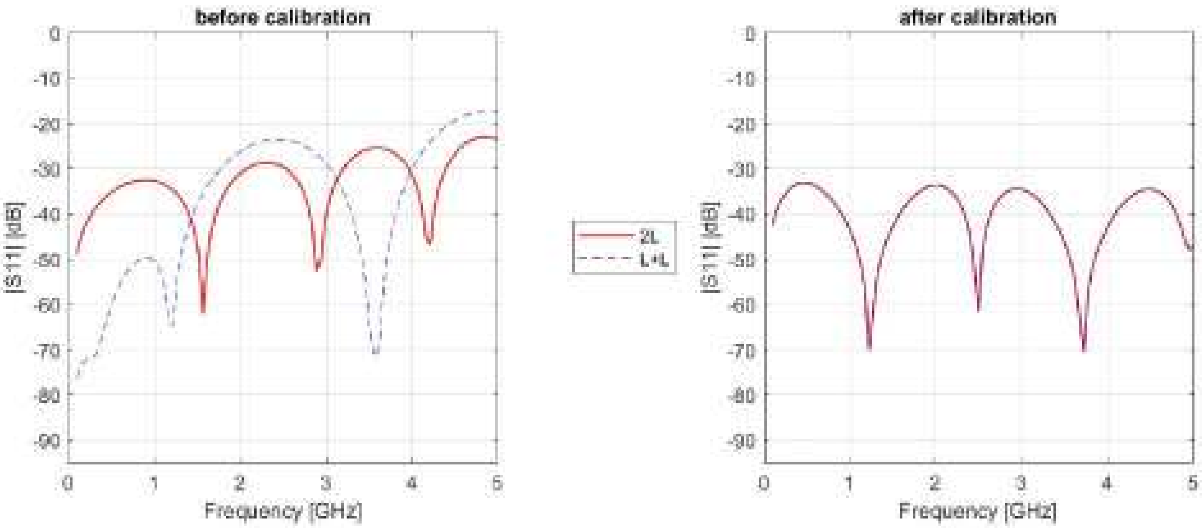


Figure 49: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

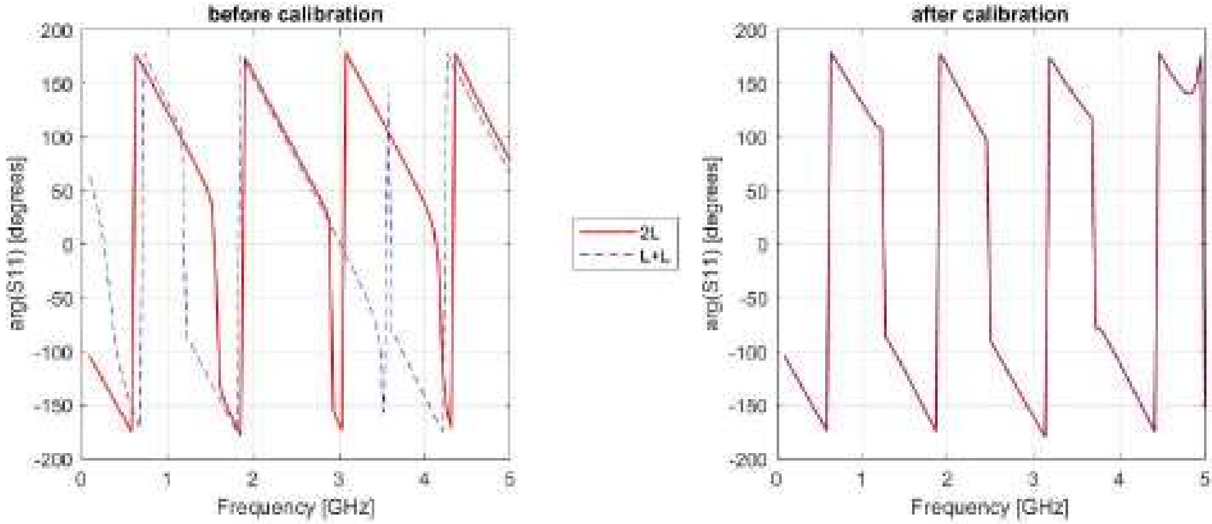


Figure 50: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

In all three cases as we can see calibratioc gave better match and approaching to some extent reference be. On the diagonal of the double port matrix ABCD, the value close to one appears, but these values are not perfectly equal to one. As a result, the DUT (line length L) has not been fully calibrated. The discontinuity is a form of an unknown system, but it is similar to one dominant element (of a high value that has been eliminated). The smallest correct was obtained in lump port on the side wall internal line, where the match is quite good before calibration.

4 Conclusion

In the case of TEM lines, the characteristic impedance is constant (does not change in frequency) and e.g for the coaxial line, the results are convergent in other cases the lumped port should be calibrated. Our calibration goal is the lump port in InventSim, in waveguides with the quasi-TEM wave (microstrip line). The classic double Delay method assumes that the port discontinuity is pure admittance, which is why the overall calibration effect can not always give an improvement. This is due to the fact In the general case, we are not able to pull out parameters for a single port. This is because on both sides of the port we have the same schema of discontinuities, but it is symmetrical to each other. After combining such systems into a cascade, we get a dual port matrix. To obtain a single port matrix (for any matrix) we get 3 equations with 4 unknowns. The only possibility at this time for this **L, 2L** method is to predict what kind of discontinuity is present in the port (eg. whether it is a serial or shunt connection) - then you can get an improvement in the calibration result. However, this is problematic in the case of InventSim. In the next part of the work, other methods of software calibration will be tested, e.g. (TRL, TML or SOC) [4]

References

[1] Ke Wu, Sheng Sun, Lin Li, Liang Han, Lei Zhu, and C.K. Michael Tse „The Match Game", IEEE Microwave Magazine (Volume: 17, Issue: 4, April 2016)

[2] J.C.Rautio, V.I.Okhmatovski „Unification of Double-Delay and SOC Electromagnetic Deembedding", IEEE Transactions on Microwave Theory and Techniques (Volume: 53 , Issue: 9 , Sept. 2005)

[3] James C. Rautio, "High-Frequency and Microwave Electromagnetic Analysis Calibration and De-embedding", CHAPTER 4, Sonnet Software, Inc., North Syracuse, NY, USA

[4] Lei Zhu, Sheng Sun „A Review on Numerical Calibration and De-embedding Techniques in Full-Wave Algorithms", 2015 IEEE International Conference on Computational Electromagnetics

Appendix : Verification of the correctness of the written matlab script

This appendix presents tests that validated the written matlab scripts used during calibration. It will be eliminated possible programming software error during calibration.

A.1 Verification script of cascaded connection of systems

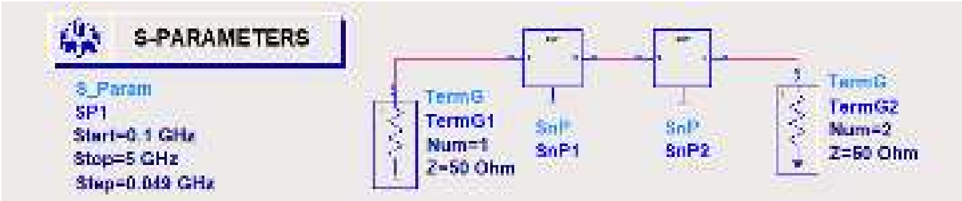


Figure 51: Way of peripheral connection in ADS based on .s2p files.

The script was written in Matlab, to convert the matrix S to the ABCD matrix, and to combine these matrices into a cascade. The obtained results will be compared with the built-in tool in ADS for combining systems into a cascade.

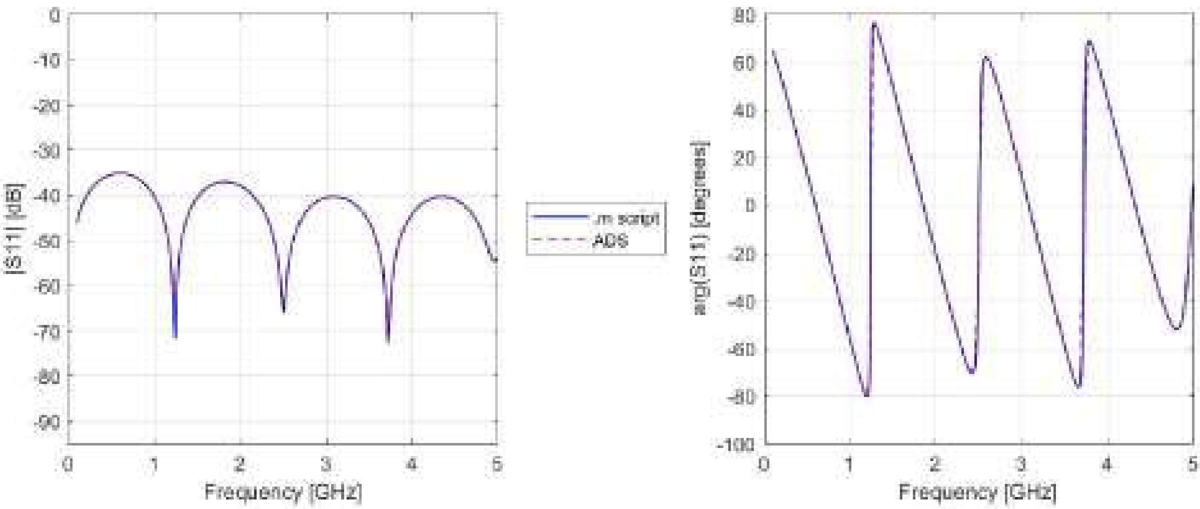


Figure 52: Connection of two lines length **L** with each other in a cascade (based on results from Momentum with calibration TML.)

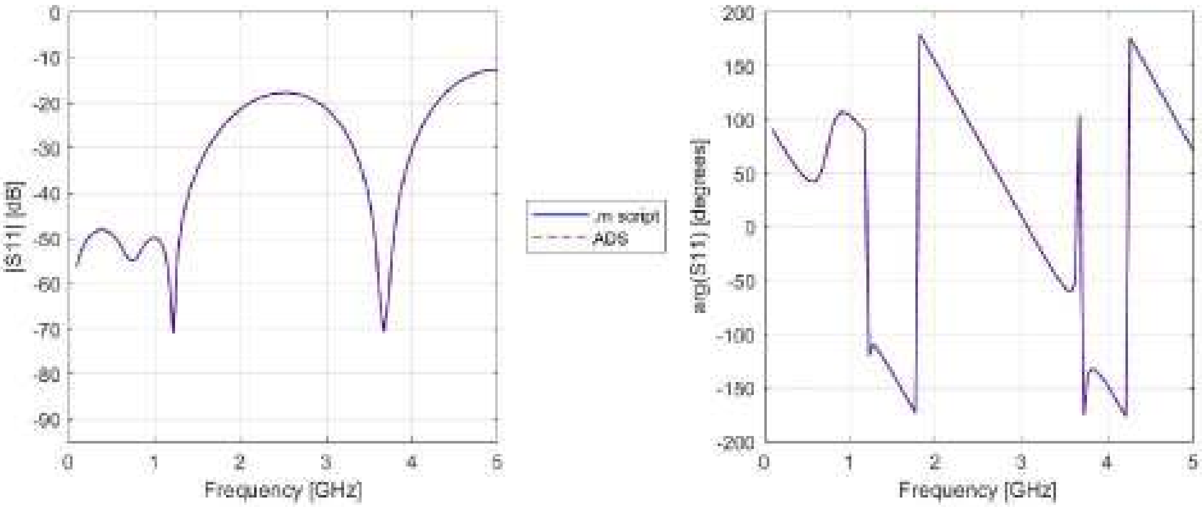


Figure 53: Connection of two length **L** with each other in a cascade (based on results from InventSim, lump port).

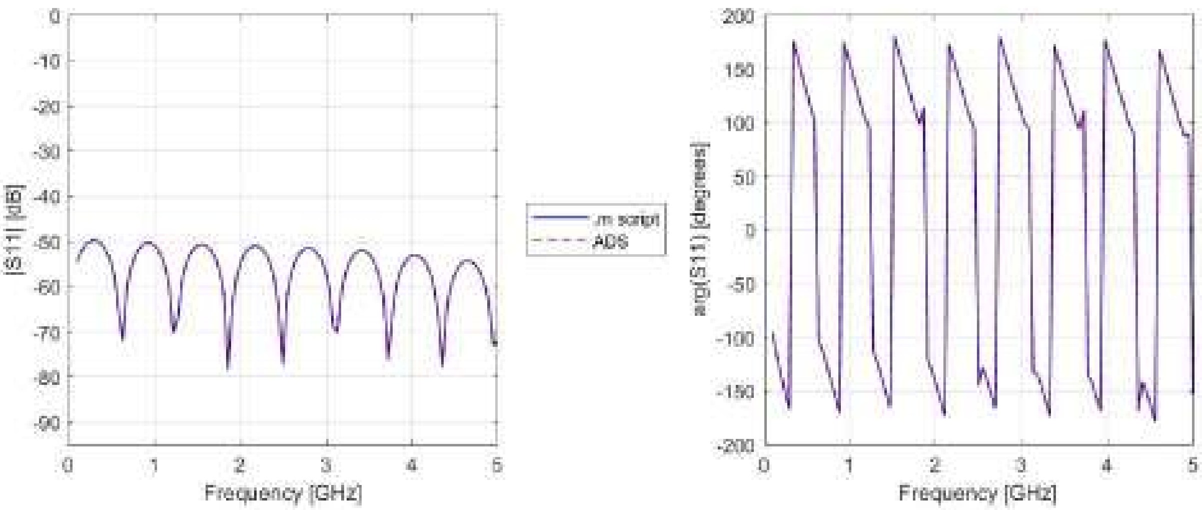


Figure 54: Connection of two length **L** with each other in a cascade (based on results from ADS circuit analysis).

As you can see, the results are convergent, which leads to the conclusion that the script has been implemented correctly.

A.2 Verification of the implementation of the method double delay

The main part of the report presents double delay methody tests. In this appendix, the same tests were shown, in several other combinations, attached as a load simulating the discontinuity of the port.

A.2.1 ADS circuit analysis with a shunt intuctance attached

Figure 55: DUT - line with length **L**, 50Ω and shunt inductance equal $1nH$.

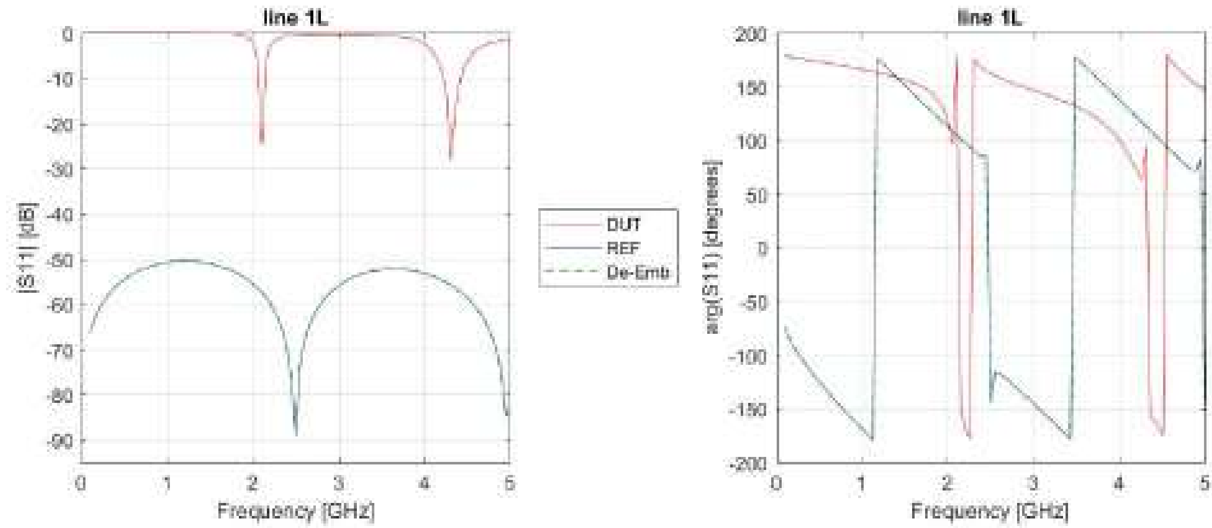


Figure 56: S_{11} reflectance characteristics before and after line length **L** calibration.

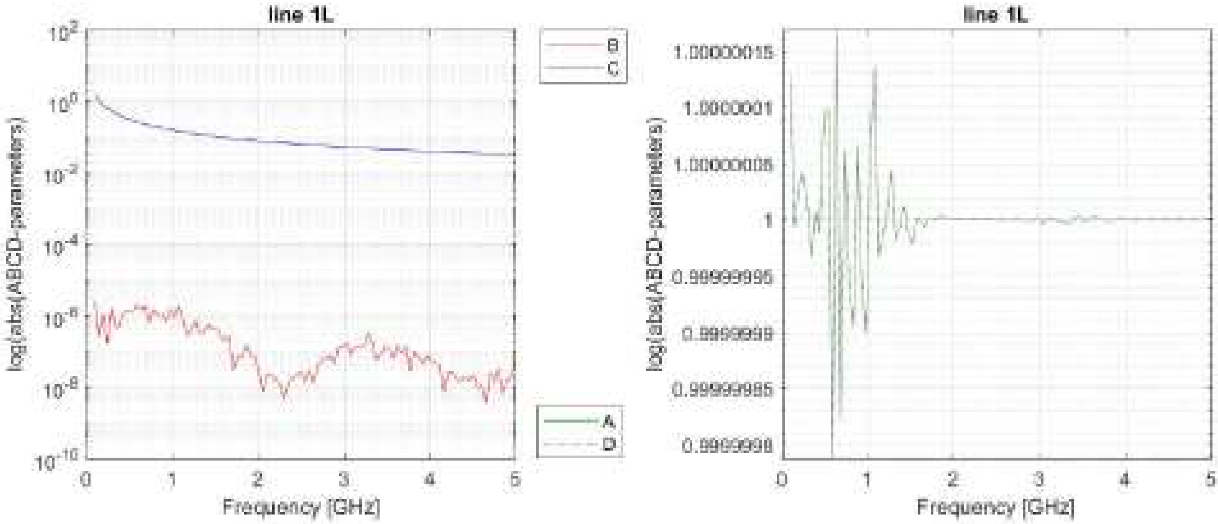


Figure 57: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port} \approx \begin{bmatrix} 1 & 0 \\ \frac{1}{j\omega L_{1,2}} & 1 \end{bmatrix}_{Shunt} \tag{6}$$

Analysing the above results, $C_{Port} = \frac{1}{j\omega L_{1,2}}$, where $L_{1,2} = 1nH$ calibration was successful and we managed to extract the added inductance and get the characteristics of the line itself.

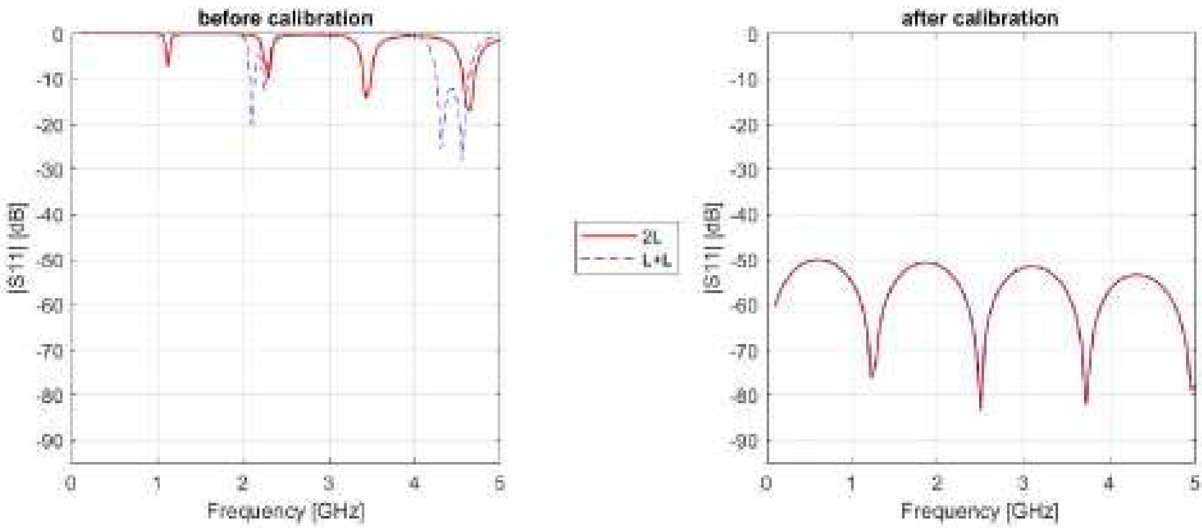


Figure 58: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

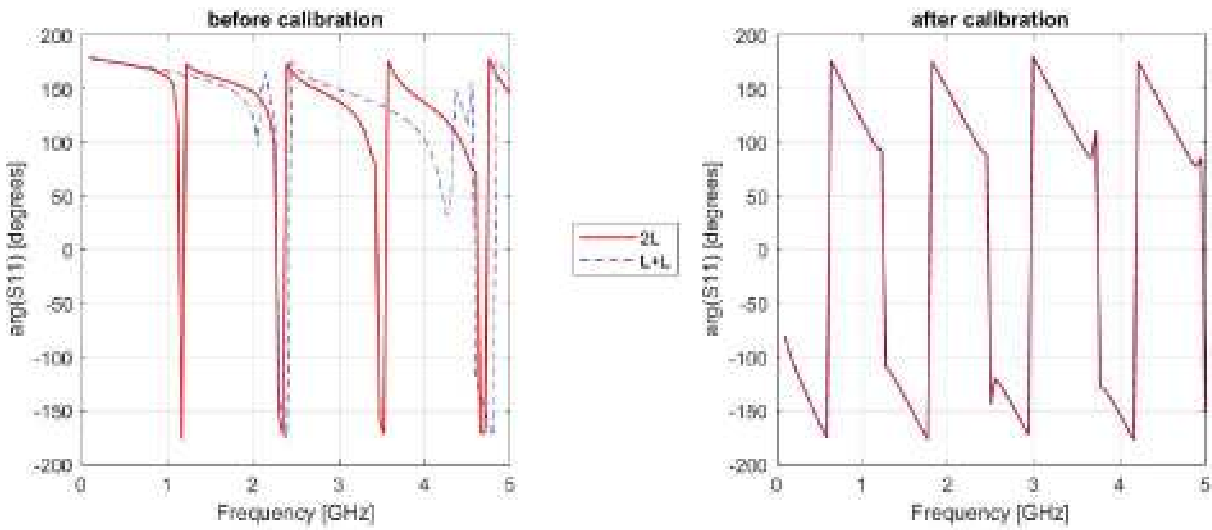


Figure 59: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

A.2.2 ADS circuit analysis with a series capacity attached

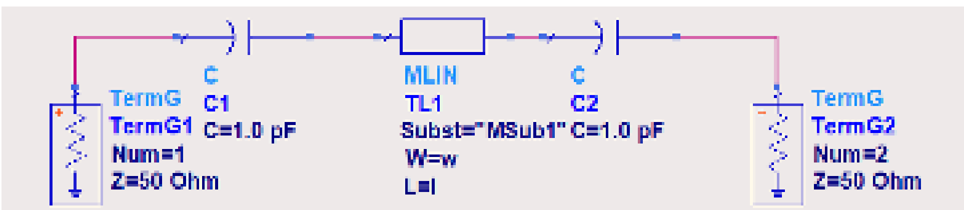


Figure 60: DUT - line with length **L**, 50Ω and series capacity equal $1pF$.

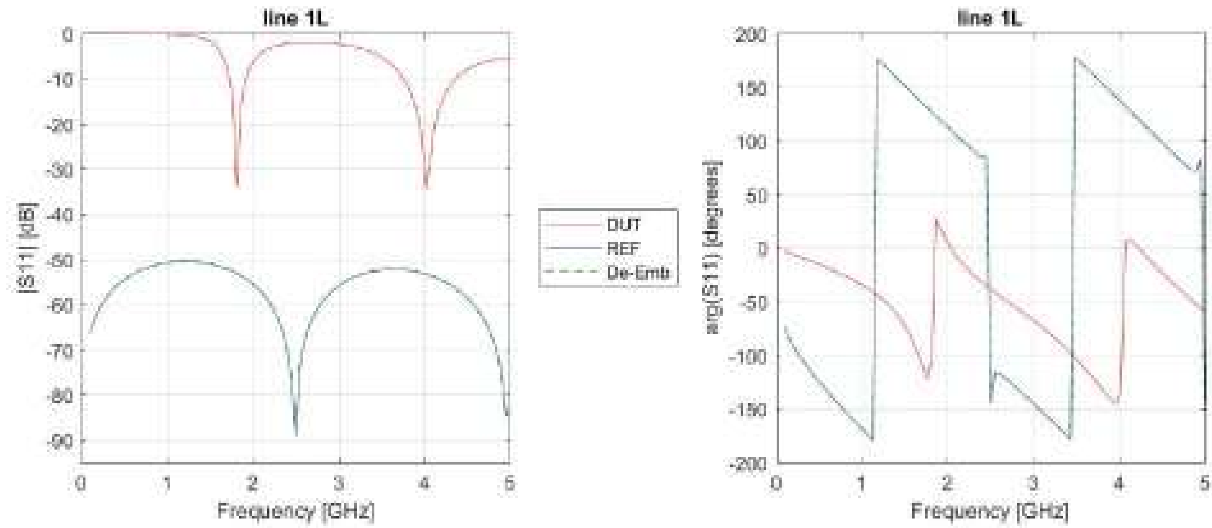


Figure 61: S_{11} reflectance characteristics before and after line length **L** calibration.

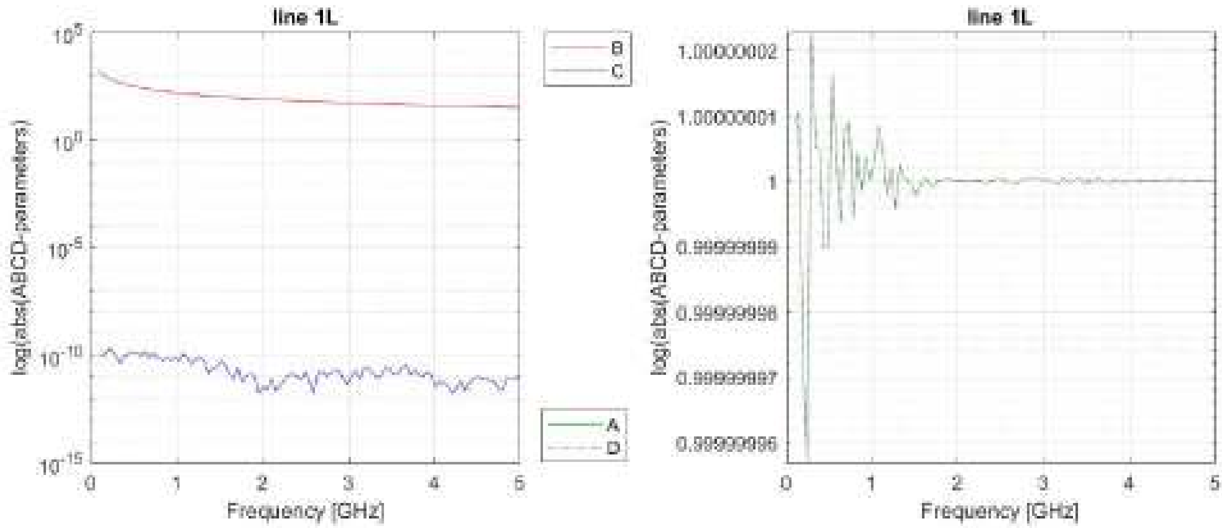


Figure 62: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port} \approx \begin{bmatrix} 1 & \frac{1}{j\omega C_{1,2}} \\ 0 & 1 \end{bmatrix}_{Series} \tag{7}$$

Analysing the above results, $B_{Port} = \frac{1}{j\omega C_{1,2}}$, where $C_{1,2} = 1pF$ calibration was successful and we managed to extract the added capacity and get the characteristics of the line itself.

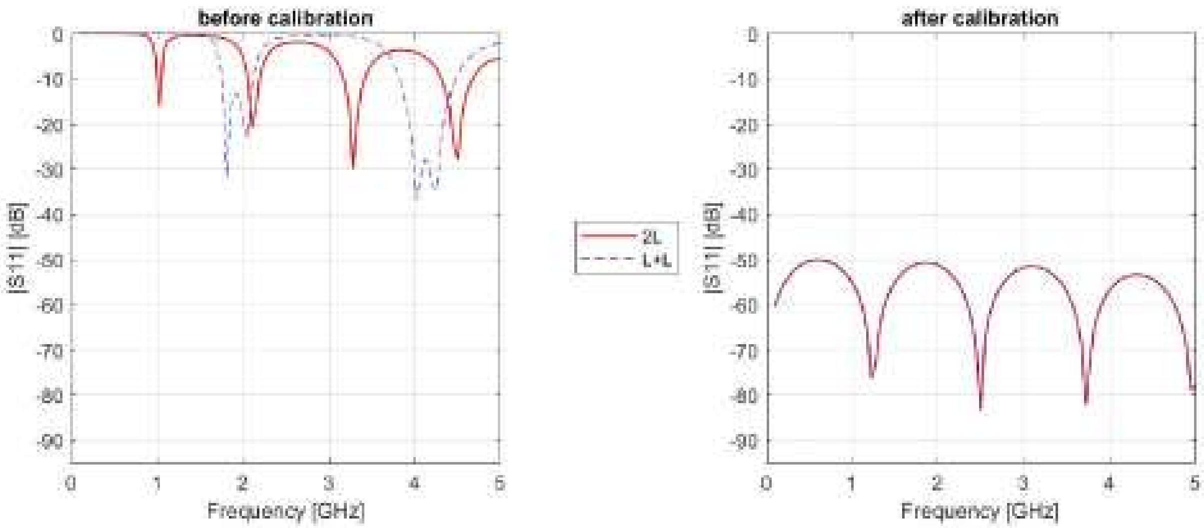


Figure 63: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

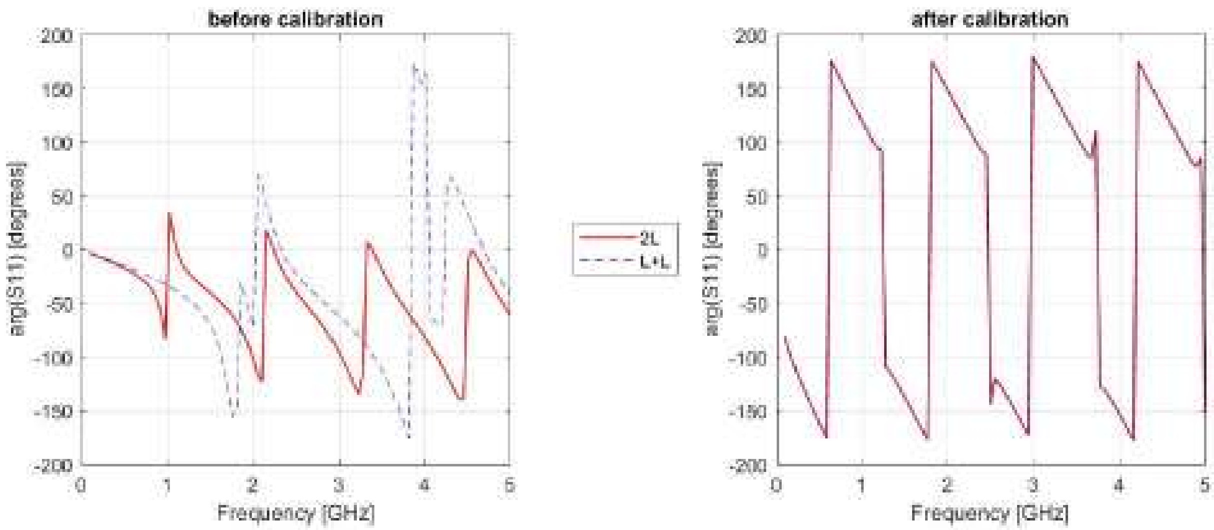


Figure 64: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

A.2.3 ADS circuit analysis with a series intuctance attached

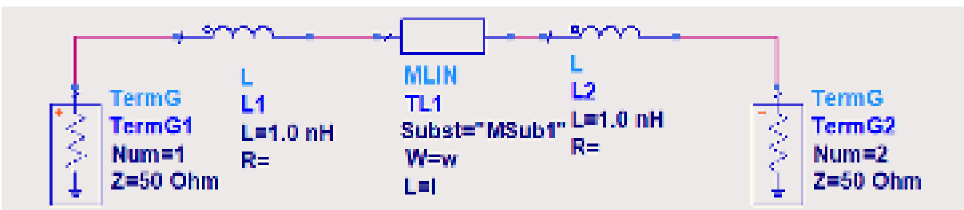


Figure 65: DUT - line with length **L**, 50Ω and series inductance equal $1nH$.

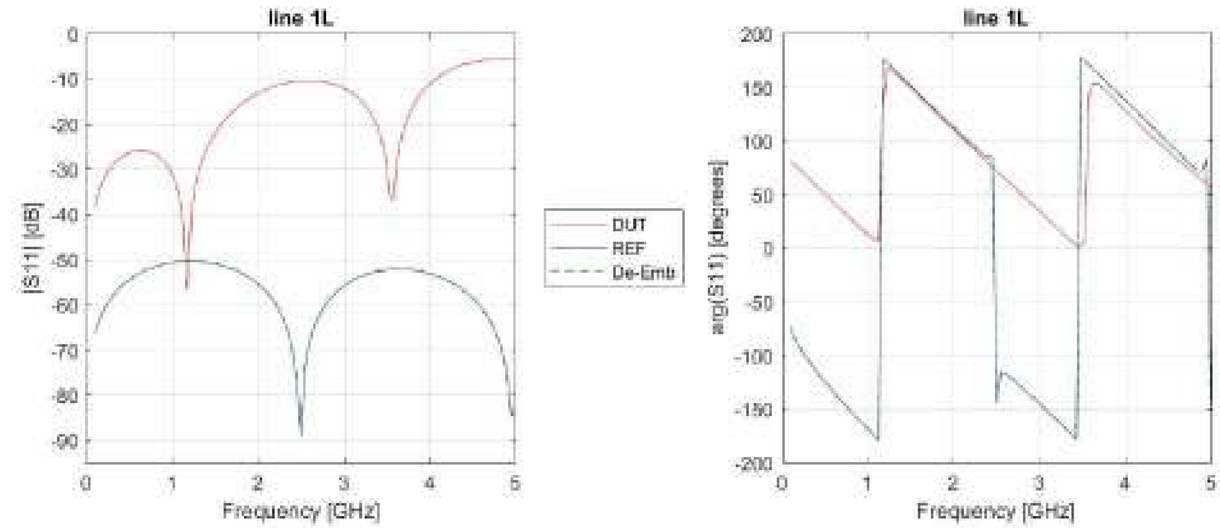


Figure 66: S_{11} reflectance characteristics before and after line length **L** calibration.

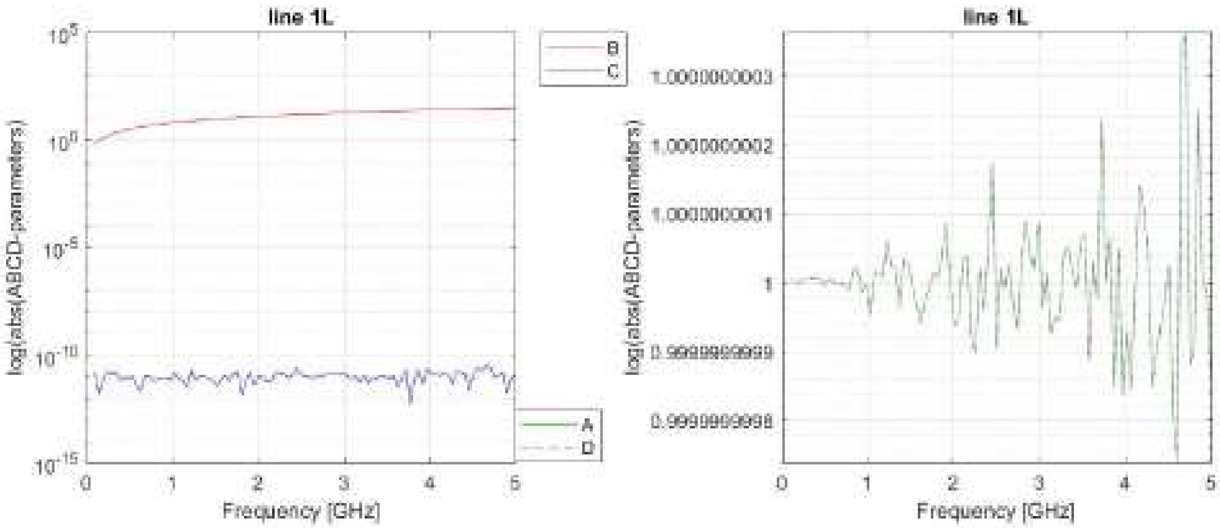


Figure 67: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

$$\begin{bmatrix} A_{Port} & B_{Port} \\ C_{Port} & D_{Port} \end{bmatrix}_{Port} \approx \begin{bmatrix} 1 & j\omega L_{1,2} \\ 0 & 1 \end{bmatrix}_{Series} \tag{8}$$

Analyzing the above results, $B_{Port} = j\omega L_{1,2}$, where $L_{1,2} = 1nH$ calibration was successful and we managed to extract the added inductance and get the characteristics of the line itself.

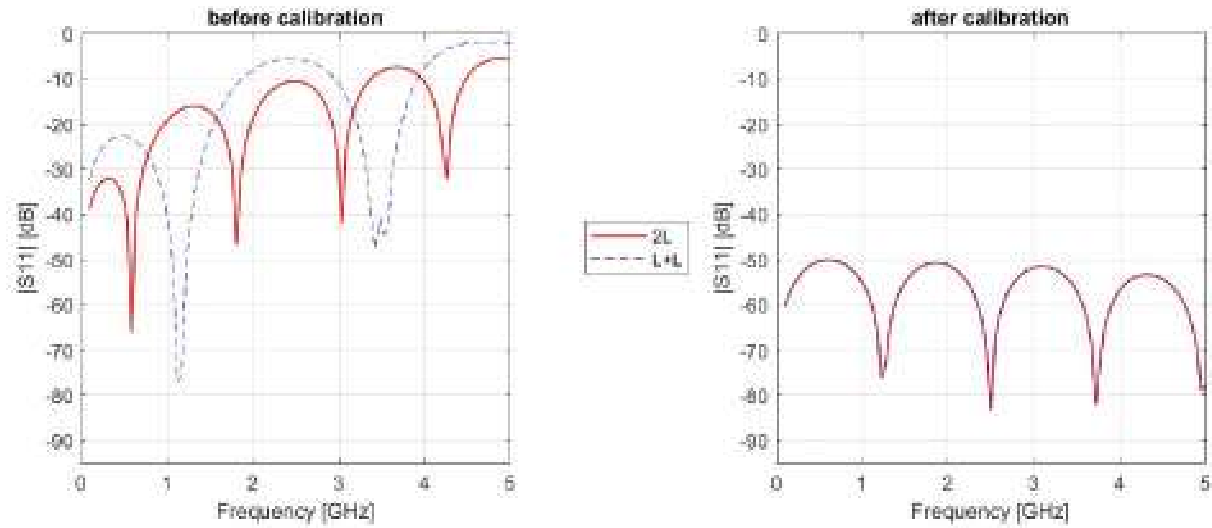


Figure 68: The test checking the characteristics of the S_{11} module before and after the calibration, in the case of connecting the line length **L** to the cascade and the line length **2L**.

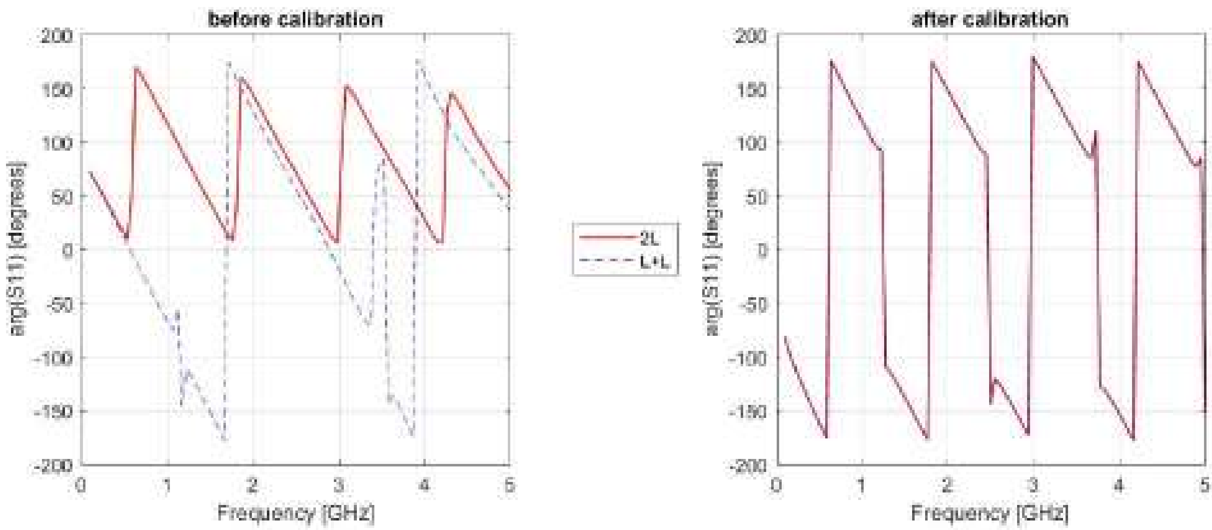


Figure 69: The test checking the characteristics of the S_{11} phase before and after the calibration, in the case of connecting the line **L** to the cascade and the line **2L**.

A.2.4 ADS circuit analysis with a series intuctance and shunt capacity attached

Figure 70: DUT - line with length **L**, 50Ω and series inductance equal 1nH and shunt capacity equal $1pF$.

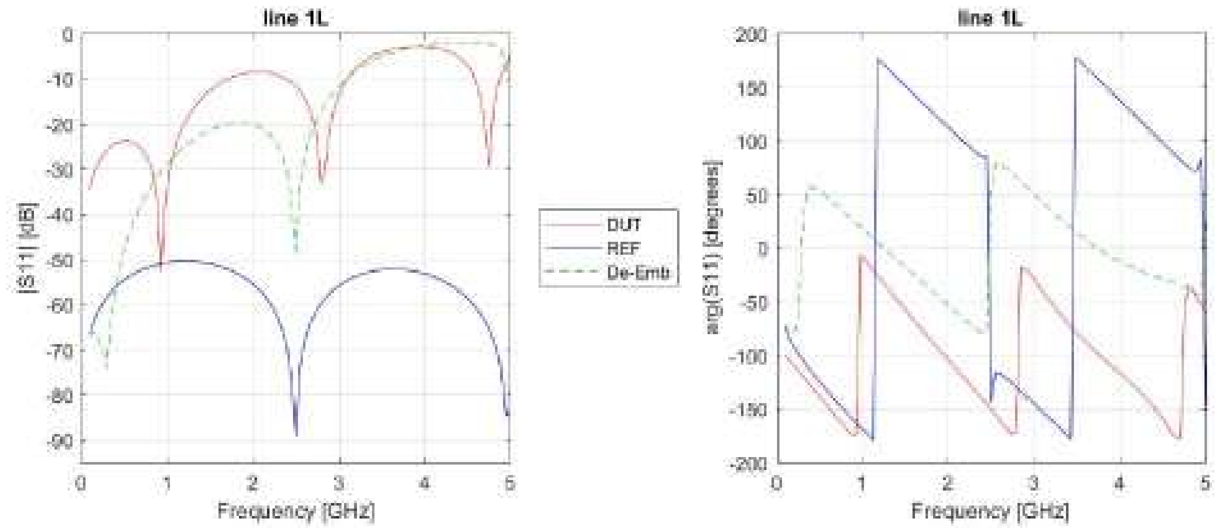


Figure 71: S_{11} reflectance characteristics before and after line length **L** calibration (square root of the matrix method).

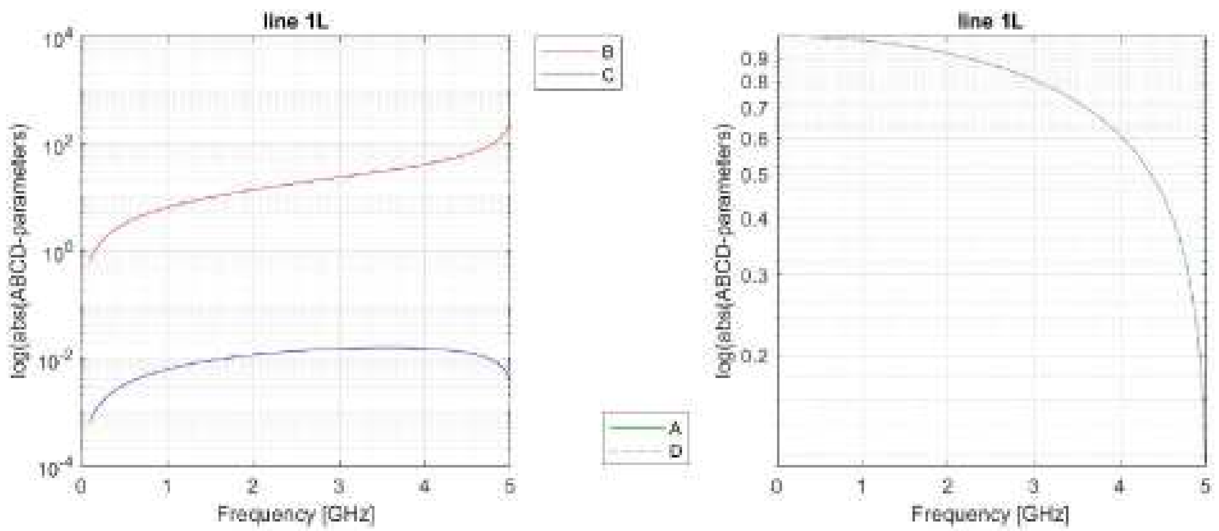


Figure 72: Coefficient modules A, B, C, D of the discontinuity matrix of a double port.

Analyzing the above results, calibration was not successful. the obtained matrix is difficult to define clearly in the frequency function. One does not appear on the diagonal.

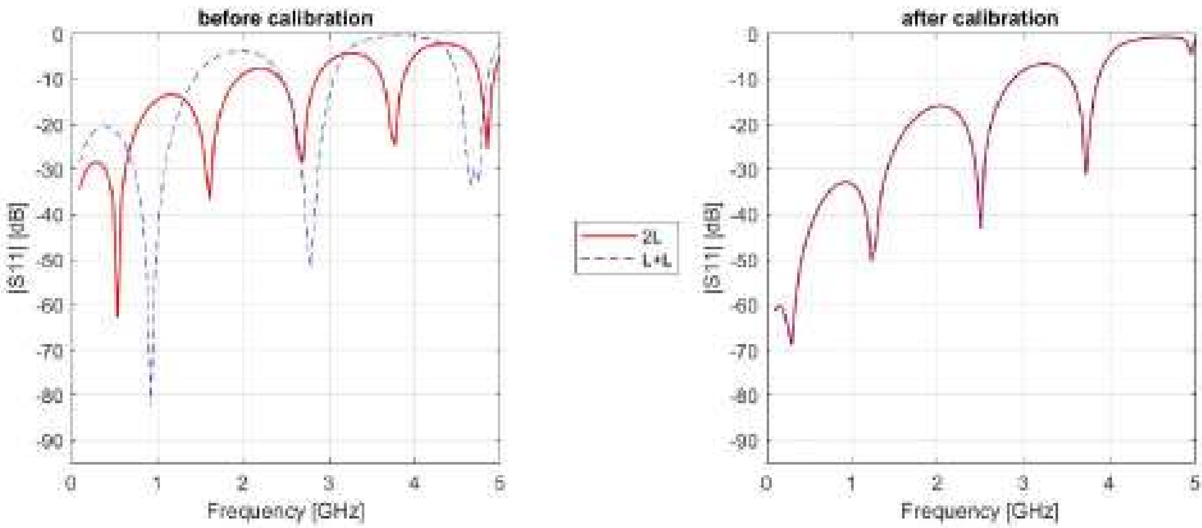


Figure 73: The test checking the characteristics of the S_{11} module before and after the calibration (square root of the matrix method), in the case of connecting the line length **L** to the cascade and the line length **2L**.

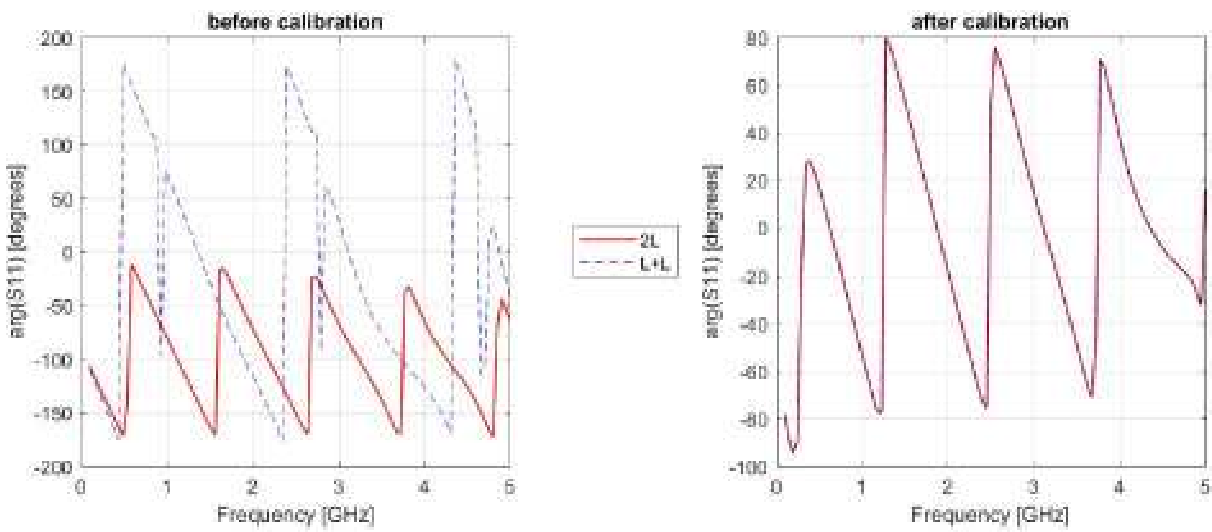


Figure 74: The test checking the characteristics of the S_{11} phase before and after the calibration (square root of the matrix method), in the case of connecting the line **L** to the cascade and the line **2L**.

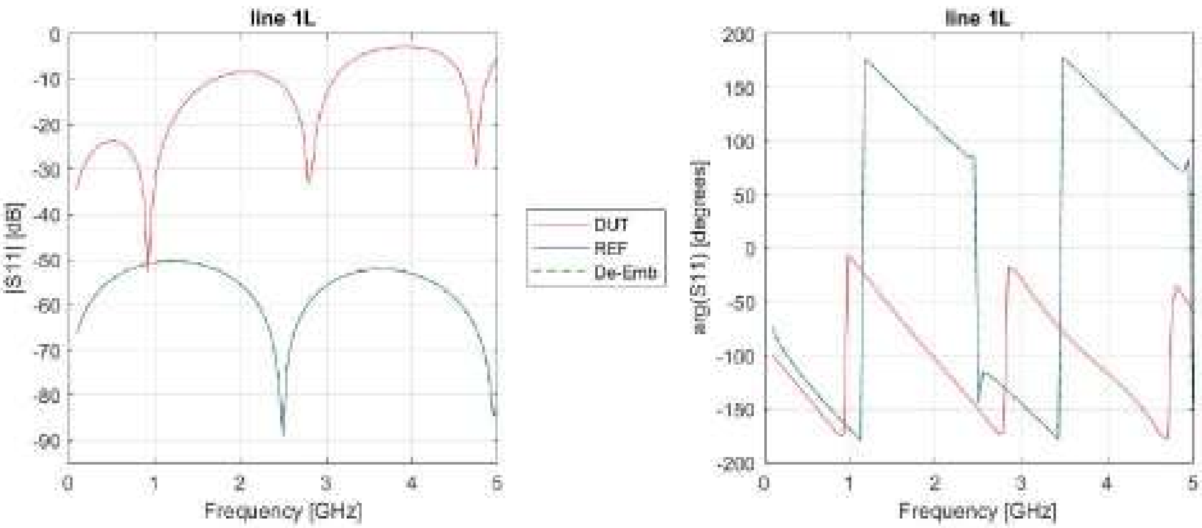


Figure 75: S_{11} reflectance characteristics before and after line length $\mathbf{L}$ calibration (double port double load attached predictive method).

The received result confirms previous conclusions. When we have a single load, to calibrate the system, it is enough to extract the element square root from the double port matrix, which is uniquely defined. In the case of a double load, it is necessary to predict what form the double port matrix will have and, on this basis, to extract individual values of series and shunt elements.