ANTENNA DESIGN COURSE

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CHAPTER 3

ARRAY ANTENNA THEORY

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3.1 Basic Array Antenna Theory

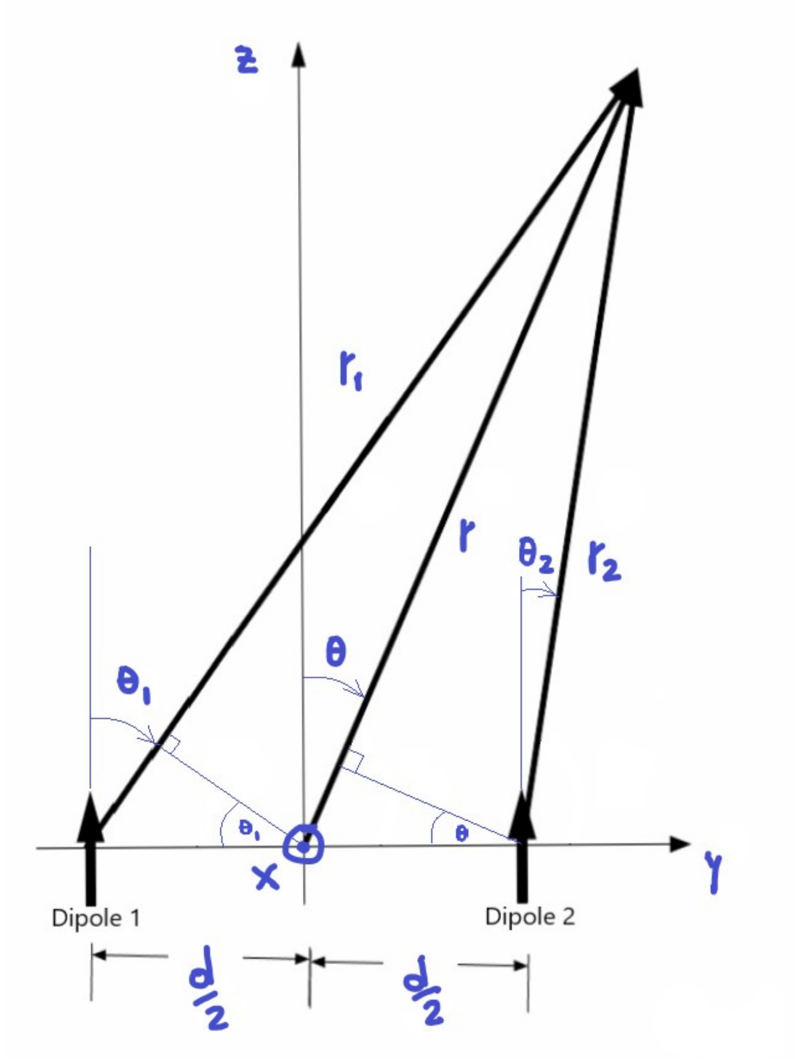


Fig. 3.1: Two dipoles placed vertically.

A general expression for an electric field for a dipole placed vertically in y=0 is:

$$E(\theta,\phi,r)=E_0(\theta,\phi)\frac{e^{-jk(r)}}{r} \qquad (1)$$

Now if it is assumed that two dipoles are placed like it is shown in Fig. 3.1, and these dipoles are excited with a phase difference β, then the electric fields of these dipoles are:

$$E_1(\theta,\phi,r)=E_0(\theta,\phi)\frac{e^{-jk\left(r_1-\frac{\beta}{2}\right)}}{r_1} \qquad (2) \qquad E_2(\theta,\phi,r)=E_0(\theta,\phi)\frac{e^{-jk\left(r_2+\frac{\beta}{2}\right)}}{r_2} \qquad (3)$$

By using the following approximations (see pg. 250 in [CABAL]).

For phase calculations:

$$\theta_1 \approx \theta_2 \approx \theta \qquad (4)$$

$$r_1 \approx r + d/2.\sin(\theta) \qquad (5)$$

$$r_2 \approx r - d/2.\sin(\theta) \qquad (6)$$

For amplitude calculations:

$$r_2 \approx r_1 \approx r \qquad (7)$$

The total electric field generated by both dipoles is:

$$E_T(\theta,\phi,r) = E_1(\theta,\phi,r) + E_2(\theta,\phi,r) \qquad (8)$$

$$E_T(\theta,\phi,r) = E_0(\theta,\phi)\frac{e^{-jk\left(r+\frac{d}{2}\sin(\theta)-\frac{\beta}{2}\right)}}{r} + E_0(\theta,\phi)\frac{e^{-jk\left(r-\frac{d}{2}\sin(\theta)+\frac{\beta}{2}\right)}}{r} \qquad (9)$$

$$E_T(\theta,\phi,r) = E_0(\theta,\phi)\frac{e^{-jkr}}{r}\left(e^{\frac{jk}{2}(-d\sin(\theta)+\beta)} + e^{\frac{jk}{2}(d\sin(\theta)-\beta)}\right) \qquad (10)$$

$$E_T(\theta,\phi,r) = E_0(\theta,\phi)\frac{e^{-jkr}}{r}\left(2\cos\left(\frac{k}{2}(d\sin(\theta)-\beta)\right)\right) \qquad (11)$$

What can be written in terms of the Array Factor (AF) as follows:

$$E_T(\theta,\phi,r) = E_0(\theta,\phi)\frac{e^{-jkr}}{r}(AF) \qquad (12)$$

Where AF is:

$$AF = 2\cos\left(\frac{k}{2}(d\sin(\theta)-\beta)\right) \qquad (13)$$

Considering d=λ and k=2π/λ AF would be:

$$AF = 2\cos\left(\pi\sin(\theta) - \pi\frac{\beta}{\lambda}\right) \qquad (14)$$

If we assume that there is no difference in the phase of the excitation of both dipoles (β=0), then the AF is:

$$AF = 2\cos(\pi\sin(\theta)) \qquad (15)$$

In next section this calculations will be compared with the corresponding simulations. There, will be explored how the resulting radiation pattern varies with d and β and the variety of radiation patterns that can be obtained just by controlling this two parameters of the array antenna.

3.2 Basic Array Antenna Simulation with CST

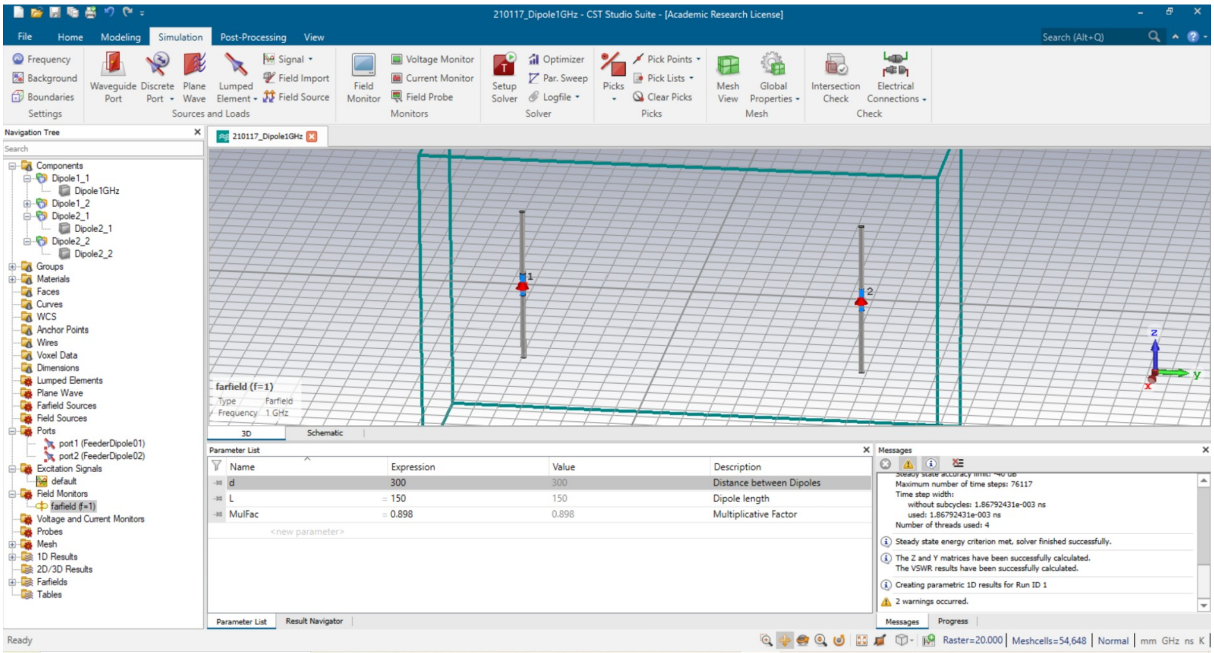


Fig. 3.2.1: Two 1 GHz dipoles separated by a distance d.

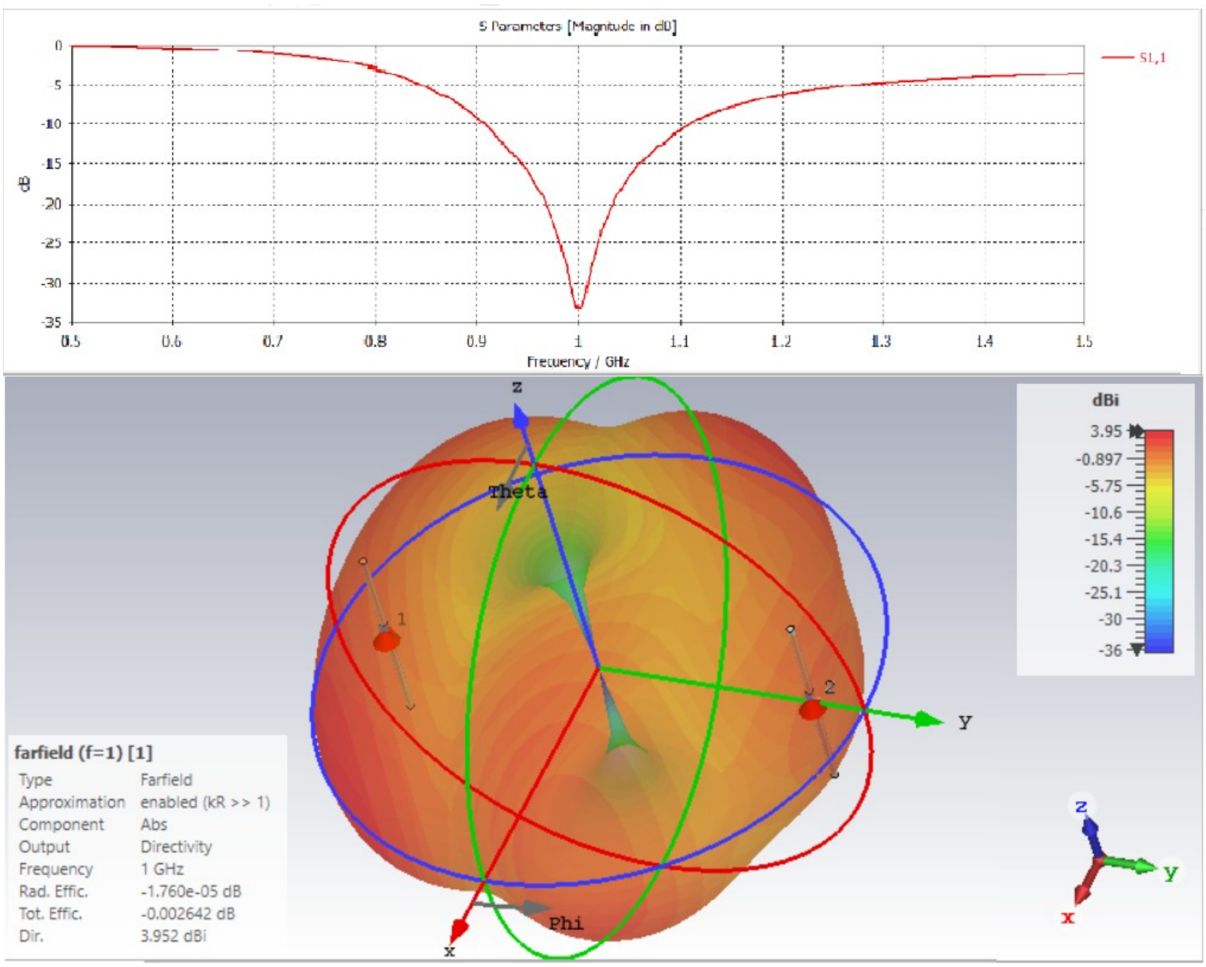


Fig. 3.2.2: Two 1 GHz dipoles separated by a distance **d=λ** and a phase difference in excitation β=0, S11 and Radiation Pattern.

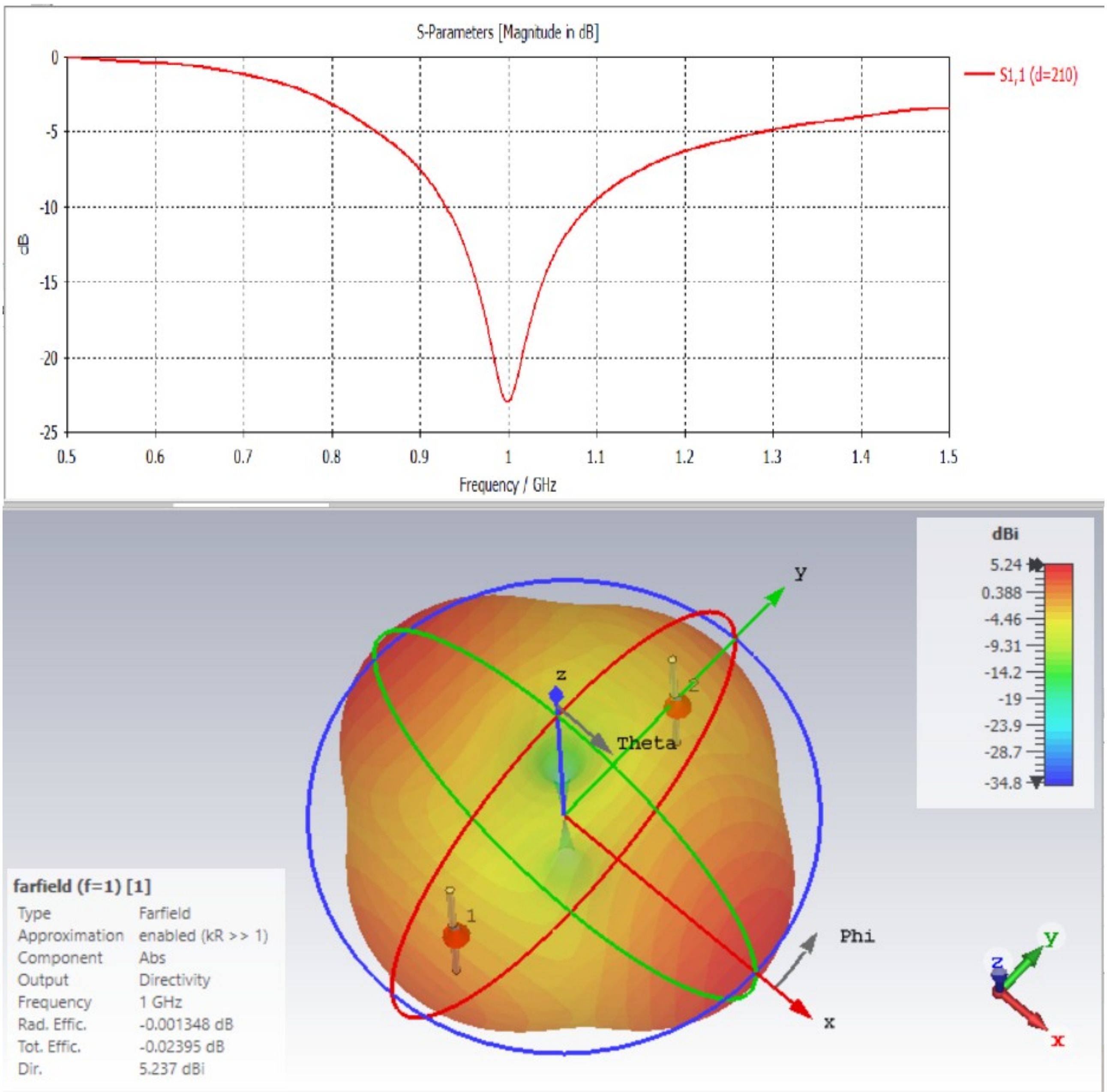


Fig. 3.2.3: Two 1 GHz dipoles separated by a distance **d=0.7λ** and a phase difference in excitation β=0, S11 and Radiation Pattern.

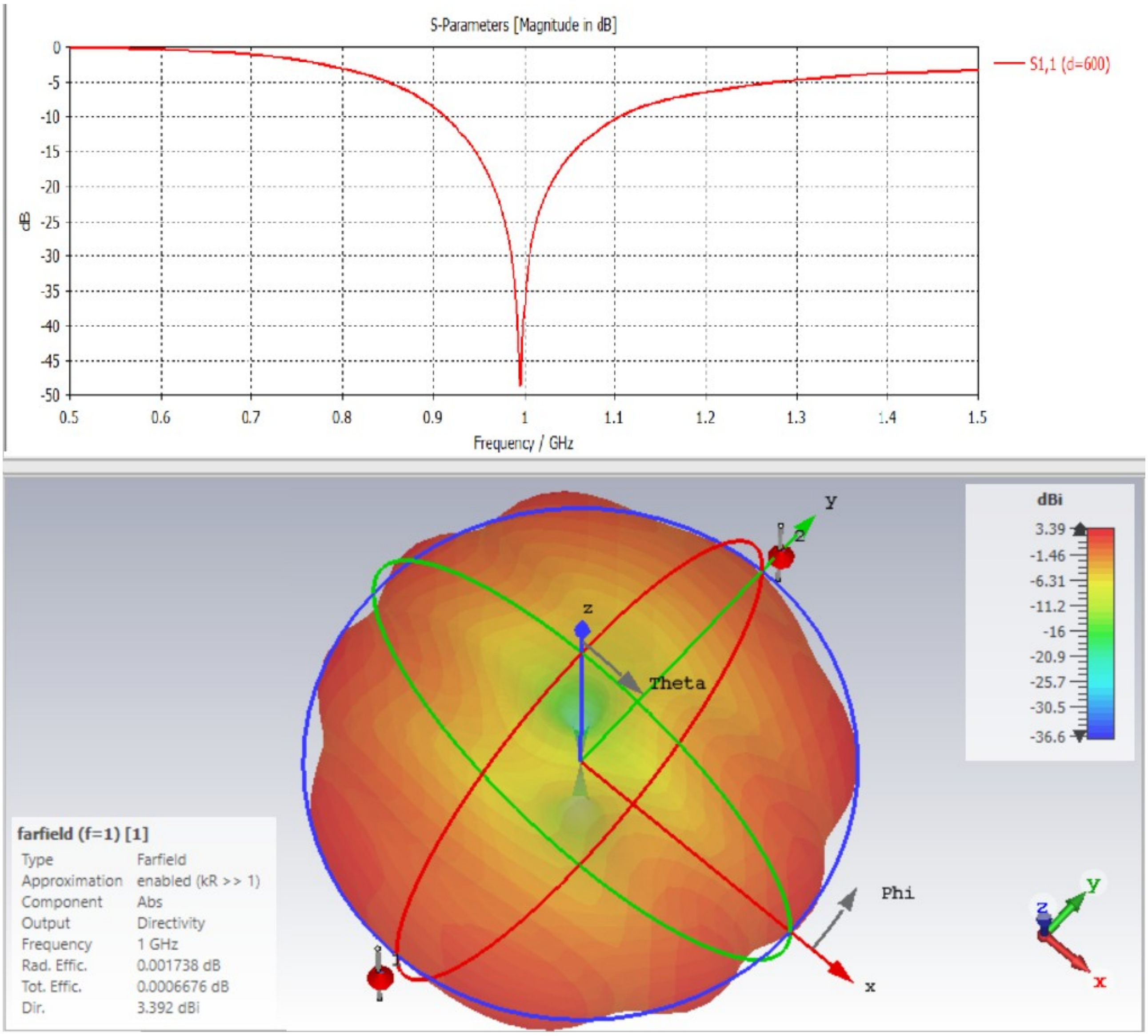


Fig. 3.2.4: Two 1 GHz dipoles separated by a distance **d=2λ** and a phase difference in exitation β=0, S11 and Radiation Pattern.

In Figs. 3.2.2, 3.2.3 and 3.3.4 it can be observed that by varying only the distance d between the two dipoles, large variations are produced in the parameter S11, in the radiation pattern and in the gain (directivity+e_{cd} in dB, e_{cd}=Rad. Effic.).

3.3 Deeper Array Antenna Simulation with CST

Now a deeper analysis is presented, using sequential excitation or simultaneous excitation, varying the amplitudes and phases of the excitation, and finally also adjusting the separation between the dipoles to improve the array performance.

Dipole array simulation with sequential excitation (S parameters) or with simultaneous excitation (F parameters).

Two $\lambda/2$ dipoles, excited with two ports with the same amplitude and phase, separated by a distance $d = \lambda/2$, are first excited sequentially (Fig. 3.2.7) and then simultaneously (Fig. 3.2.9).

To do this in CST, in Simulation go to Setup Solver, Simulation settings, Source type, Selection, Excitation list and a pop up opens that allows you to select amplitude and phase for each of the ports. For Excitation type, select simultaneous or sequential. In this example we will select “Sequential (port S-parameter)”. Since the phase shift will only be valid for one frequency, that frequency must be indicated in Reference frequency (in this case it is 1, because we set the frequency in GHz).

Table 1: Excitation Parameters for a sequential case with the same amplitudes and phases.

Excitation type:	Sequential (port S-parameter)	
Port 1	Amplitude: 1	Phase shift: 0.0
Port 2	Amplitude: 1	Phase shift: 0.0

Then give Apply, Close, Save the project, Setup Solver, and Start to launch the simulation.

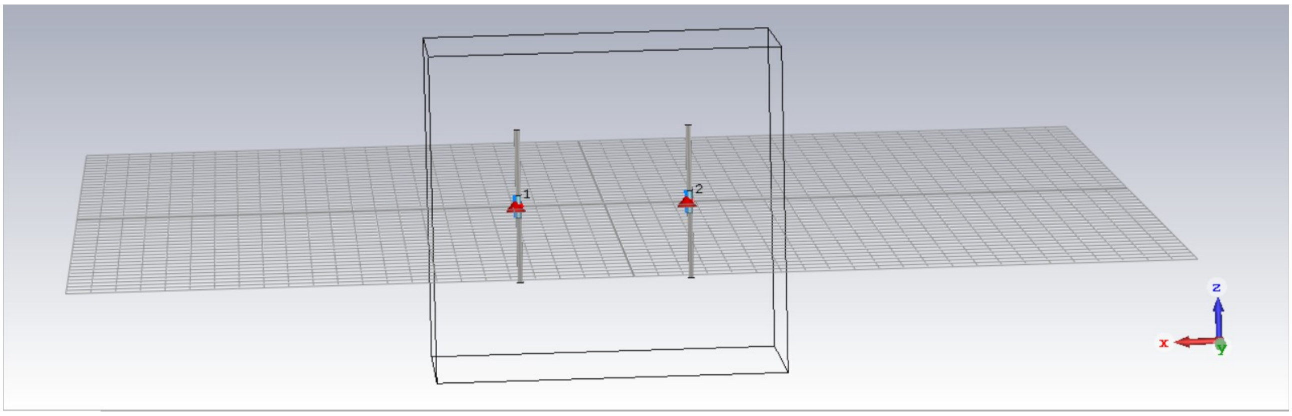


Fig. 3.2.5: Array model, two $\lambda/2$ dipoles separated by a distance $d = \lambda/2$.

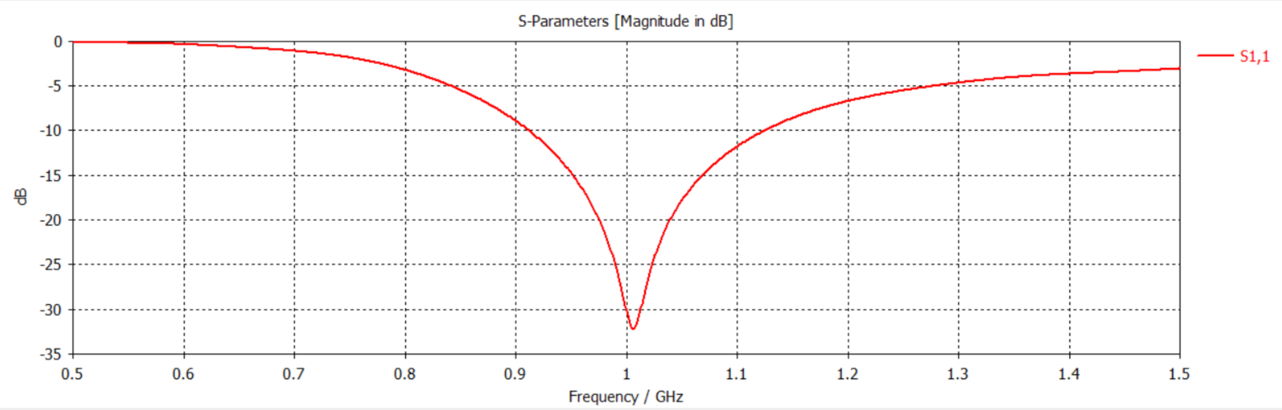
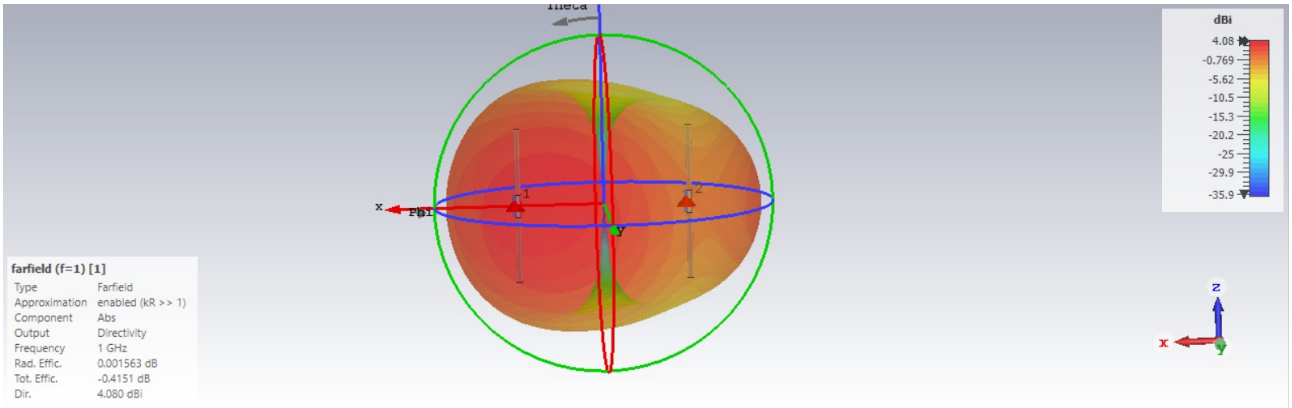
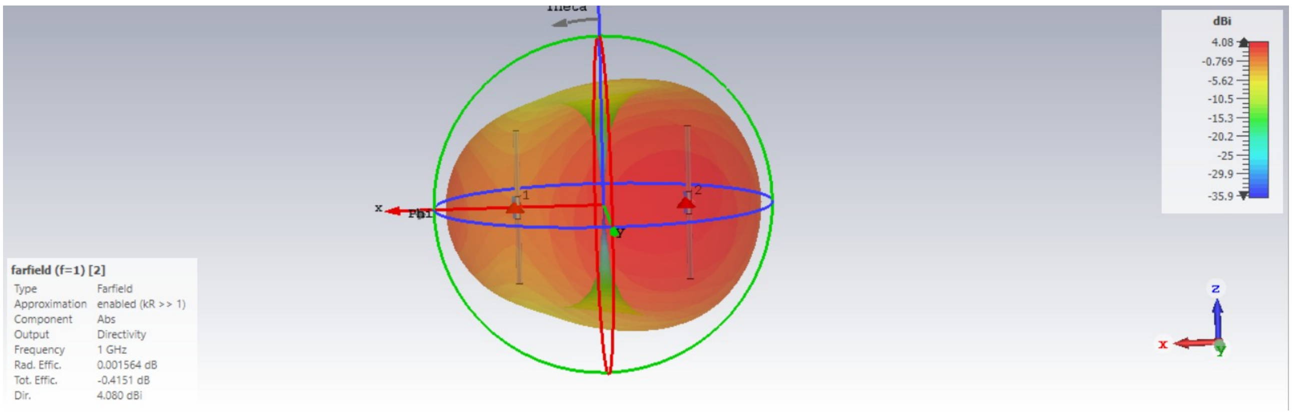


Fig. 3.2.6: S11 parameter (sequential excitation).



(a) excitation in dipole 1.



(b) excitation in dipole 2.

Fig. 3.2.7: Radiation pattern for a two dipoles array with sequential excitation.

In Fig. 3.2.7 it is observed that when a dipole is not excited, it acts as a director element.

The array model used in the next simulation is the same used in the previous simulation, shown in Fig. 3.2.5, but now the ports excite the dipoles simultaneously and the results can be observed in Figs. 3.2.8 and 3.2.9. The parameters for this simulation are:

Table 2: Excitation Parameters for a simultaneous case with the same amplitudes and phases.

Excitation type:	Simultaneous	Reference frequency: **1**
Port 1	Amplitude: **1.0**	Phase shift: **0.0**
Port 2	Amplitude: **1.0**	Phase shift: **0.0**

This combination for the excitation can be expressed in short notation as: **1[1.0,0.0]+2[1.0,0.0][1]**.

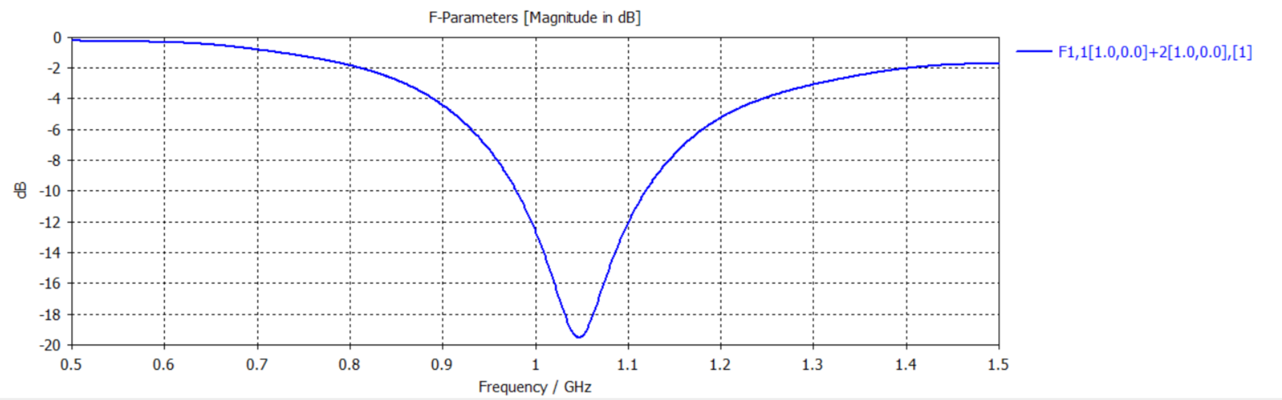


Fig. 3.2.8: F11 parameter (simultaneous excitation).

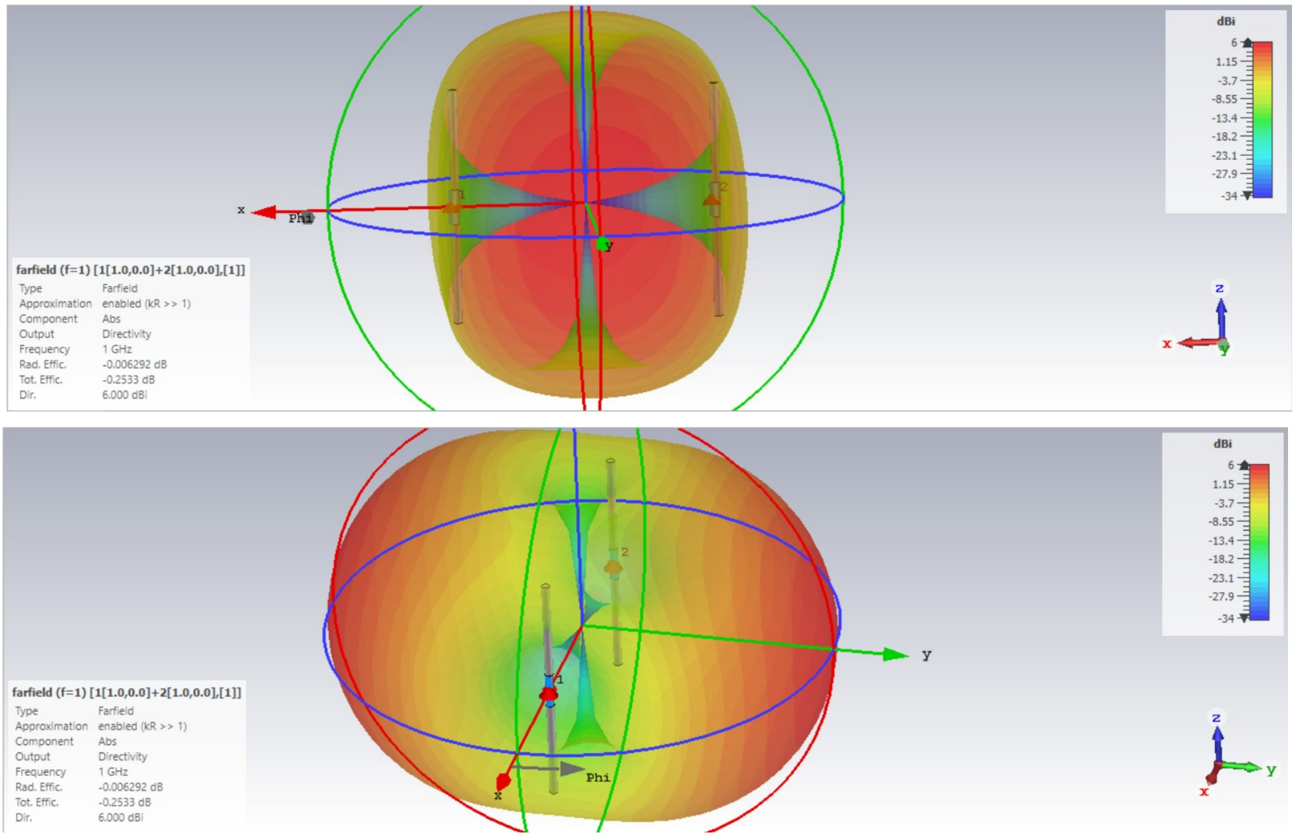


Fig.: 3.2.9: Radiation pattern for a two dipoles array with simultaneous excitation (farfield (f=1) [1[1.0,0.0]+2[1.0,0.0].[1]]).

A very interesting radiation pattern can be observed in Fig. 3.2.9, with very low radiation in the plane containing the dipoles.

The results for the same two dipoles array (see Fig. 3.2.5) are presented below, but now changing the amplitude and phase of each of the dipoles. In this case, simultaneous excitation is considered as described below:

Table 3: Excitation Parameters for a simultaneous case with different amplitudes and phases.

Excitation type:	Simultaneous	Reference frequency: **1**
Port 1	Amplitude: **3**	Phase shift: **0.0**
Port 2	Amplitude: **1.0**	Phase shift: **180**

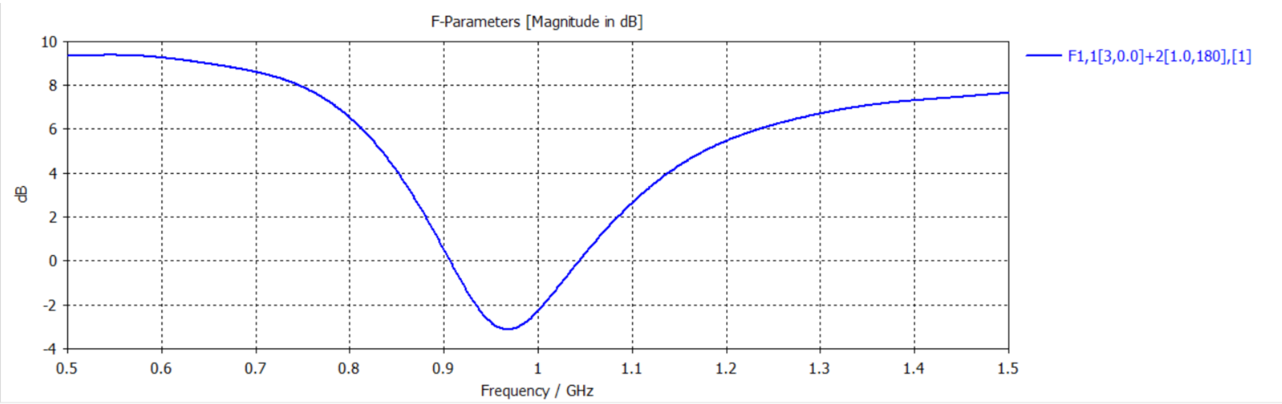


Fig. 3.2.10: F11 parameter (simultaneous excitation defined in Table 3, F1,1[3,0,0]+2[1.0,180].[1]).

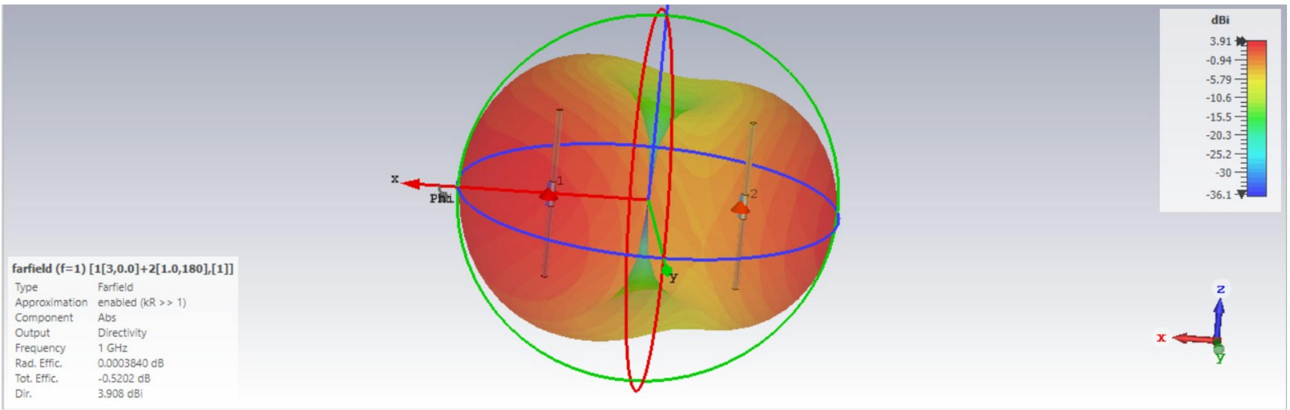


Fig. 3.2.11: Radiation pattern for a two dipoles array with simultaneous excitation.

In this case a different radiation pattern is obtained, and the S11 parameter is quite deteriorated for this excitation combination.

Below is another example of amplitude and phase change for the same array (see Fig. 3.2.5). In this case, simultaneous excitation is considered as described below:

Table 4: Excitation Parameters for a simultaneous case with different amplitudes and phases.

Excitation type:	Simultaneous	Reference frequency: **1**
Port 1	Amplitude: **2**	Phase shift: **0.0**
Port 2	Amplitude: **0,5**	Phase shift: **80**

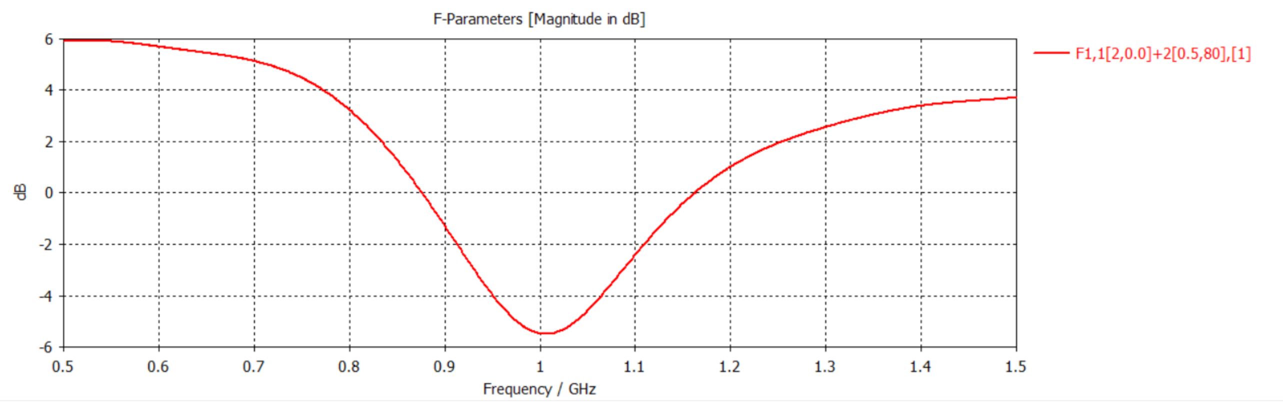


Fig. 3.2.12: F11 parameter (simultaneous excitation defined in Table 4, F1,1[2,0,0]+2[0.5,80].[1]).

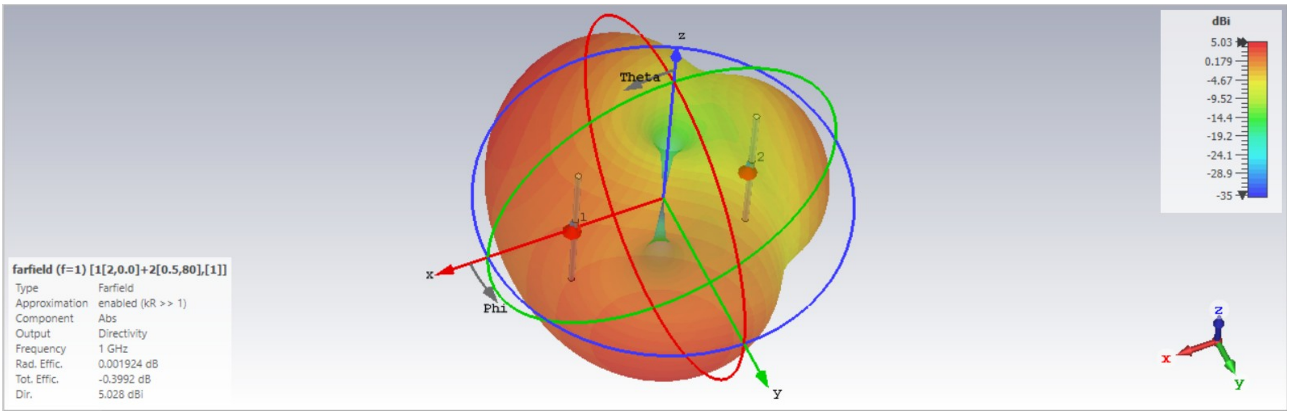


Fig. 3.2.13: Radiation pattern for a two dipoles array with simultaneous excitation.

In this case a new radiation pattern is obtained and the S11 parameter is still not good. In the following example the S11 parameter will be significantly improved, just by varying the distance between the dipoles.

Now is analyzed a particular case varying the distance between the dipoles, for this example a distance **d '= d * 0.7 = (λ/2) * 0.7 = 112.5 mm** between dipoles is used, with the same amplitudes and phases for the excitations than in the previous example. The only difference with that is the smaller separation between the dipoles. Simultaneous excitation is considered in this case as described below:

Table 5: Excitation Parameters for a simultaneous case with different amplitudes and phases.

Excitation type:	Simultaneous	Reference frequency: **1**
Port 1	Amplitude: **2**	Phase shift: **0.0**
Port 2	Amplitude: **0,5**	Phase shift: **80**

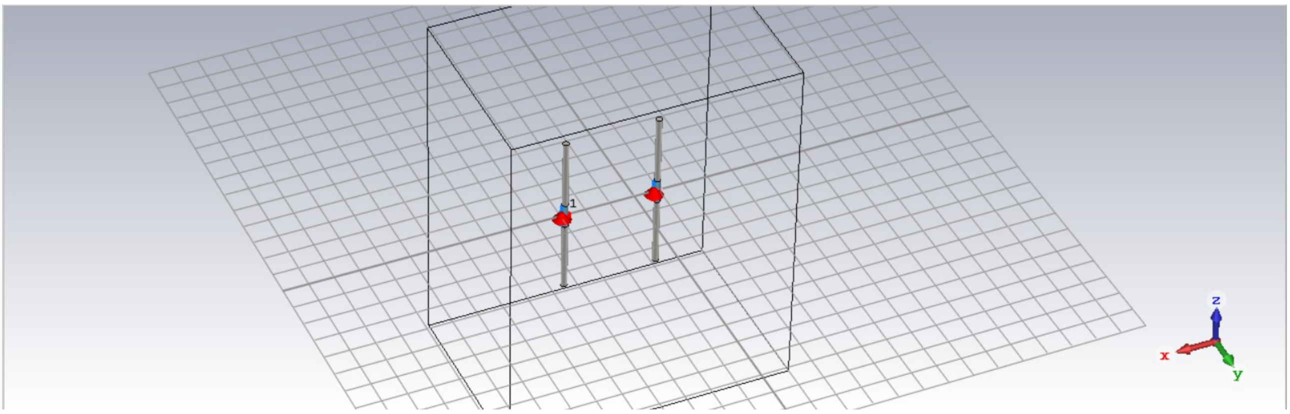


Fig. 3.2.14: Array model.

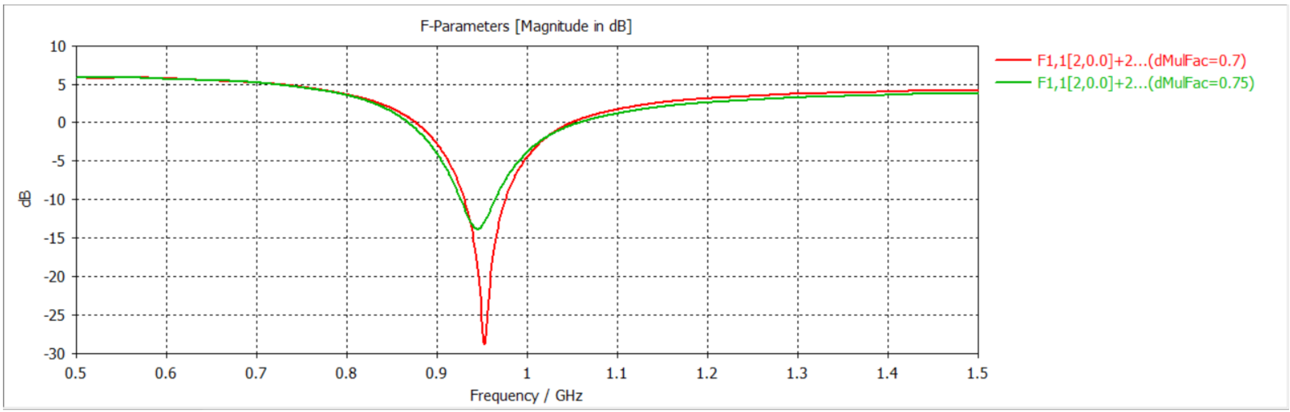


Fig. 3.2.15: F11 parameter (simultaneous excitation defined in Table 5, F1,1[2,0,0]+2[0.5,80].[1]).

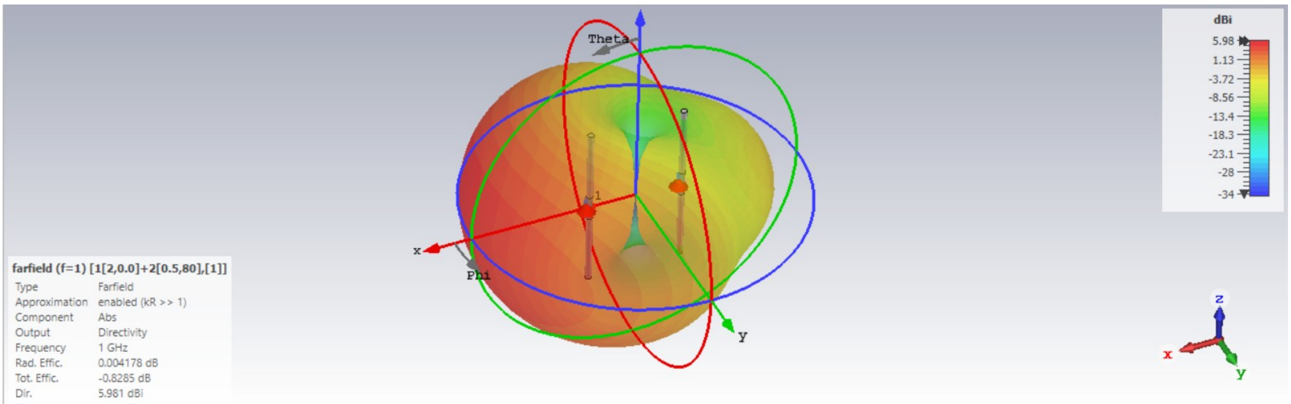


Fig. 3.2.16: Radiation pattern for a two dipoles array with simultaneous excitation.

In this case an interesting radiation pattern and a very improved S11 parameter was obtained.

These results show the enormous variety of performances that can be obtained with a simple array of two dipoles, varying the distance between them and the amplitudes and phases of their supplies.

REFERENCES

[CABAL] C. A. Balanis, ANTENNA THEORY Analysis and Design,2da.,John Wiley & Sons,1997.

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