<u>CST Project #2 – Patch Antenna Simulation</u>

In this project you will design and simulate a patch antenna and an array using CST. The antenna design is based on parameters that are given in the table below (each student has different design parameters!).

Note the following definitions and remarks:

- The microstrip antenna is a "planar antenna", meaning, implemented on a (relatively) thin grounded substrate. You are required to implement the antenna in the X-Y plane, meaning, the normal of the substrate plane is in the Z-axis direction.
- θ is the angle between the Z-axis and the X-Y plane.
- φ is defined as the angle between the X-axis and the Y-axis, in the X-Y plane.
- The Y-Z plane will be the "Elevation" plane, and θ is the elevation angle assuming that $\varphi=90°$.
- The plane X-Z will be the "Azimuth" plane, and θ is the elevation angle assuming that $\varphi=0°$.
- f is the center frequency of your design, as specified in the table below. Accordingly, T is the time period: $T=1/f$.
- The parameters of the antenna that are allowed to be fine tuned are only the size of the patch (its length and width), the feeding point of the patch antenna, the width of the microstrip lines and the diameter of the outer shield of the coax line. Also the thickness (height) of the dielectric substrate can be modified but it can have only integer values in mm units! (such as 1mm, 2mm, etc.).
- Input matching, Return Loss, or S_{11} in dB scale are all defined to be: $20\log|\Gamma|$, where Γ is the reflection coefficient of the antenna.
- Your submission should include each of the CST model files (optimized models, with configuration ready for simulations!), all of your Matlab code files and a final document that answers all the questions below, presents all the plots and describes the full design procedure of each of the models.

The design is based on the following steps. Each of the steps is graded independently.

1. (5 points) Build a CST model of a 50Ω coaxial line with an inner pin diameter of 1mm, and with a dielectric medium (in between the inner pin and the external shield) of a material named Teflon. The length of the coax cable should be two wavelengths (according to the frequency given in the table below). Place ports at the input and at the output of the coax line, with characteristic impedance (of the ports) according to that of the coax cable (as specified in the table) and simulate the 2ports S-Parameters over the frequency band of $0.7f$ -$1.3f$.
   - Optimize the parameters of the coax cable so that S_{ii} (S_{11} and S_{22}) will be below -25dB.
   - What is the insertion loss of the cable at the frequency f?
   - Present the S-Parameters results of the optimized cable over the given frequency band.
2. (15 points) Build a CST model of the patch antenna, according to the above guidelines and your patch antenna parameters in the table below. Use the designed coax cable in a length of a <u>quarter wavelength</u> in order to feed the patch antenna, without using a microstrip line: create a hole in the ground plane in a diameter which is identical to that of the shield of the coax cable, insert the edge of the coax cable into this hole, and extend the inner core of the coax above the ground plane so that it will touch the metal plate that implements the patch. Now, fine-tune the (allowed) parameters of the antenna in order to achieve a matching (Return Loss, or S_{11} in dB scale) of better than -10dB over the frequency band $0.98f$ -$1.02f$. <u>Note that the impedance of the coax cable must remain 50Ω</u>!

- Present the input matching over the bandwidth 0.7*f* -1.3*f*. Use markers on the plot in order to demonstrate the achieved design goals.
- Compare the optimized size of the patch to the theoretical one. If there is any difference, what is the reason for that?
- Present the 3D far field radiation pattern of the patch antenna at the frequency *f*, and the radiation pattern over the 2 main planes: the Y-Z plane ("Elevation") as a function of θ, and the X-Z plane ("Azimuth") as a function of θ.
- What is the direction of the peak gain of the patch antenna, and what is the peak gain and directivity values? – The ideal patch can have a gain of above 7.5dBi. Compare it to the gain of your patch and explain the differences. What is the antenna efficiency?
- Present the surface currents on the patch antenna and on the ground plane at the time points t=0, t=T/4, t=T/2 and t=3T/4. Compare it to the expected results according to the theory and explain the differences, if those exist.

3. (5 points) Build a CST model of a 100Ω microstrip line that it is implemented on the same dielectric substrate as your optimized patch antenna. The length of the microstrip should be two wavelengths (according to the frequency given in the table below). Place wave ports at the input and at the output of the microstrip line and simulate the 2ports S-Parameters over the frequency band of 0.7*f* -1.3*f*.
   - Optimize the parameters of the microstrip line so that S_{ii} (S_{11} and S_{22}) will be below -25dB.
   - What is the insertion loss of the microstrip at the frequency *f*? – compare it to that of the coax cable at the same length and explain the differences.
   - Present the S-Parameters results of the optimized microstrip line at the given frequency band.
4. (15 points) In this section you are required to replace the coax feed with a microstrip feed for the patch antenna: feed the patch antenna that you designed in Section 2 using the microstrip line that you designed in Section 3. In this case, the microstrip line should have a length of a half wavelength. Place a lumped port on the far edge of the microstrip line in order to feed it. The impedance of the line must remain 100Ω and all the patch parameters (width, length, height of the substrate) must remain the same as in Section 2 above! If needed, a quarter wavelength transmission line can be designed in order to match the patch antenna to the 100Ω microstrip line. Other matching options of the patch antenna to the line can be used instead. Now, fine-tune the (allowed) parameters in order to achieve a matching (Return Loss, or S_{11} in dB scale) of better than 10dB over the frequency band 0.98*f* -1.02*f*.
   - Present the input matching over the bandwidth 0.7*f* -1.3*f*. Use markers on the plot in order to demonstrate the achieved design goals.
   - Present the 3D far field radiation pattern of the patch antenna at the frequency *f*, and the radiation pattern over the 2 main planes: the Y-Z plane ("Elevation") as a function of θ, and the X-Z plane ("Azimuth") as a function of θ. Is there any difference comparing the radiation patterns that you got in Section 3? – if there are, explain the differences.
5. (60 points) In this section you are requested to use again the antenna that was optimized in Section 4 in order to implement an array as described in the table below. Follow the sections below:
   - (5 points) Write down the expression for the <u>normalized</u> Array Factor of the array that you should implement. For your convenience, you can change the axis along which the

array is implemented, as long as your final conclusion in the sections below remain correct. For example – it might be easier to set the array elements along the Z-axis.

- (5 points) Plot in Matlab the normalized array factor as a function of the observation angle for which the beam-width is set by the array size. Attach your code file to the solution.
- (5 points) Find the directivity of the array, assuming that it is implemented by isotropic elements. If an analytical solution is not trivial, a numerical integration is allowed, conditioned that you attach your code file to the solution.
- (5 points) Calculate the required electrical phase $\Delta\phi$ that is required in order to steer the beam to an angle of 20° along the array's axis. Note the configuration of your array (along the Z-axis or the Y-axis)!
- (2 points) Plot in Matlab the normalized array factor as a function of the θ angle for the array that its beam is steered to the angle of 20° along the array's axis. Attach your code file to the solution.
- (15 points) Implement the array in CST by duplicating the single patch and its microstrip feed, according to the configuration of your array (elements number and polarization). If the substrate + metal ground planes of the patches are not overlapping, fill the entire gap with the same substrate + ground plane. Design the microstrip network so that all the patches will be fed by microstrip lines and the microstrip network will have a single feeding point that will be connected to a quarter wavelength 50Ω coax line that you designed in Section 1. Simulate this structure while feeding all of the patches with the same electrical phase and plot the 3D radiation pattern, as well as 2D the radiation pattern in the azimuth and in the elevation.
- (3 points) Compare the radiation pattern along the array's axis to the theoretical radiation pattern of the array factor. Explain the differences.
- (5 points) Compare between the peak directivity and gain of the implemented array to the theoretical directivity and gain of the array of isotropic elements that you found above. What is the reason for the differences? Does it correspond with the expected results? What is the antenna efficiency?
- (5 points) Present the input matching over the bandwidth $0.5f$ -$2f$ of your array (as seen by the port at the input of the coax line). Use markers on the plot in order to demonstrate the achieved design goals – matching of -10dB or better at the frequency range $0.98f$-$1.02f$. What is the reason for the difference between this matching performance and the one of a single patch antenna that was implemented in Section 4?
- (5 points) Next, apply the electrical phase offset that you found ($\Delta\phi$) between one array's element port and its neighbor, in order to steer the beam to the mechanical (geometrical) angle of 20° along the array's axis. Plot the 3D radiation pattern, as well as 2D the radiation pattern in the azimuth and in the elevation. Explain the results.
- (5 points) Present again the input matching over the bandwidth $0.5f$ -$2f$, when the monopoles are fed with a linear phase. Use markers on the plot in order to demonstrate the achieved design goals. What is the reason for the difference between this matching performance and the one of a single element in the array where no electrical phase was applied?

Student's username	**Dielectric Substrate**	**Frequency *f* [GHz]**	**Array parameters**	**Polarization**
203288501	Arlon 270	2	2 elements along the X-axis. Spacing of d=0.5λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
205475643	Arlon 300	12	2 elements along the Y-axis. Spacing of d=0.5λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
206362121	Arlon 350	7	4 elements along the X-axis. Spacing of d=0.5λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
206582488	Arlon 450	2.3	4 elements along the Y-axis. Spacing of d=0.5λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
207932526	Fr4	11.7	2 elements along the X-axis. Spacing of d=0.6λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
208237131	Rogers RO3035	7.3	2 elements along the Y-axis. Spacing of d=0.6λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
212675326	Rogers RO4003C	2.6	4 elements along the X-axis. Spacing of d=0.6λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
307854398	Rogers RO4450B	11.4	4 elements along the Y-axis. Spacing of d=0.6λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
315017954	Rogers RT5880LZ	6.7	2 elements along the X-axis. Spacing of d=0.7λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
315749937	Rogers RT5870	2.9	2 elements along the Y-axis. Spacing of d=0.7λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
322317355	Rogers RT6202	11.1	4 elements along the X-axis. Spacing of d=0.7λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
330403163	Rogers XT8000	7.6	4 elements along the Y-axis. Spacing of d=0.7λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
332740547	Rogers XT8100	3.2	2 elements along the X-axis. Spacing of d=0.8λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
345219877	Rogers Ultram 3850	10.8	2 elements along the Y-axis. Spacing of d=0.8λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
901281675	Taconic HT-1.5	6.4	4 elements along the X-axis. Spacing of d=0.8λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
905504452	Taconic HT-30	3.5	4 elements along the Y-axis. Spacing of d=0.8λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
907296594	Taconic HT-35	10.5	2 elements along the X-axis. Spacing of d=0.9λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
923000848	Taconic HT-43	7.9	2 elements along the Y-axis. Spacing of d=0.9λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
928506963	Arlon 270	3.8	4 elements along the X-axis. Spacing of d=0.9λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
930539747	Arlon 350	10.2	4 elements along the Y-axis. Spacing of d=0.9λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$
932912850	Fr4	6.1	2 elements along the X-axis. Spacing of d=λ.	Vertical: $E(\theta=0°,\varphi)=E_0\hat{y}$
934381971	Rogers RO3035	4.1	2 elements along the Y-axis. Spacing of d=λ.	Horizontal: $E(\theta=0°,\varphi)=E_0\hat{x}$

940823297	Rogers RO4003C	9.9	4 elements along the X-axis. Spacing of d=λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
946806015	Rogers RO4450B	8.2	4 elements along the Y-axis. Spacing of d=λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$
951265768	Rogers RT6202	4.4	2 elements along the X-axis. Spacing of d=0.75λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
962505947	Rogers XT8000	9.6	2 elements along the Y-axis. Spacing of d=0.75λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$
963211446	Rogers XT8100	5.8	4 elements along the X-axis. Spacing of d=0.75λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
967518150	Rogers Ultram 3850	4.7	4 elements along the Y-axis. Spacing of d=0.75λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$
967931932	Taconic HT-1.5	9.3	2 elements along the X-axis. Spacing of d=0.65λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
969580232	Taconic HT-30	8.5	2 elements along the Y-axis. Spacing of d=0.65λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$
970387635	Taconic HT-35	5	4 elements along the X-axis. Spacing of d=0.65λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
984004101	Taconic HT-43	9	4 elements along the Y-axis. Spacing of d=0.65λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$
996118063	Arlon 300	5.5	4 elements along the X-axis. Spacing of d=0.85λ.	Vertical: $E(\theta=0°,\varphi) = E_0\hat{y}$
997660873	Taconic HT-30	4.8	4 elements along the X-axis. Spacing of d=0.6λ.	Horizontal: $E(\theta=0°,\varphi) = E_0\hat{x}$

Good luck!