<u>CST Project #1 – antenna simulation</u>

In this project you will design and simulate a monopole antenna and arrays using CST. The antenna design is based on parameters that are given in the table below (each student has different design parameters!). The antenna should be fed by a coaxial line with a characteristic impedance that is also given by the same table.

Note the following definitions and remarks:

- 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.
- f is the center frequency of your design, as specified in the table below. Accordingly, T is the time period: $T=1/f$.
- 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.
- While the design task in section #2 is recommended to be done only after the Scattering Parameters (SP) are studied, the rest of the sections require no additional theoretical background (other than studied in class so far).
- 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) Design a coaxial cable with a characteristic impedance that is given by the table below. Specifically, set the radius of the inner core, *a*, and the radius of the external shield, *b*, while the medium in between the inner pin and the external shield is a dielectric material named "Teflon" (its relative dielectric constant can be found in the material's library in CST).
   <u>Note</u>: this coax cable will feed the monopole antenna. Therefore, set its parameters so that they will be mechanically convenient to be used with your monopole. You can also use standard coaxial cable parameters as initial design values.
   Specify the equation/s that helped you choosing the parameters.
2. (10 points) Build a CST model of the coaxial line that was designed in Section #1 above. The length of the coax cable should be 10 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 $0.1f$ -$2f$.
   - 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.
3. (5 points) Change the length of the coax cable to two wavelengths and present the electric field (amplitude and direction) at the middle of the coax cable and the surface current on the coax conductors at the time points t=0, t=T/4, t=T/2, and t=3T/4.
4. (15 points) Now build a model of the monopole antenna along the Z-axis, and its ground plane, according to their parameters in the table below. Use the designed coax cable in order to feed the monopole antenna: create a hole in the ground plane in a diameter which is identical to 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 in order to implement the monopole antenna. Now, fine-tune the length of the monopole in order to achieve a matching (Return Loss, or S_{11} in dB scale) of better than -10dB over the frequency band 0.95*f* -1.05*f*.

- Present the input matching over the bandwidth 0.5*f* -2*f*. Use markers on the plot in order to demonstrate the achieved design goals.
- What is the value of the reflection coefficient at the frequency *f*?
- Compare the optimized length to the theoretical one. If there is any difference, what is the reason for that?
- Present the 3D far field radiation pattern of the monopole at the frequency *f*, and the radiation pattern over the 2 main planes: the X-Z plane ("Elevation") as a function of θ, and the X-Y plane ("Azimuth") as a function of φ. Compare it to the expected radiation pattern according to the theory and explain the differences.
- What is the direction of the peak gain of the monopole, and what is the peak gain and peak directivity values? – Compare them to the expected performance according to the theory and explain the differences. What is the antenna efficiency?
- Present the surface currents on the monopole antenna and on the ground plane. Compare it to the expected results according to the theory and explain the differences, if those exist.

5. (10 points) Next, add to the existing monopole model a "reflector" – another metal plate which is perpendicular to the ground plane, and has a size of 20cm x 20cm, where its normal is in the direction of the X-axis. Place this reflector at a chosen distance of 0.2λ to λ from the monopole, where this distance is optimized in order to achieve maximum peak gain for the antenna. Now, fine-tune the length of the monopole in order to achieve a matching of better than -10dB over the frequency band 0.95*f* -1.05*f*.
    - Present the input matching over the bandwidth 0.5*f* -2*f*. Use markers on the plot in order to demonstrate the achieved design goals.
    - Compare the optimized length to the theoretical one. If there is any difference, what is the reason for that?
    - Present the far field radiation pattern and the gain and directivity of the monopole at the frequency *f*. Compare it to the expected radiation pattern according to the theory and explain the differences. What is the antenna efficiency?
6. (55 points) In this section you are requested to use again the same monopole that was optimized in Section #4 (before adding the side reflector) 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.
    - (5 points) Plot in Matlab the normalized array factor as a function of the φ angle (where φ is defined as the angle between the X-axis and the Y-axis, in the X-Y plane). 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 φ=30°. Note the configuration of your array (along the X-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 was steered to the angle φ=30°. Attach your code file to the solution.
- (10 points) Implement the array in CST by duplicating the single monopole and its feed, according to the total number of elements of your array. If the metal ground planes of the monopoles are not overlapping, fill the entire gap with PEC. Simulate this structure while feeding all of the monopoles with the same electrical phase and plot the 3D radiation pattern, as well as the radiation pattern in the X-Y plane (over the φ angle).
- (3 points) Compare the radiation pattern in the X-Y plane to the theoretical radiation pattern of the array factor.
- (5 points) Compare between the peak directivity of the implemented array to the theoretical directivity of the array of isotropic elements that you found above. What is the antenna efficiency?
- (5 points) Present the input matching over the bandwidth 0.5f -2f of one of the middle elements of your array. 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 monopole?
- (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 geometrical angle φ=30°. Plot the 3D radiation pattern, as well as the radiation pattern in the X-Y plane (over the φ angle).
- (5 points) Present again the input matching over the bandwidth 0.5f -2f, now 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	**Ground plane**	**Frequency *f* [GHz]**	**Coax cable characteristic Impedance [Ω]**	**Array parameters**
203288501	Disc with diameter of 2λ	6.2	50	3 elements along the X-axis. Spacing of d=0.6λ.
205475643	3λ x 1.5λ rectangular	7.2	40	3 elements along the Y-axis. Spacing of d=0.6λ.
206362121	2λ x 2λ rectangular	8.1	30	3 elements along the X-axis. Spacing of d=0.7λ.
206582488	Disc with diameter of λ	10	35	3 elements along the Y-axis. Spacing of d=0.7λ.
207932526	2.75λ x 2.25λ rectangular	10.5	45	3 elements along the X-axis. Spacing of d=0.8λ.
208237131	2λ x 2λ rectangular	11	25	3 elements along the Y-axis. Spacing of d=0.8λ.
212675326	Disc with diameter of 2.5λ	5.8	50	3 elements along the X-axis. Spacing of d=0.9λ.
307854398	2.5λ x 1.75λ rectangular	7.3	40	3 elements along the Y-axis. Spacing of d=0.9λ.

315017954	2λ x 1.75λ rectangular	8.2	30	3 elements along the X-axis. Spacing of d=0.6λ.
315749937	Disc with diameter of 2.25λ	11.3	35	3 elements along the Y-axis. Spacing of d=0.6λ.
322317355	2.25λ x 1.8λ rectangular	8.3	45	3 elements along the X-axis. Spacing of d=0.7λ.
330403163	3λ x 1.7λ rectangular	9.5	25	3 elements along the Y-axis. Spacing of d=0.7λ.
332740547	Disc with diameter of 2.75λ	6.5	50	3 elements along the X-axis. Spacing of d=0.8λ.
345219877	1.5λ x 2.25λ rectangular	6.8	40	3 elements along the Y-axis. Spacing of d=0.8λ.
901281675	1.75λ x 2.8λ rectangular	7.5	30	3 elements along the X-axis. Spacing of d=0.9λ.
905504452	Disc with diameter of 1.75λ	9.7	35	3 elements along the Y-axis. Spacing of d=0.9λ.
907296594	1.25λ x 3λ rectangular	5	45	4 elements along the X-axis. Spacing of d=0.6λ.
923000848	2λ x 4λ rectangular	6.6	25	4 elements along the Y-axis. Spacing of d=0.6λ.
928506963	Disc with diameter of 1.95λ	7.1	50	4 elements along the X-axis. Spacing of d=0.7λ.
930539747	2λ x 2λ rectangular	7.3	40	4 elements along the Y-axis. Spacing of d=0.7λ.
932912850	1.3λ x 2.3λ rectangular	5.2	30	4 elements along the X-axis. Spacing of d=0.8λ.
934381971	Disc with diameter of 2.15λ	6.1	35	4 elements along the Y-axis. Spacing of d=0.8λ.
940823297	2.75λ x 1.75λ rectangular	5.4	45	4 elements along the X-axis. Spacing of d=0.9λ.
946806015	1.95λ x 2.25λ rectangular	7.2	25	4 elements along the Y-axis. Spacing of d=0.9λ.
951265768	Disc with diameter of 2.55λ	5.1	50	4 elements along the Y-axis. Spacing of d=0.6λ.
962505947	0.95λ x 1.75λ rectangular	5.7	40	4 elements along the X-axis. Spacing of d=0.7λ.
963211446	1.75λ x 1.75λ rectangular	6.4	30	4 elements along the Y-axis. Spacing of d=0.7λ.
967518150	Disc with diameter of 2.45λ	6.2	35	4 elements along the X-axis. Spacing of d=0.8λ.
967931932	1.5λ x 1.5λ rectangular	5.3	45	4 elements along the Y-axis. Spacing of d=0.8λ.
969580232	1.5λ x 2.15λ rectangular	6.7	25	4 elements along the X-axis. Spacing of d=0.9λ.
970387635	Disc with diameter of 2.25λ	5.9	35	4 elements along the Y-axis. Spacing of d=0.9λ.
984004101	1.5λ x 2.55λ rectangular	6.8	30	4 elements along the Y-axis. Spacing of d=0.7λ.
996118063	1.95λ x 2.85λ rectangular	5.2	45	4 elements along the X-axis. Spacing of d=0.8λ.
997660873	Disc with diameter of 1.35λ	4.7	50	3 elements along the X-axis. Spacing of d=0.6λ.

Good luck!