Electromagnetics Class Project (2 Credits)   Spring 2019

You will work on the class project of the Electromagnetics course, which accounts for 2 credits, during this summer semester. You are to team up with one other student in the class for all the technical portion of the project. You can simply adopt the grouping of your previous experiments. One team turn in one project report and both team members get the same grade for this class project. **The report is due July 23.** This class project pertains to the study, design, simulation and fabrication of microstrip antennas and frequency selective surface, measurement of dielectric constant using rectangular waveguides, as well as designing novel electromagnetic beams. Fundamentals of patch antennas, frequency selective surface and microwave radar can be found in the book chapter and slides provided to you. You may also need to dig out some useful information from other books or online resources by yourself.

There are in total four problem sets formed by five different topics for you to choose, which are listed in the table shown below. Each problem set has two topics and detailed descriptions are as follows. Topic 1 is mandatory for all groups while the other topic is chosen from Topic 2 to 5. The other topic can also be replaced by some customized projects. You can propose any topics related to electromagnetics that you would like to explore and need to get my permission by **June 28**. Your proposals must have sufficient details of procedures and expected results.

	Topic 1	***Topic 2***	***Topic 3***	***Topic 4***	***Topic 5***
Problem Set 1	√	√			
Problem Set 2	√		√		
Problem Set 3	√			√	
Problem Set 4	√				√

CST software will be used to simulate the antennas. The software is installed on computers in the lab 1D102, which will be open for you during the summer semester. The VNA for experimental measurement is at my lab 1D406. Your TAs will provide necessary help on all the simulation, derivation and experiments. **You have to be very careful and follow the advice of your TAs when using the experimental devices.**

Successful completion of the topics includes the simulation work, derivation, measurements and reports. Your TAs will check your simulation results as well.

Topic 1

Read 14.1 and 14.2.1 of the book *Antenna Theory and Design* to gain basic knowledge of patch antenna.

Design one patch antenna working at the frequency and using the substrate given below.

Each team performs the design of the antenna at a unique frequency ranging from **2 to 3.7 GHz with a step of 0.05 GHz**, meaning in total 35 different frequencies for 35 teams. You will draw lots to determine the specific frequency of each group, which will be arranged on **June 24, 1:00 pm at SIST 1A200**.

The substrate is lossless and has a relative permittivity of **4.4** and a height of 1 mm. The copper layer on top and bottom of the substrate is 35 μm.

Use the microstrip line feed method. The characteristic impedance of the air-filled coaxial probe is 50 Ω. Its inner conductor has a diameter of 2 mm and outer conductor has a diameter of 4.6 mm. You will need to figure out the location of the coaxial probe where the optimal matching condition at your design frequency can be achieved.

Use CST software to draw the models of the antenna. Set all the materials and simulation parameters. After the simulations are done, you need to check the simulation results to judge if some design considerations are fulfilled, which includes the following aspects.

1) Check $|S_{11}|$ (return loss) to see if the antenna is working at your design frequency. This can be judged by observing if the dip of the $|S_{11}|$ curve is at your design frequency. If not, adjust the size of the patch or the location of the feed as well.
2) Check $|S_{11}|$ to see if acceptable matching condition is obtained. Acceptable matching condition means that $|S_{11}| < -10$ dB at the working frequency. If not, try to tune the location of the coaxial probe and/or the size of the patch. Tuning the location of the coaxial probe may in turn alter the working frequency of the antenna, so you need to readjust the size of the patch.
3) Try to make the relative bandwidth (frequency range in which $|S_{11}|$ is less than -10 dB) as wide as possible, which is defined as $(f_{high} - f_{low})/f_{design}$. Here f_{high} and f_{low} denote the higher and lower frequency of the band, respectively. Try to make its relative bandwidth greater than 2%.
4) Also check the radiation pattern, efficiency and gain.

The antenna will be fabricated by a company. You need to prepare a file of the antenna structure in proper format. Be sure to follow the advice of your TAs when making these files. After you obtain the fabricated antenna, solder a coaxial connector to it and use a VNA to measure its reflection coefficient. Compare their measured and simulated results in your report. It is also possible to measure the 3D radiation pattern of your patch antenna using an anechoic chamber.

Please give the TA your detailed design parameters and proper layout file for the antenna in ***Topic 1*** by **July 4**. It takes about 10 days to fabricate it. **This is a firm deadline!!!**

Topic 2

Read 14.8 of the book *Antenna Theory and Design* to gain basic concepts of patch antenna array.

Design two patch antenna arrays working at the **same frequency** as you used in Topic 1. Use the one you designed with relative permittivity of **4.4** as the element of these arrays. Each array has **four elements**.

For the first array, use the microstrip line feed method. Also use a coaxial probe port at the beginning of the microstrip line. The characteristic impedance of the microstrip line and air-filled coaxial probe are both 50 Ω. The four elements of this array are arranged in a line. Try at least 6 different phase combinations to see the overall effects and enclose the results in your report. This designed array will be then fabricated. For the subsequent measurements, a signal generator and a one-to-four power divider is employed to provide excitation signals for the array. Four phase shifters are applied to tune the phases of the excitation signals for the four elements. Radiation pattern of this array will be measured.

For the second array, use the probe feed method. CST has a function that can assign arbitrary amplitude and phase to each array element. Try at least 6 different combinations (including both phase and amplitude) to see the overall effects and enclose the results in your report. The four elements of this array should be arranged in a square manner (2 × 2). This array will not be fabricated and only simulation results are needed.

Use CST software to draw the models of the two arrays in two different files. Set all the materials and simulation parameters. After the simulations are done, you need to check the simulation results including the working frequency, return loss, matching, radiation pattern and gain.

Please give the TA your detailed design parameters and proper layout file for the first array in ***Topic 2*** by **July 4**. It takes about 10 days to fabricate it. **This is a firm deadline!!!**

Topic 3

Read the slides regarding frequency selective surface (FSS) to gain basic concepts.

Design a transmission type metal FSS that can only allow the transmission of waves at 24 GHz (the working frequency of a radar system in the teaching lab) but suppress other frequencies. This means $|S_{11}|$ curve has a very sharp dip at 24 GHz.

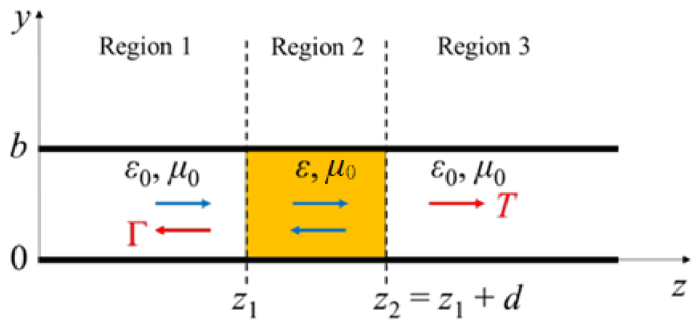
The FSS should be made on a copper layer with a thickness of 35 μm. Use the substrate with a relative permittivity of **4.4** and a height of 1 mm to support the metal layer. Actually, the substrate is not necessary, but it is convenient to fabricate the FSS on a circuit board.

The FSS will be fabricated by a company. You need to prepare a file of the FSS structure in proper format. Be sure to follow the advice of your TAs when making these files. After you obtain the fabricated FSS, put the FSS just in front of the radar antenna to see if good performance of the radar system can still be obtained.

Topic 4

Use a rectangular waveguide to measure dielectric property of some materials. Schematic configuration of this problem is shown below. The incident wave propagating in $+z$ direction is in air-filled Region 1 and hits the material to be measured in Region 2. The material to be investigated is machined into a rectangular shape that with a cross sectional dimension of $a \times b$ and a thickness of d in the z direction, so the material can exactly fit inside the waveguide (no air gap between the material and the metal walls of the waveguide). Some wave will be transmitted to Region 3, which is also air-filled. In reality, we can measure the reflection and transmission coefficients and derive the dielectric properties from these two factors, both with amplitude and phase. The material to be tested can be assumed to be nonmagnetic and lossless, which can greatly simplify the problem. You need to first write out the fields in all the three regions using the method we have covered in class. Then solve for the reflection and transmission coefficients, which will be expressed in terms of the permittivity of the material under test. Finally, derive the permittivity of the material under test in terms of the reflection and transmission coefficients.

We provide some polymer bricks made by a 3D printer to serve as the lossless material to be tested. You can also bring some other kinds of materials you would like to measure, but they should be lossless and can be shaped into a brick with proper size that can fill the waveguide you use. Experiment will be done using a VNA. We have in total eight different waveguide sets working at different frequencies. You can choose any one from them.



Topic 5

Read the slides and papers regarding metasurface, Bessel beams, Airy beams or beams with orbital angular momentum (OAM) to gain basic concepts.

Design a metasurface to generate a Bessel beam or an Airy beam in the millimeter wave range or sub-THz range (around 100 GHz). Different phase shift is achieved by tuning the unit element of the metasurface. The designed metasurface needs to offer a required phase distribution for a Bessel beam, an Airy beam, or an OAM beam. Example designs at lower frequencies are provided as a reference. Simply adjusting dimensions of the structure of the unit element can tune the operating frequency of the metasurface. TAs will guide you step by step for all the related details.

Use CST software to first draw the models of the unit element and tune its parameters. Then set up another model of the entire metasurface consists of at least 50 $\times$ 50 unit elements to simulate the generated beam. You need to check the simulated phase and amplitude of the generated beam to verify your design. Only simulation results are needed.