Texas A&M University

Earth Reflections Mission

ECEN 322 - Project #2

Group 17: Otabek Mavlonov, Daniel Pasket, Joaquin Salas, Joey See

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Division of Work among Members of the Team

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Deliverable 4	Daniel Pasket, Joey See

The division of deliverables is shown above. Each member of the team worked to complete each deliverable before the project deadline to ensure time for the other team members to complete cross-checking. Effectively communicating and working together in person made this project successful.

Deliverable 1

Mission Statement

Team 17 is dedicated to advancing radar mapping technologies through the deployment of an airborne radar system. Our mission involves detailed mapping of a specific region suspected to contain Material X, which is a critical component for upcoming projects. The project's scope includes characterizing Material X's electromagnetic properties, studying its frequency-dependent behavior, and designing a specialized radome to enhance radar performance and protect the radar equipment on the aircraft. Our team discovered the frequency and the dielectric constant which are shown below:

Material X (Group 17):

Frequency (GHz) - 26.08 GHz

Estimated Dielectric Constant - 32.89

Dielectric Constant Variation as a Function of Frequency

Understanding the dielectric constant's variation with frequency is important for radar signal analysis. This determines how the electromagnetic waves transmitted by the radar will interact with the material. It has been observed that Material X has an inverse relationship between frequency and dielectric constant; as the frequency increases, the dielectric constant decreases. This information is important for setting up our radar system to have proper penetration and reflection measurements.

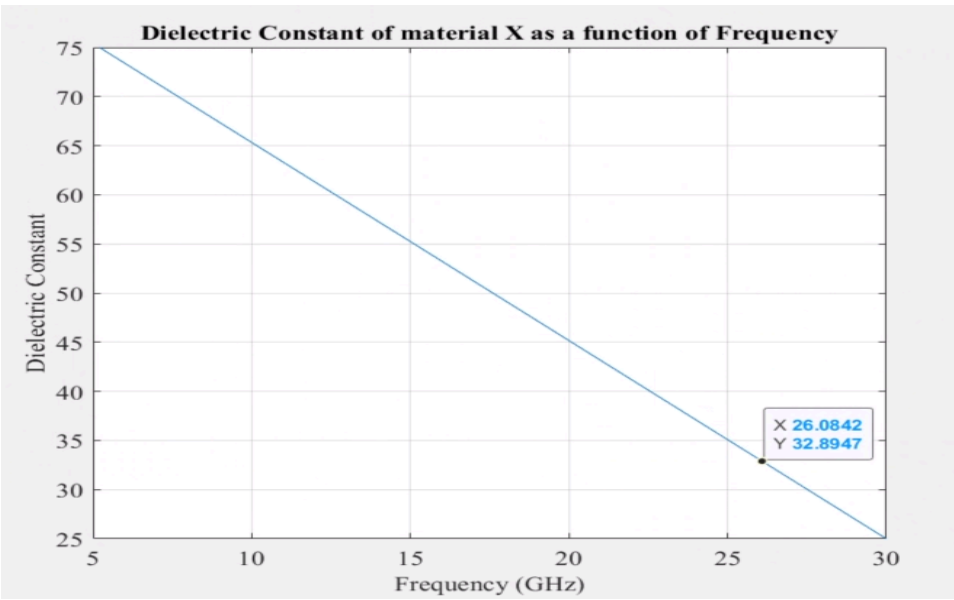

Figure 1 - Dielectric Constant of Material X as a function of Frequency (code in the appendix)

Deliverable 2

Process for Calculating the Reflection Coefficient

First, take the value of the dielectric constant found in part 1 (32.8947) and take the square root of it to get the refractive index (5.73539) of the dielectric as shown below. Set this as n2.

$$n = \sqrt{\varepsilon_r} \qquad \textbf{Refractive Index Equation}$$

Assuming air to be our incident media, we can set $n_1 = 1$ (relative permittivity of air is approximately 1 and hence the refractive index is $\sqrt{1} = 1$).
Now we have everything we need to find the reflection constant for parallel (p) polarization over a range of angles by using the rightmost expression in the following equation.

$$R_p = \left| \frac{n_1 cos(\theta_t) - n_2 cos(\theta_i)}{n_1 cos(\theta_t) + n_2 cos(\theta_i)} \right|^2 = \left| \frac{n_1 \sqrt{1 - (\frac{n_1}{n_2} sin(\theta_i))^2} - n_2 cos(\theta_i)}{n_1 \sqrt{1 - (\frac{n_1}{n_2} sin(\theta_i))^2} + n_2 cos(\theta_i)} \right|^2 \qquad \textbf{Reflection Coefficient Equation}$$

Once again, n_1 is the refractive index of air (1) and n_2 is the refractive index of the dielectric (5.73539), as previously calculated.

The equation giving the reflection coefficient can be found by combining the Fresnel equation (the middle expression without any square roots) for parallel polarization with Snell's Law (below) to get the rightmost equation (above) and the one we will use to get the Fresnel coefficient graph (pictured below).

$$n_1 sin(\theta_1) = n_2 sin(\theta_2) \qquad \textbf{Snell's Law}$$

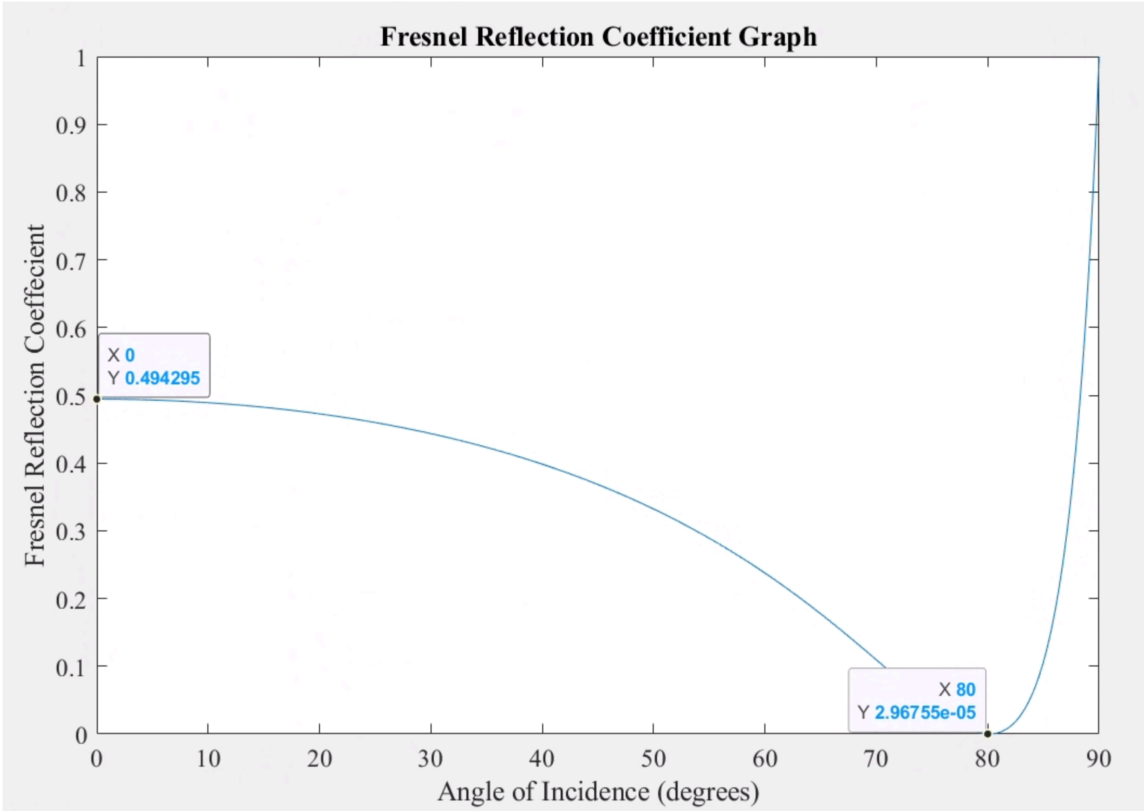

Figure 2 - Fresnel Reflection Coefficient Graph (code in the appendix)

Description of the Plot and Angles of Interest

Observing the plot, we can see that the graph initially has a slight negative slope, which increases as it reaches Brewster's angle (the point at which ~0 reflection occurs). Up to this point, the graph looked somewhat like an upside-down parabola. However, after hitting Brewster's angle the graph's slope becomes positive and increasingly so, such that by 90° the reflection coefficient equals 1, and complete reflection occurs. In other words, Fresnel's reflection coefficient initially decreases as the angle of incidence is increased, decreasing more rapidly the closer the angle is to Brewster's angle, and then, after reaching Brewster's angle, increases rapidly to ensure that at 90° Fresnel's reflection coefficient is essentially 1 (unity).

At the incidence angle of 80°, we encounter Brewster's angle and there is (basically) zero reflection; the entire signal gets transmitted into Material X. We'd like to avoid this occurring in our experiments since we rely on reflection for our radar to work (if there is no reflection we will have no radar echo to analyze and measure).

At an incidence angle of 0° the magnitude of the reflection coefficient is 0.494295, which means that at an incidence angle of 0°, approximately half the wave will be transmitted and half reflected.

Deliverable 3

Radome Material Synopsis Table

	Material Name	Dielectric Constant
Radome Material #1	FR-4 Glass Epoxy	4.0 - 4.5 @1MHz
Radome Material #2	Ceramic-Filled PTFE Composites	6.50 @10GHz; ~2.5 @1MHz
Radome Material #3	High-Density Polyethylene (HDPE)	2.3 @1MHz (2.2 - 2.4)

Radome Design Process and Key Considerations

When selecting a material for the radome, our team considered several factors including the dielectric constant, cost, and performance under specific conditions. Among the options, FR-4 Glass Epoxy, known for its high dielectric constant, was found unsuitable as it could negatively impact the radar's performance. Ceramic-filled PTFE Composites offered a lower dielectric constant but were not selected due to the project's requirements not demanding ultra-precise measurements.

Choice of Radome Material: High Density Polyethylene (HDPE)

Material Selection Rationale

Our team ultimately chose High-Density Polyethylene (HDPE) for the radome's construction. This decision was driven by HDPE's dielectric properties and its cost-effectiveness. HDPE's dielectric constant was close enough to that of Ceramic-Filled PTFE Composites to meet the operational needs without the higher costs.

Considerations and Material Drawbacks

We identified a drawback with HDPE related to its performance in varying temperatures. While HDPE has a high melting point, it can deform under constant high temperatures. Fortunately, the operational environment of an aircraft typically involves high altitudes where temperatures are cooler and constant air movement mitigates this risk, allowing the radome to maintain its structural integrity and functional performance.

Calculations

$t = \frac{n \cdot \lambda_m}{2}$ $\quad l = \frac{n \cdot \lambda_0}{2}$ $\quad \lambda_0 = \frac{c}{f}$ $\quad \lambda_m = \frac{c}{f \cdot \sqrt{\varepsilon_r}}$ **Equations used**

Known Variables

$c = 3 \times 10^{8} m/s$ $\quad f = 26.08 \times 10^{9} Hz$ $\quad \varepsilon_r = 2.3\ (for\ HDPE)$

$n = \sqrt{\varepsilon_r} = \sqrt{2.3} = 1.51657$

$t = \frac{\sqrt{2.3} \cdot \frac{3\times10^{8}}{26.08\times10^{9} \cdot \sqrt{2.3}}}{2} = 0.00575 = 5.75mm$ $\quad l = \frac{\sqrt{2.3} \cdot \frac{3\times10^{8}}{26.08\times10^{9}}}{2} = 0.0087m = 8.7mm$

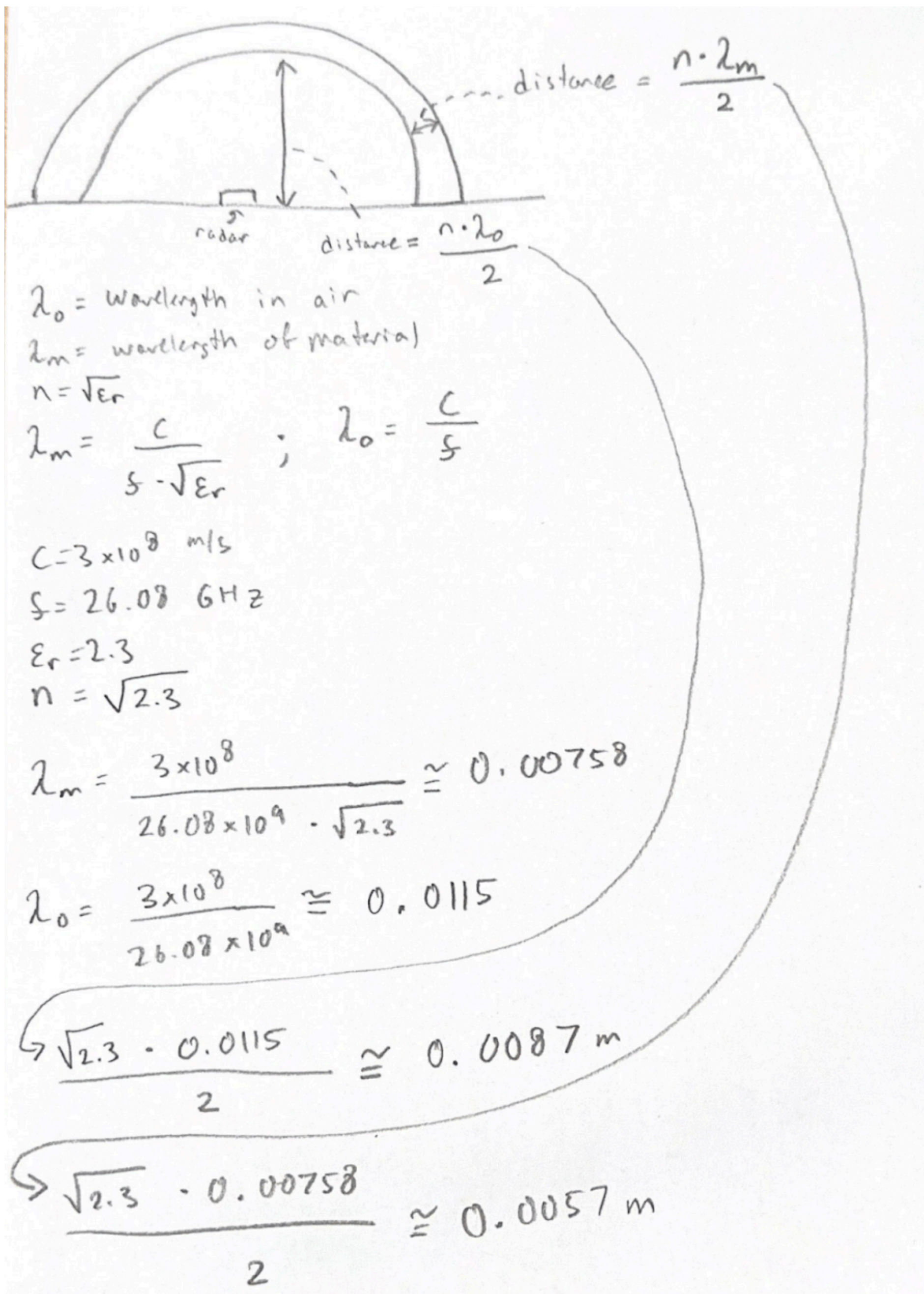

Figure 3 - The geometry of the radome with designed thickness and calculations.

Deliverable 4

Equation for Dielectric Constant from Reflection

The equation to find the dielectric constant of a material from the reflection constant measured when directing radar onto it is as follows:

$$\varepsilon_{r,2} = \left(\frac{1-\Gamma}{1+\Gamma}\right)^2$$

Figure 4 - Derivation for $\varepsilon_{r,2}$ (Full derivation in Appendix)

MatLab Calculations

By running the code located in the appendix associated with this section and querying it via the command line, it was possible to get the $\varepsilon_{r,2}$ values for the requested pixels.

$\varepsilon_{r,2}(516,\ 305)\ =\ 31.6598$

$\varepsilon_{r,2}(90,\ 156)\ =\ 15.6081$

Requested Pixel Values

Furthermore, from that code, we were able to generate the following image (on the next page), scaled and labeled as requested. With regards to scaling, our minimum $\varepsilon_{r,2}$ value was 2.5 and our maximum was 35.3947, as such the color bar was scaled to a minimum of 2 and a maximum of 37.

Plotted Data and Analysis

The plotted data seems to primarily have two types of material with small differences in properties within said regimes of material, with there being present only two primary (although static-y) types of color on the color map. Furthermore, it is immediately apparent to any Texan that the image generated by the data is that of the Gulf of Mexico, with the blue color (low dielectric value) representing land and the yellow color (high dielectric value) representing water or the ocean. Knowing this, it'd appear that the data was collected by either satellite or high-altitude plane using radar altimetry.

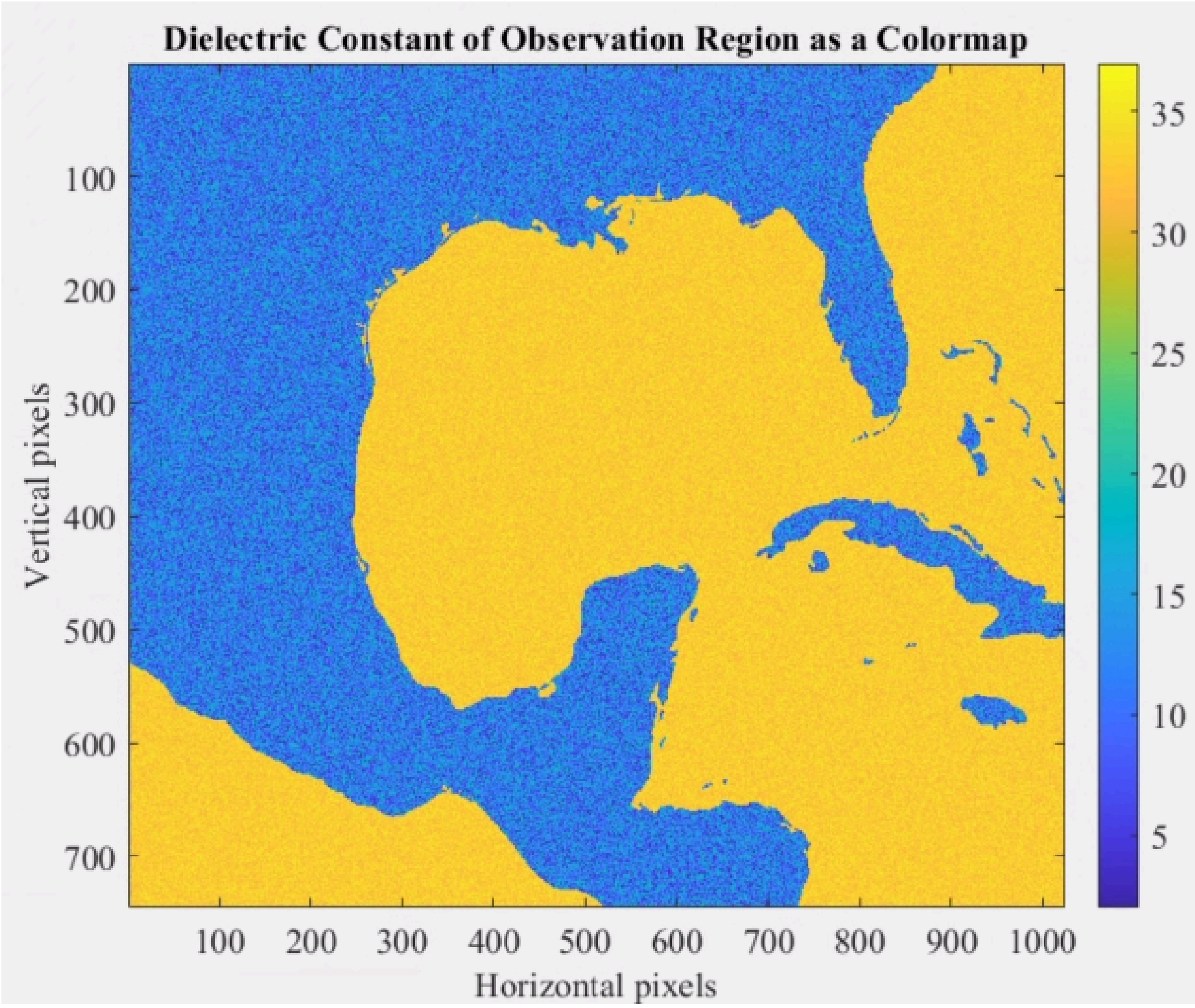

Figure 5 - Dielectric Constant of Observation Region as a Colormap (code in the appendix).

Comparison with Part 1:

The region that consists of Material X would be the region corresponding to the ocean in the image above, AKA the area shaded with cross-hatching in the image below. This is because the ocean region in the mapping was found to have dielectric constant values that approximate the dielectric constant found for Material X, which was found to be 32.89.

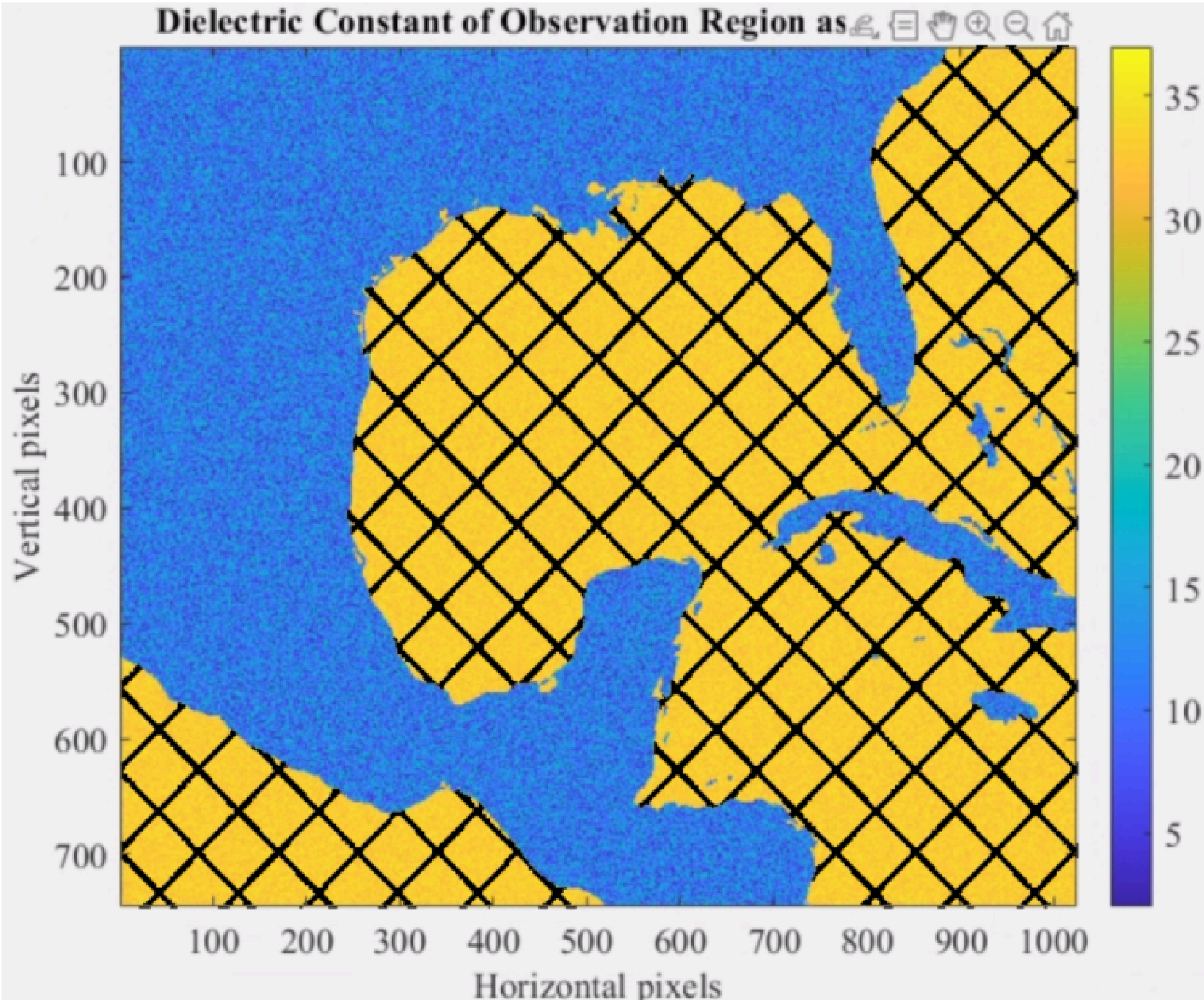

Figure 5a - Plot with cross-hatching to identify regions of Material X.

Identity of Material X:

Material X appears to be seawater, as the dielectric constant material X calculated in part 1 matches the average dielectric constant found in the ocean in the image above.

Frequency for greatest contrast between Material X and rest of measurement region:

10GHz would be ideal to view the greatest contrast between Material X and the rest of the measurement region. This is because at lower frequencies the dielectric constants would be larger and thus would portray a larger contrast.

Appendix

Figure 1 - Dielectric Constant of Material X as a function of Frequency

---

```
dielec = readmatrix('Dielectric_constant_data');
disp(dielec(17,1)); % for group 17, output - 26.0842 GHz
disp(dielec(17,2)); % output - 32.8947 (dielectric constant)
frequency = dielec(:,1); % first column is frequency
dielectric_constant = dielec(:,2); % second is dielectric constant
% plot
figure;
dielectricPlot = plot(frequency, dielectric_constant);
% labels
xlabel('Frequency (GHz)');
ylabel('Dielectric Constant');
title('Dielectric Constant of material X as a function of Frequency');
grid on;
% prettify, place marker
fontsize(14,"points")
fontname("Times New Roman")
datatip(dielectricPlot, 26.0842, 32.8947)
```

Figure 2 - Fresnel Reflection Coefficient Graph

```
dielectricConstant = 32.8947;
n1 = 1; %since Er of air = 1
n2 = sqrt(dielectricConstant);
a = 0:.01:90;
% do calculations
Rp =
abs(((n1.*sqrt(1-(n1.*sind(a)./n2).^2))-n2.*cosd(a))./((n1.*sqrt(1-(n1.*sind(a
)./n2).^2))+n2.*cosd(a))).^2;
RpPlot = plot(a, Rp);
% prettify, place markers
fontsize(14,"points")
fontname("Times New Roman")
title("Fresnel Reflection Coefficient Graph")
xlabel('Angle of Incidence (degrees)')
ylabel('Fresnel Reflection Coefficient')
datatip(RpPlot, 80, 0)
datatip(RpPlot, 0, .5)
```

Figure 3 - Derivation for $\varepsilon_{r,2}$

The materials are assumed to be lossless and nonmagnetic and we can assume $\varepsilon_{r,0}$ is approximately 1 (the relative permittivity of air), so intrinsic impedance can be found as follows:

$$\eta_0 = \sqrt{\frac{\mu_{r0}\mu_0}{\varepsilon_{r,0}\varepsilon_0}} = 376.734$$

$$\eta_2 = \sqrt{\frac{\mu_{r2}\mu_0}{\varepsilon_{r,2}\varepsilon_0}} = 376.734\sqrt{\frac{1}{\varepsilon_{r,2}}}$$

As such, we can find

$$\Gamma = \frac{376.734\sqrt{\frac{1}{\varepsilon_{r,2}}}-376.734}{376.734\sqrt{\frac{1}{\varepsilon_{r,2}}}+376.734} = \frac{\sqrt{\frac{1}{\varepsilon_{r,2}}}-1}{\sqrt{\frac{1}{\varepsilon_{r,2}}}+1}$$

We can then use this equation to solve for $\varepsilon_{r,2}$ in terms of Γ, as follows:

$$\Gamma\sqrt{\frac{1}{\varepsilon_{r,2}}} + \Gamma = \sqrt{\frac{1}{\varepsilon_{r,2}}} - 1$$

$$\Gamma + 1 = \sqrt{\frac{1}{\varepsilon_{r,2}}} - \Gamma\sqrt{\frac{1}{\varepsilon_{r,2}}}$$

$$\Gamma + 1 = \sqrt{\frac{1}{\varepsilon_{r,2}}}(1 - \Gamma)$$

$$\sqrt{\frac{1}{\varepsilon_{r,2}}} = \frac{1+\Gamma}{1-\Gamma}$$

$$\frac{1}{\varepsilon_{r,2}} = (\frac{1+\Gamma}{1-\Gamma})^2$$

$$\varepsilon_{r,2} = (\frac{1-\Gamma}{1+\Gamma})^2$$

Figure 4 - Dielectric Constant of Observation Region as a Colormap

```
% load data into input array, prepare output array
Data = readmatrix('Team_17.txt');
[num_rows,num_cols] = size(Data);
outData = zeros(num_rows,num_cols);
% loop through input, calculate output
for rows = 1 : num_rows
  for columns = 1 : num_cols
      gamma = Data(rows,columns);
      er2 = ((1-gamma)/(1+gamma))^2;
      outData(rows,columns) = er2;
  end
end
% display and format output image
image(outData,'CDataMapping','scaled');
clim([2, 37]);
xlabel('Horizontal pixels');
ylabel('Vertical pixels');
title('Dielectric Constant of Observation Region as a Colormap');
colorbar
% prettify
fontsize(14,"points")
fontname("Times New Roman")
```