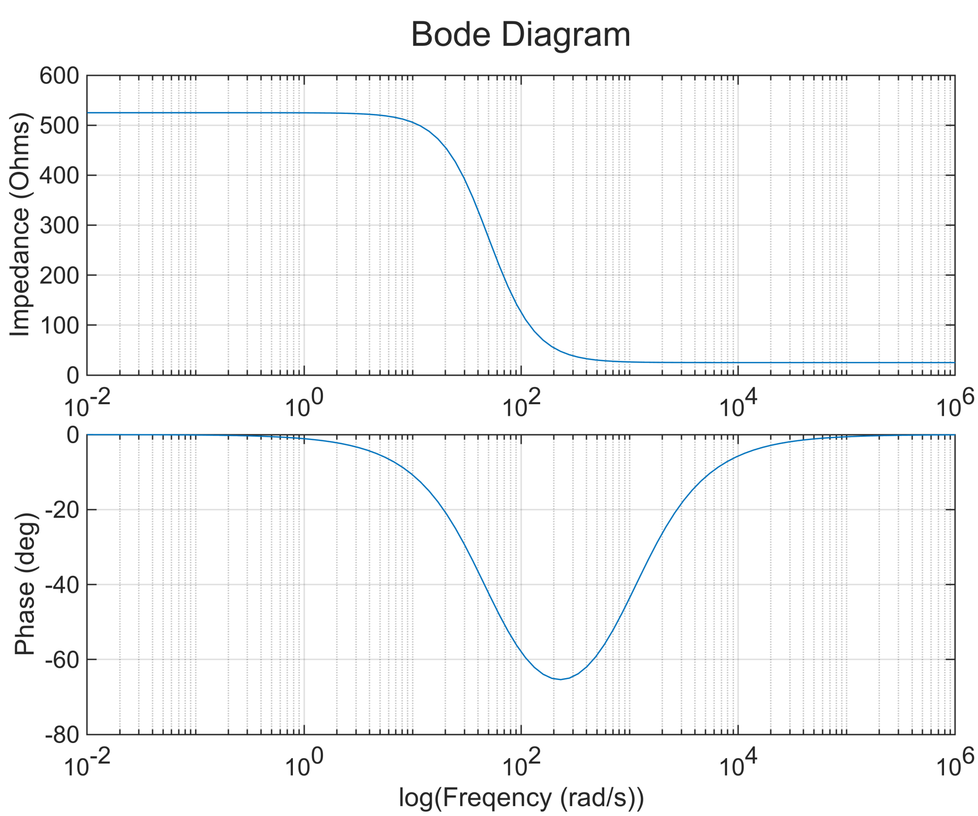
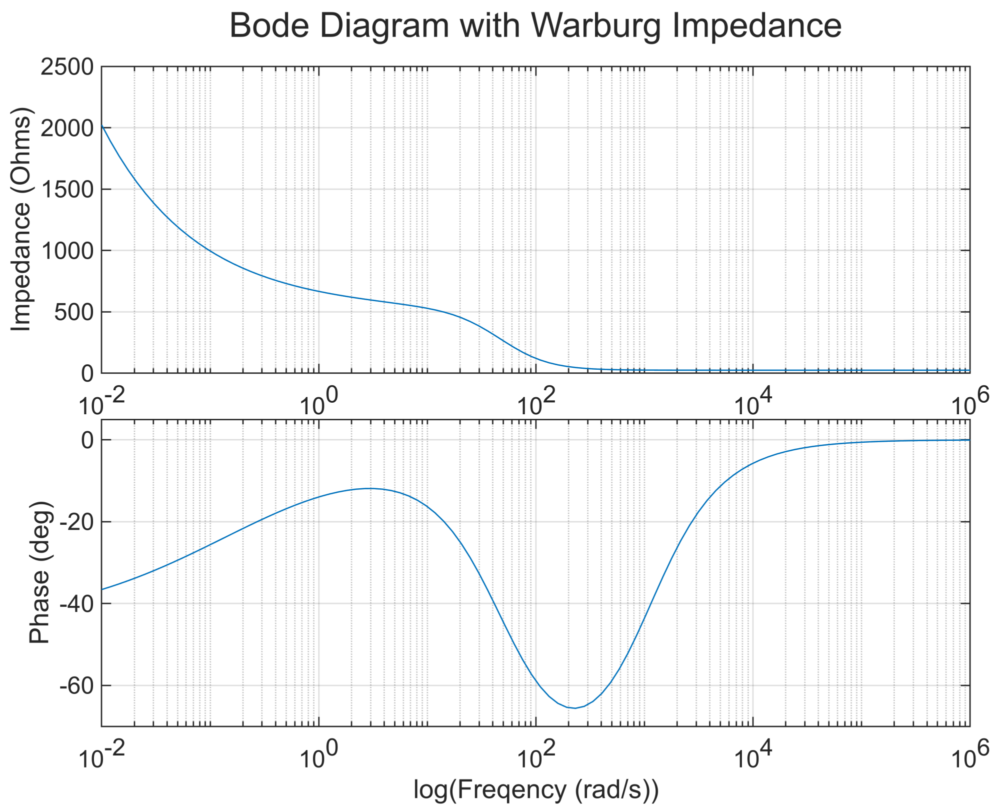
```matlab
% Question 1a
close all

R_s = 25; % Ohm
R_ct = 500; % Ohm
C_dl = 40e-6; % F
R_par = (R_s*R_ct)/(R_s+R_ct);

freq = logspace(-2,6,100);

Z_faradaic = R_s*(1i*freq+(1/(R_par*C_dl)))./(1i*freq+(1/(R_ct*C_dl)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
grid on
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)");

sgtitle("Bode Diagram")
```

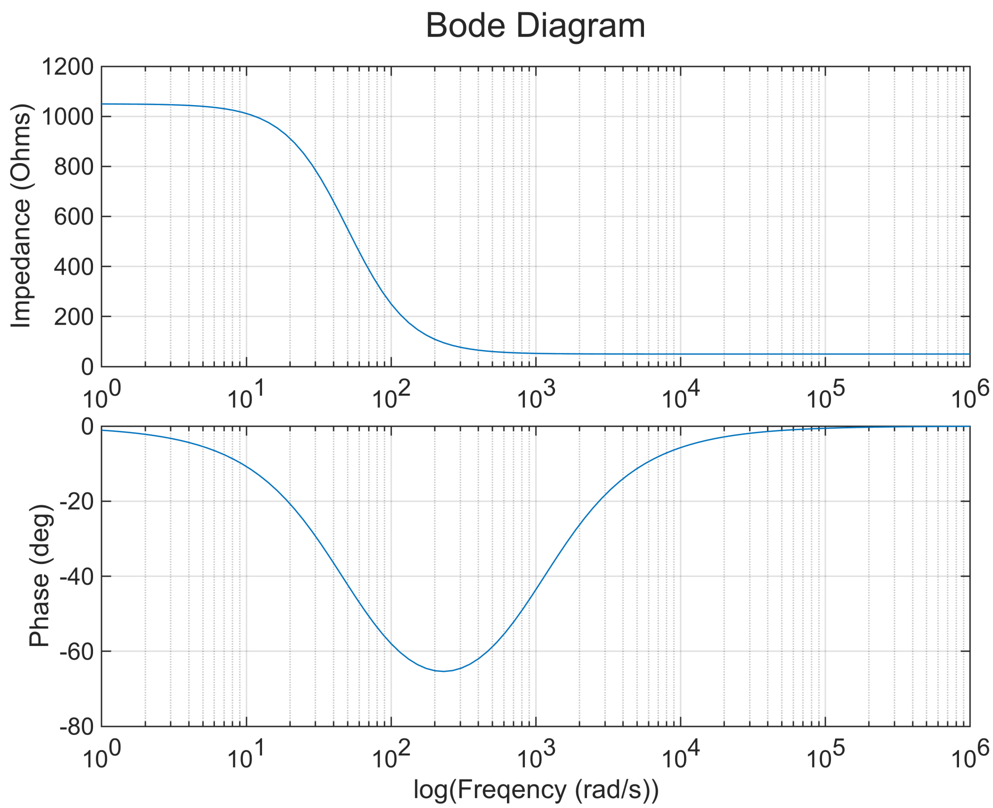


```
% Question 1b
close all

R_s = 25; % Ohm
R_ct = 500; % Ohm
C_dl = 40e-6; % F
warCoef = 150; % Ohm/s

freq = logspace(-2,6,100);

Z_w = warCoef*freq.^(-1/2).*(1-1i);

Z_1 = R_ct + Z_w;

Z_2 = (Z_1.*(1./(1i*freq*C_dl)))./(Z_1+(1./(1i*freq*C_dl)));

Z_faradaic = R_s + Z_2;

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
grid on;
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on;
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)"); ylim([-70 5]);

sgtitle("Bode Diagram with Warburg Impedance")
```



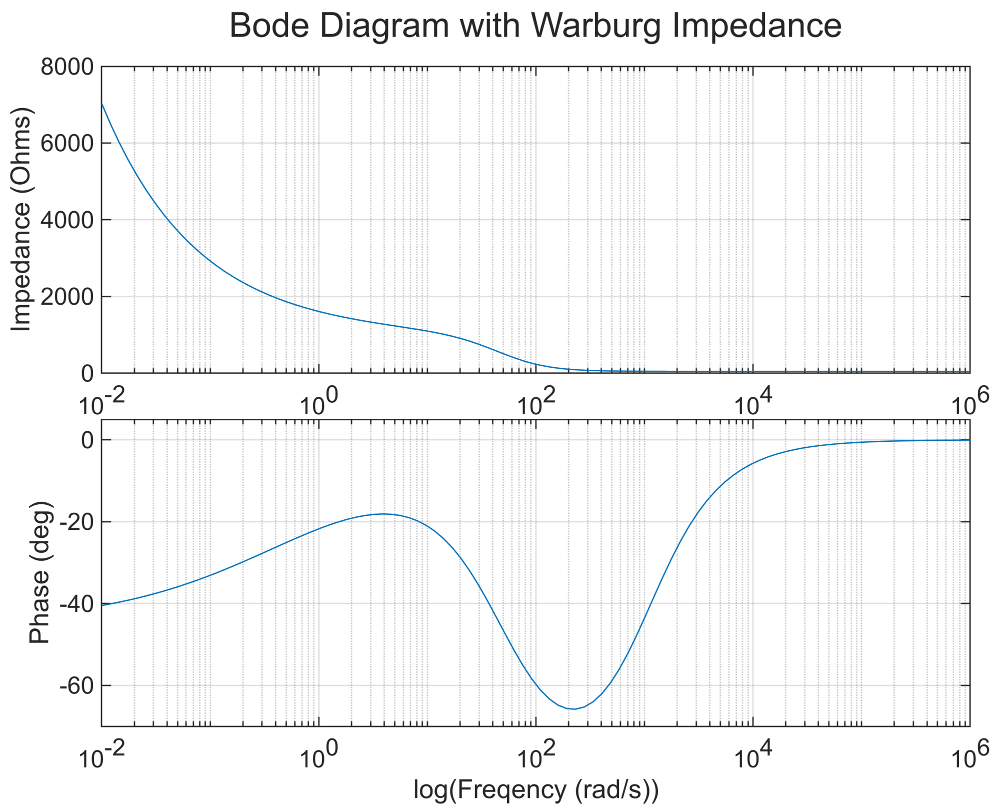

```
% Question 1c
close all

R_s = 50; % Ohm
R_ct = 1000; % Ohm
C_dl = 20e-6; % F
R_par = (R_s*R_ct)/(R_s+R_ct);

freq = logspace(0,6,100);

Z_faradaic = R_s*(1i*freq+(1/(R_par*C_dl)))./(1i*freq+(1/(R_ct*C_dl)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
grid on
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)");
```

```
sgtitle("Bode Diagram")
```

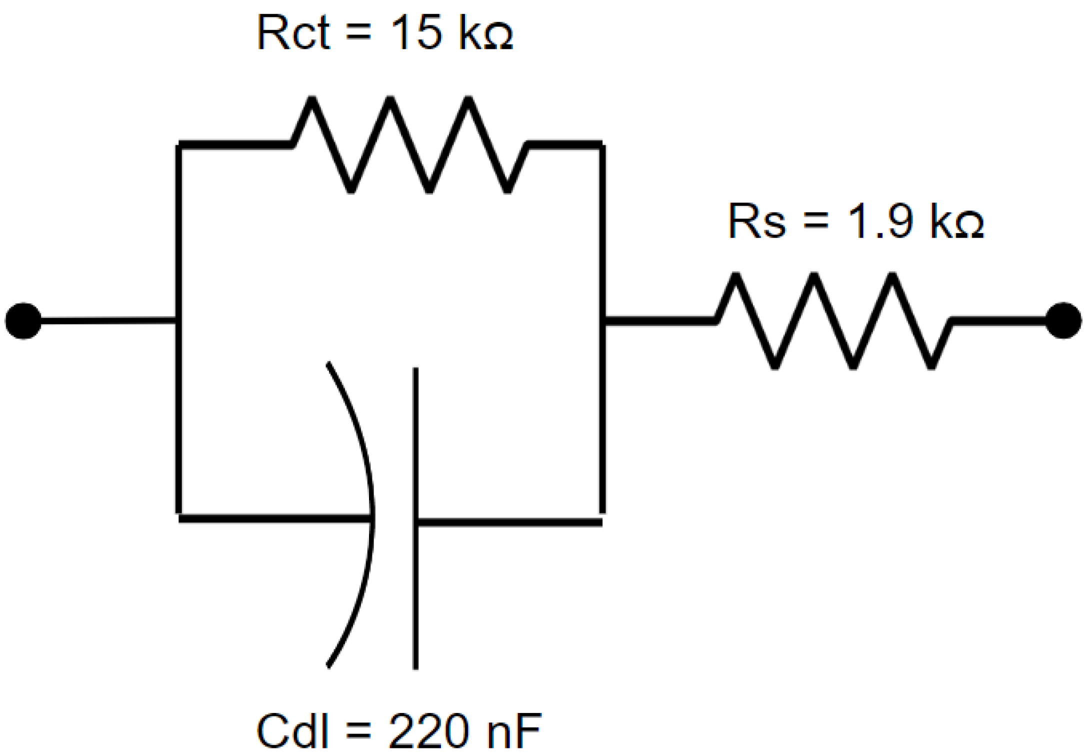



```
% Question 1d
close all

R_s = 50; % Ohm
R_ct = 1000; % Ohm
C_dl = 20e-6; % F
warCoef = 600; % Ohm/s

R_par = (R_s*R_ct)/(R_s+R_ct);

freq = logspace(-2,6,100);

Z_w = warCoef*freq.^(-1/2).*(1-1i);

Z_1 = R_ct + Z_w;

Z_2 = (Z_1.*(1./(1i*freq*C_dl)))./(Z_1+(1./(1i*freq*C_dl)));

Z_faradaic = R_s + Z_2;

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
```

```
grid on;
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on;
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)"); ylim([-70 5]);

sgtitle("Bode Diagram with Warburg Impedance")
```

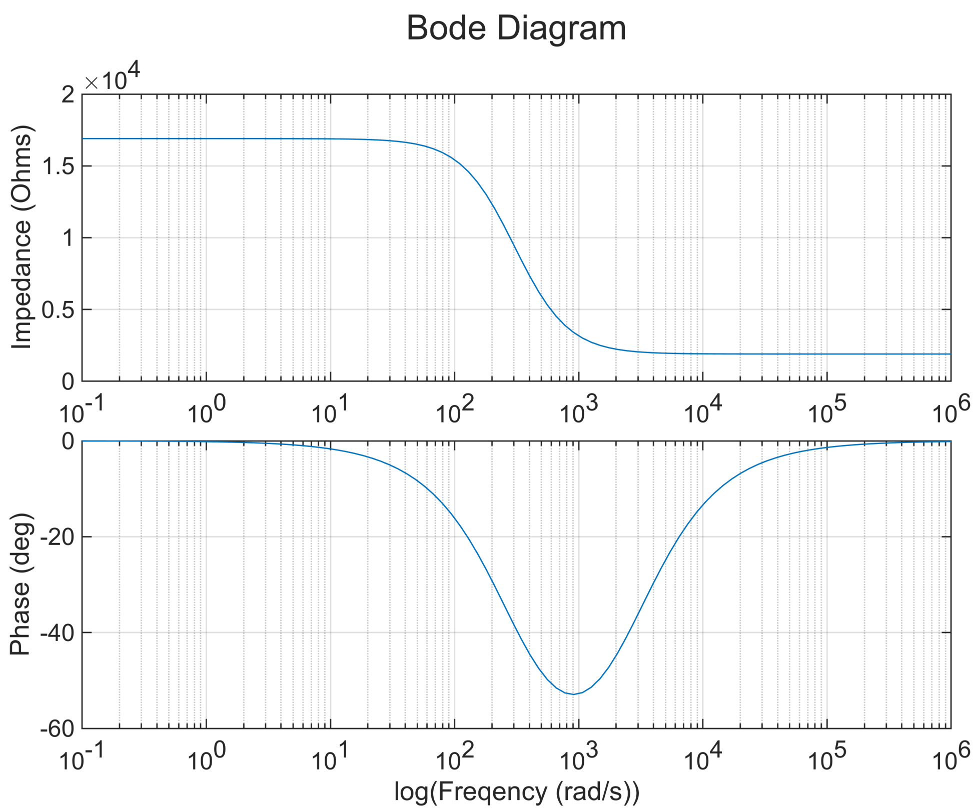



```
% Question 2a
close all
imshow("Randles_2a.png");
```




```
% Question 2b
close all

R_s = 1900; % Ohm
R_ct = 15000; % Ohm
C_dl = 220e-9; % F
R_par = (R_s*R_ct)/(R_s+R_ct);
freq = logspace(-1,6,100);

Z_faradaic = R_s*(1i*freq+(1/(R_par*C_dl)))./(1i*freq+(1/(R_ct*C_dl)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
grid on
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on
xlabel("log(Freqency (rad/s))");
```

```
ylabel("Phase (deg)");

sgtitle("Bode Diagram")
```




```
% Question 2c

effAreaFactor = 3.8; % Given

% C_dl is directly proportional to the electrochemical surface area of the
% electrode, so eliminating the roughness would decrease C_dl by the
% effective area factor

C_dl = 220e-9; % F
C_dl_no_rough = C_dl / effAreaFactor % To be used in model
```

```
C_dl_no_rough = 5.7895e-08
```

```
% R_s is dependent on the geometric surface area, so eliminating roughness
% will have no effect on R_s

R_s = 1900; % Ohm
R_s_no_rough = R_s
```

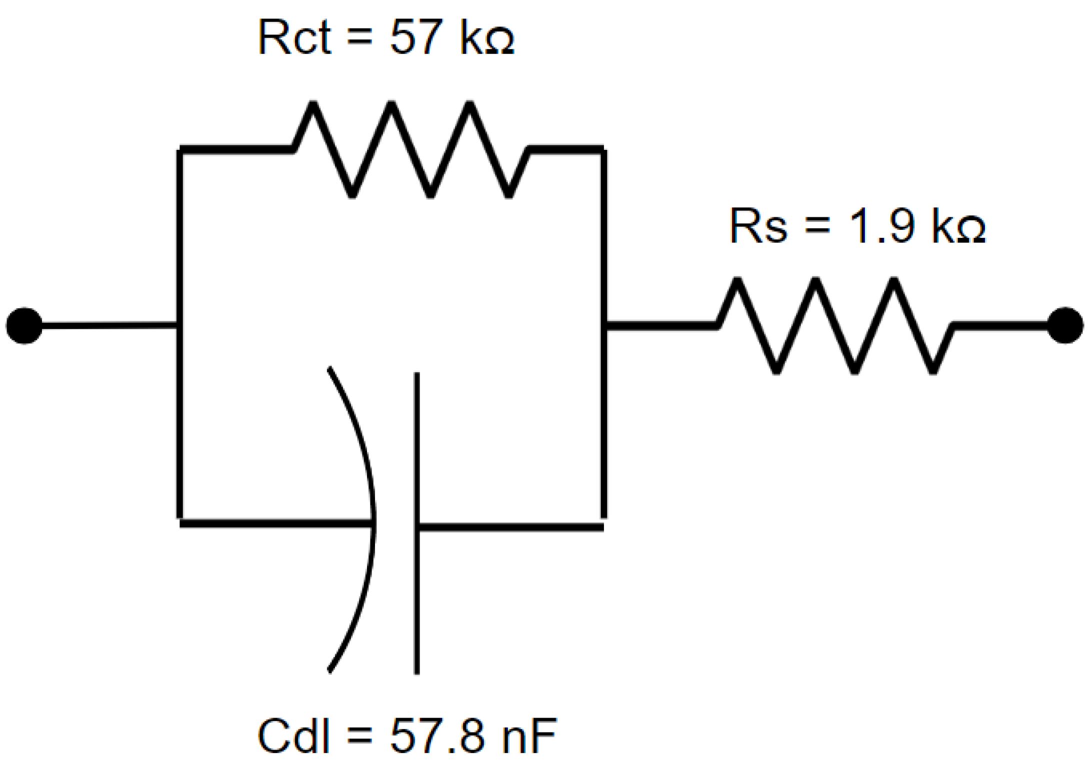
```
R_s_no_rough = 1900
```

```
% R_ct is inversely proportional to the electrochemical surface area of the
% electrode, so eliminating the roughness would increase R_ct by the
```

```
% effective area factor

R_ct = 15000; % Ohm
R_ct_no_rough = R_ct*effAreaFactor
```

```
R_ct_no_rough = 57000
```

```
close all
imshow("Randles_2c.png")
```

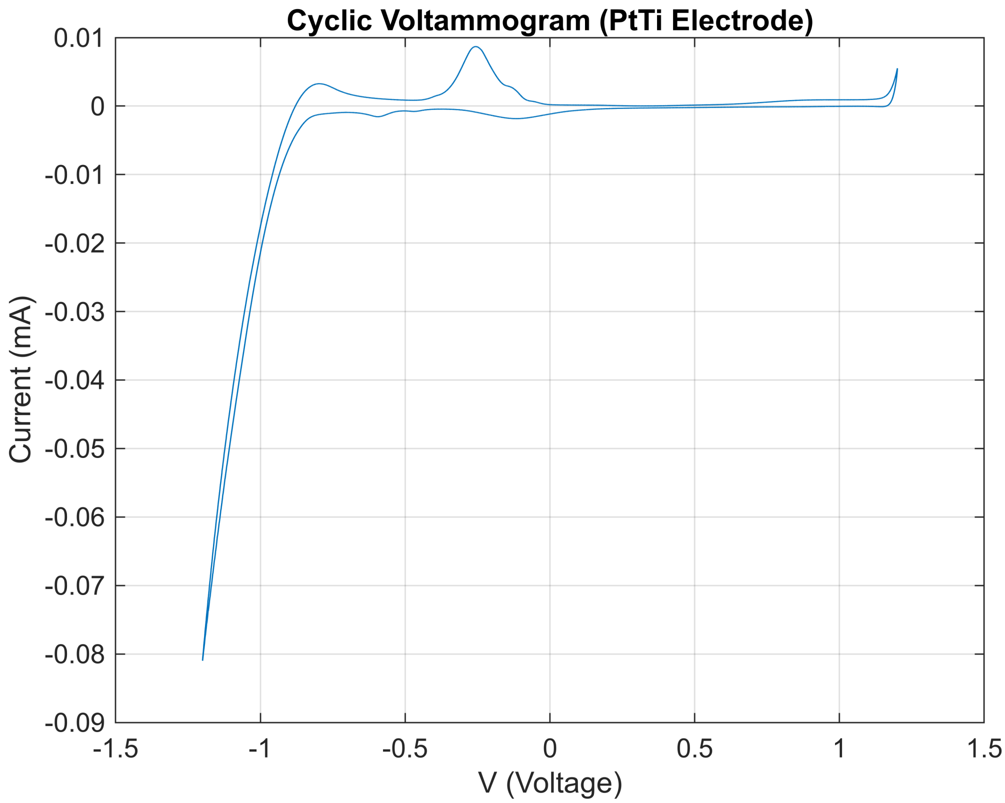



```
% Question 3a
close all

% Prior to reading in the table, I removed all of the diagnostic
% information from above the data.
pt_Data = readtable('be260-hw2-2020-fall-cv-platinum.csv');
```

```
Warning: Column headers from the file were modified to make them valid MATLAB identifiers before creating
variable names for the table. The original column headers are saved in the VariableDescriptions property.
Set 'VariableNamingRule' to 'preserve' to use the original column headers as table variable names.
```

```
V = table2array(pt_Data(:,'Ewe_V'));
I = table2array(pt_Data(:,'x_I__mA'));
```

```
plot(V,I)
grid on;
xlabel('V (Voltage)');
ylabel('Current (mA)');
title("Cyclic Voltammogram (PtTi Electrode)");
```




```
cumQ = rmmissing(cumtrapz(V,I)); % Computes the area under the curve
                                 % rmmissing removes all NaN values that
                                 % are emerging for unknown reasons
Q = cumQ(end)
```

```
Q = 0.0053
```

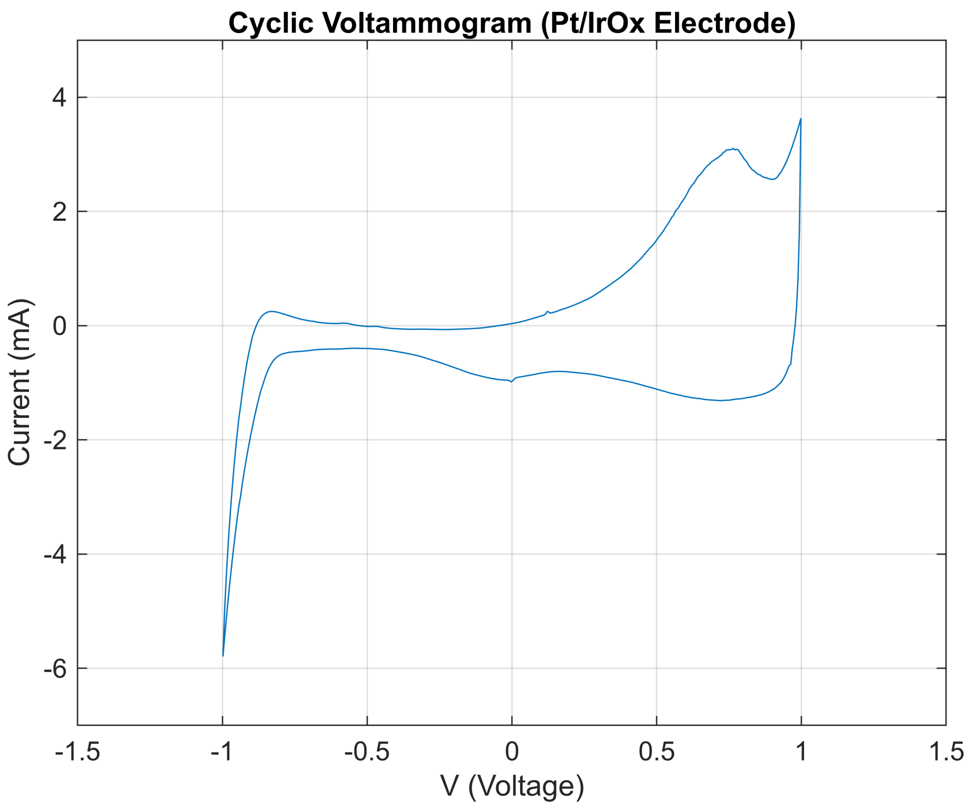
```
% The overall charge Q corresponding to its opening is 0.0027 mC
```

```
% Question 3b

ptElectrodeEffectiveArea = Q / 210 % (mC) / (mC cm^-2) = cm^2
```

```
ptElectrodeEffectiveArea = 2.5406e-05
```

```
% Using Q = 0.0053 from 3(a), the effective area of the electrode would be
% 0.0000254 cm^2. The effective area provided from problem 2 was 0.002603
% cm^2. This value is 3 magnitudes larger than the calculated effective
% area in problem 3b. This implies that one or several dimensions of the
% electrode used to record the above data were significantly smaller than
% the dimensions of the electrode from problem 2.
```

```
% Question 3c

% Prior to reading the data, I deleted the all sheets except for the one
% titled Ir_Pt_IV
ptIrox_Data = readtable('be260-hw2-2022-fall-cv-irox.xlsx');
I = table2array(ptIrox_Data(:,"Column2"));
V = table2array(ptIrox_Data(:,"Column1"));

plot(V,I)
grid on;
xlabel('V (Voltage)'); xlim([-1.5 1.5]);
ylabel('Current (mA)'); ylim([-7 5]);
title("Cyclic Voltammogram (Pt/IrOx Electrode)");
```




```
Q = trapz(V,I) % Computes the area under the curve
```

```
Q = 3.2775
```

```
ptIrOxElectrodeEffectiveArea = Q / 210 % (mC) / (mC cm^-2) = cm^2
```

```
ptIrOxElectrodeEffectiveArea = 0.0156
```

```
% Using Q = 3.2775 mC from above, the effective area of the electrode would be
% 0.0156 cm^2.

% The effective area of this electrode (0.0156 cm^2) is much closer to the
```

```
% effective area of the electrode from problem 2 (0.00260 cm^2). Since
% there is only ~1 magnitude of difference between these effective areas,
% it is reasonable to assume that the addition of the IrOx layer
% substantially increased the effective surface area of the Pt electrode
% from problem 3a.

% The overall charge and therefore the effective area of the electrode are
% both larger for the IrOx-coated Pt electrode than the Pt electrode alone.
% This makes sense because an increase in surface area directly correlates
% with an increased capacitance.
```

```
% Question 4a
imshow('Screenshot 2022-10-15 123542.png')
```

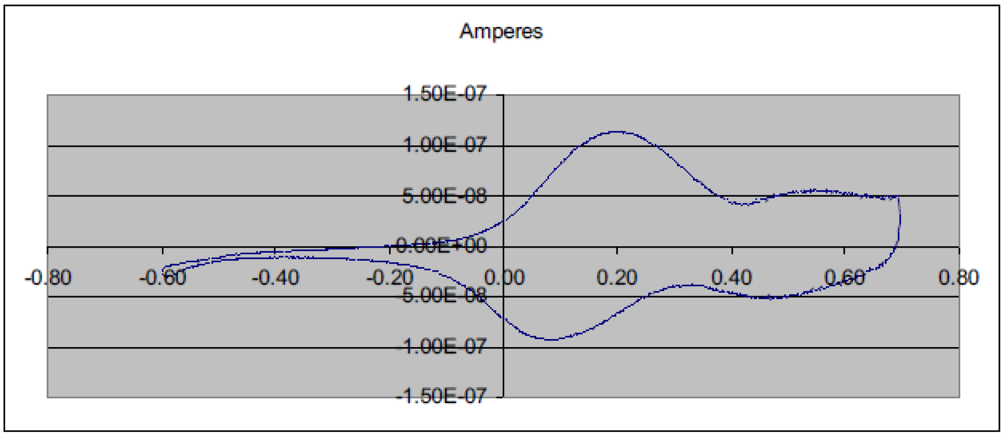


Figure 4-2: CV for Electrode X

```
% Two measurements can behave differently if the reaction occuring at the
% electrode-electrolyte interface is irreversible. These types of reactions
% will have a time-dependent decaying rate constant. Some example of
% irreversible Faradaic reactions include: (1) reduction of water, (2)
% oxidation of water, (3) corrosion of Pt, (4) gas evolution, or (5) anodic
% dissolution.
```

```
% Question 4b
imshow('Screenshot 2022-10-15 123542.png')
```

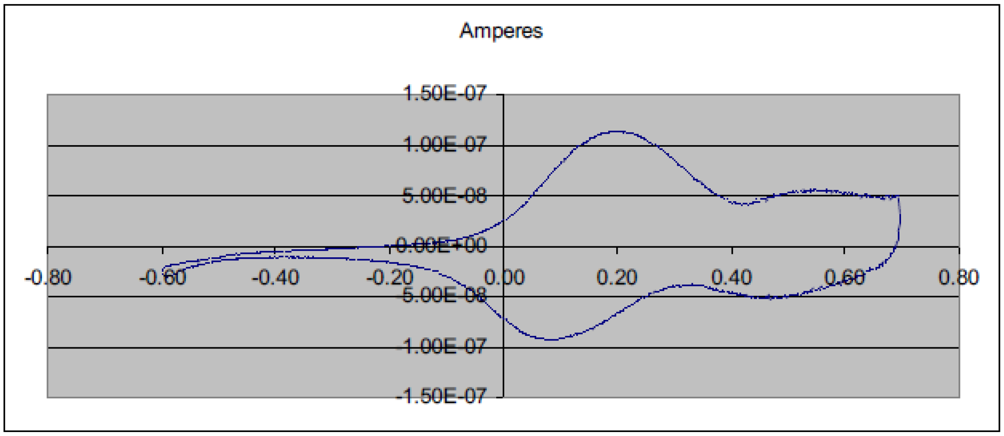


Figure 4-2: CV for Electrode X

```
% The water window is the range of potentials applied to generate the CV
% Voltammogram. In the above figure, the water window appears to be roughly
% [-0.6V 0.68V].
```

```
% Question 4c
close all
imshow("Screenshot 2022-10-15 130721.png")
```

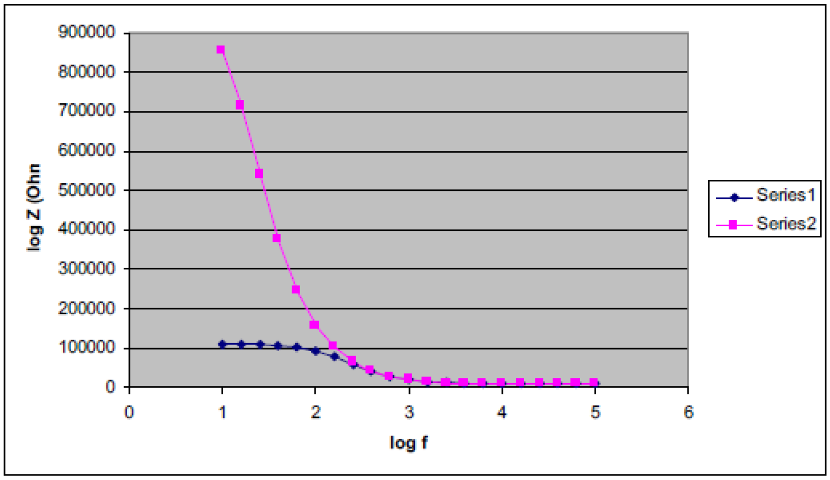


Figure 4-1: Two EIS measurements for Electrode X

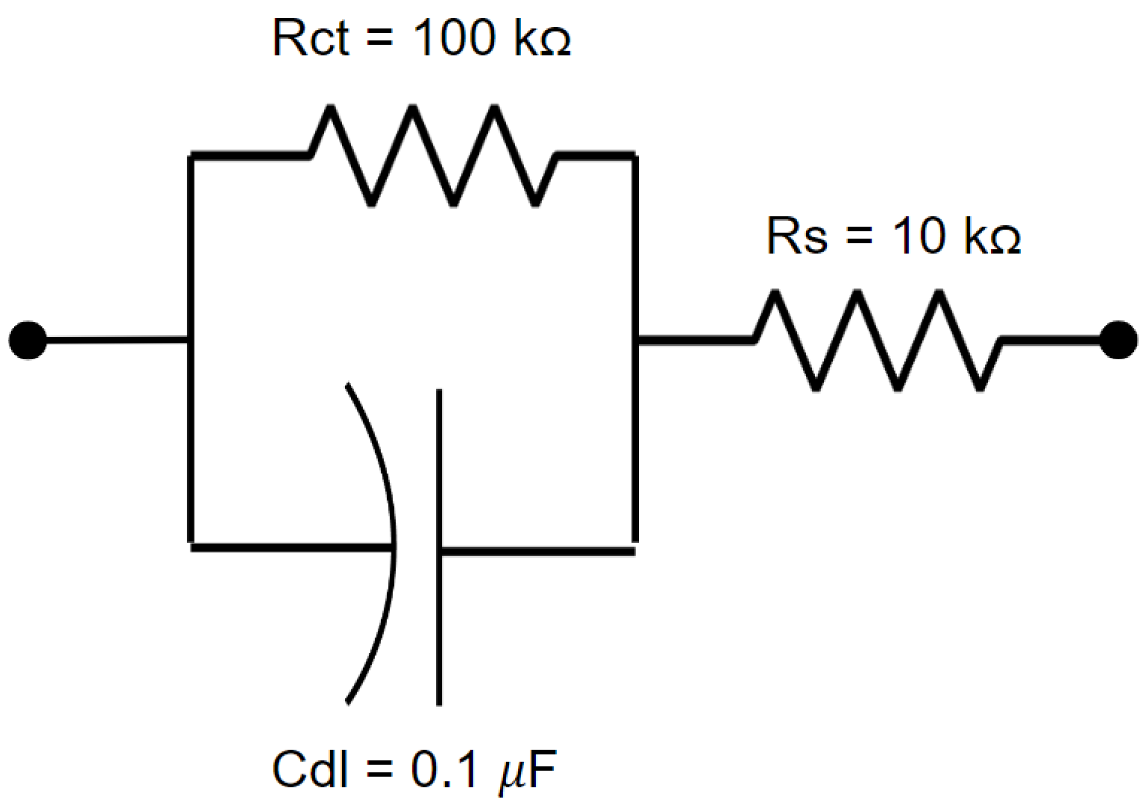
```
% The pole of this figure defines the value R_S + R_{ct} and the zero of
% this figure defines the value R_S. In this case, the pole is at roughly
% log f = 1 and the zero is at roughly log f = 3.5. Therefore, R_S = 10
```

```
% kOhm and R_S + R_{ct} = 110 kOhm, so R_{ct} = 100 kOhm. The pole of 10e2
% equals the expression 1/(R_{ct}*C_{dl}). We know R_{ct}, so the only
% unknown is C_{dl}, which we can solve for:

% logf = 1/(R_{ct}*C_{dl})
% C_{dl} = 1/(logf*R_{ct})
% C_{dl} = 1/((log2)*(1e5))
C_dl = 1/((1e2)*(1e5)) % F
```

```
C_dl = 1.0000e-07
```

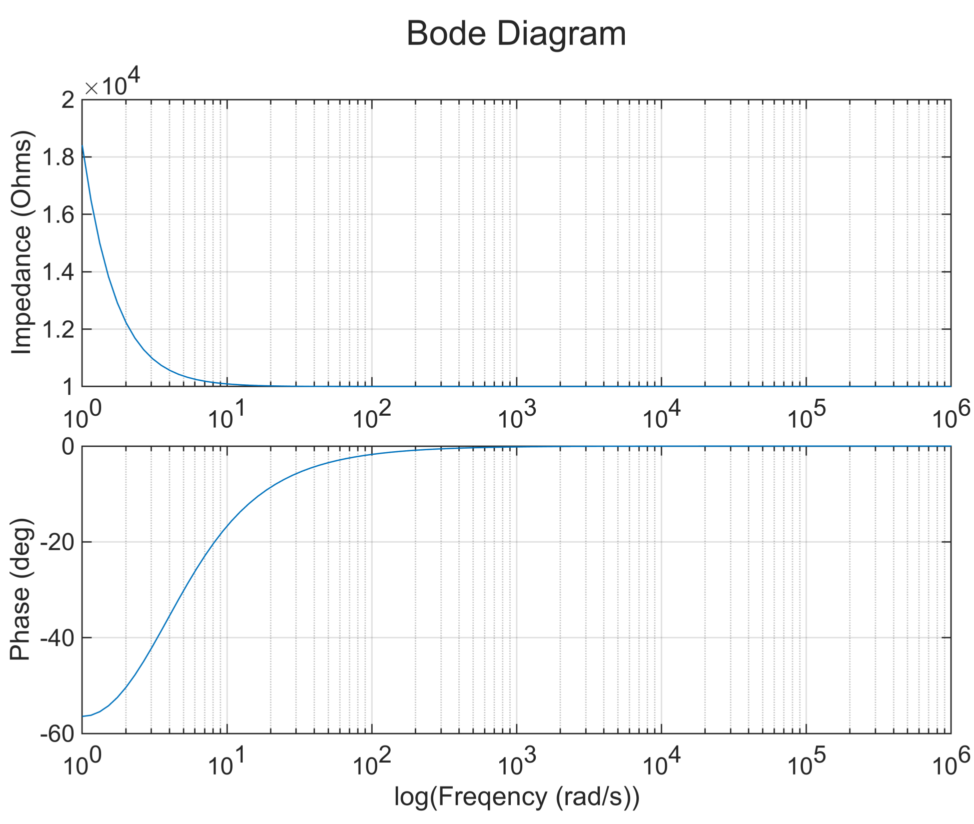
```
% Therefore, R_{ct} = 90 kOhm, R_S = 10 kOhm, and C_{dl} = 33 uF.
```

```
% Question 4d
close all
imshow("Randles_4d.png")
```




```
% Question 4e
close all

R_s = 10000; % Ohm
R_ct = 100000; % Ohm
```

```
C_dl = 33e-6; % F
R_par = (R_s*R_ct)/(R_s+R_ct);

freq = logspace(0,6,100);

Z_faradaic = R_s*(1i*freq+(1/(R_par*C_dl)))./(1i*freq+(1/(R_ct*C_dl)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_faradaic))
grid on
ylabel("Impedance (Ohms)");

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_faradaic)))
grid on
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)");

sgtitle("Bode Diagram")
```




```
% Question 5a
close all

% Definition of given parameters
```

```
rho = 560; % Ohm*s (Retina Tissue Resitivity)
r_elec = 50e-4; % cm (Radius of microelectrode)
C_dl_orig = 54.5e-6; %F/cm^2 (Original double layer capacitance)
R_ct_orig = 5.1e4; % Ohms*m^-2 (Original charge transfer resistance)

roughness_factor = 40;

% Since the electrode is circular and R_s ignores roughness, R_s can be found
% via the equation: R_S = rho / 4r
R_S_a = rho/(4*r_elec) % Ohm
```

```
R_S_a = 28000
```

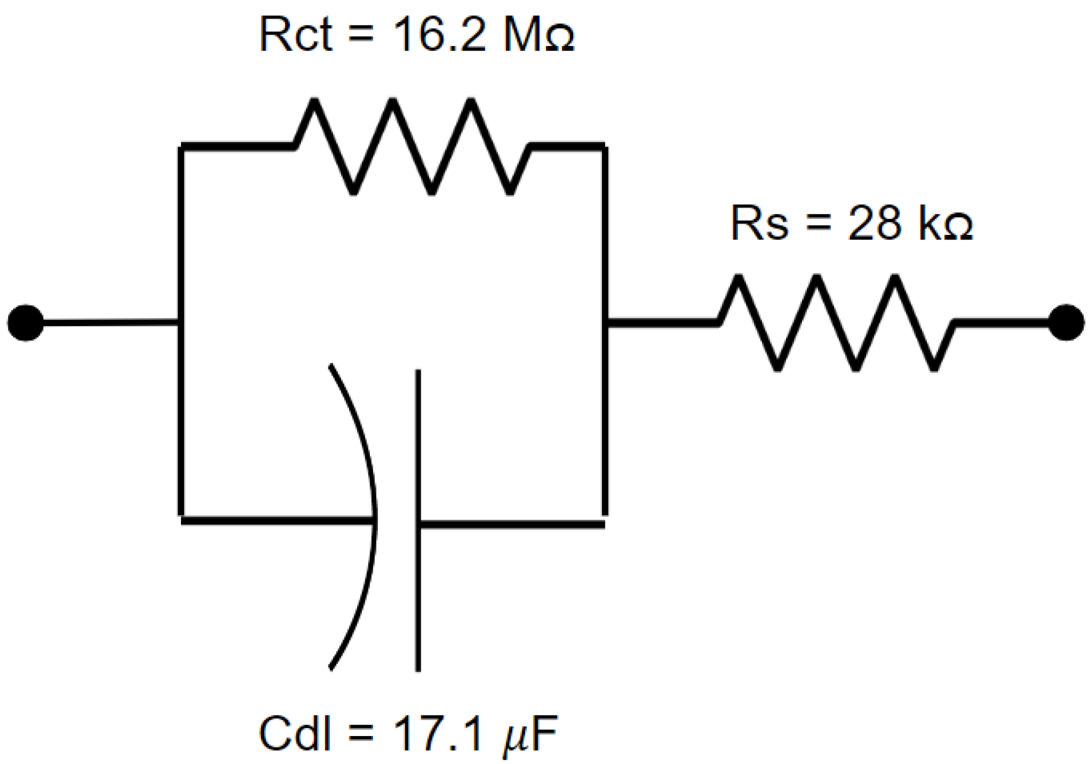
```
% Since C_dl is directly proportional to the electrode surface area,
% increasing the roughness of the area by a factor of 40x would also
% increase C_dl by a factor of 40, so
C_dl_a = C_dl_orig*40*pi*r_elec^2
```

```
C_dl_a = 1.7122e-07
```

```
% Since R_ct is inversely proportional to the electrode surface area,
% increasing the roughness of the area by a factor of 40x would
% decrease R_ct by a factor of 40, so
R_ct_a = R_ct_orig/(40*pi*r_elec^2)
```

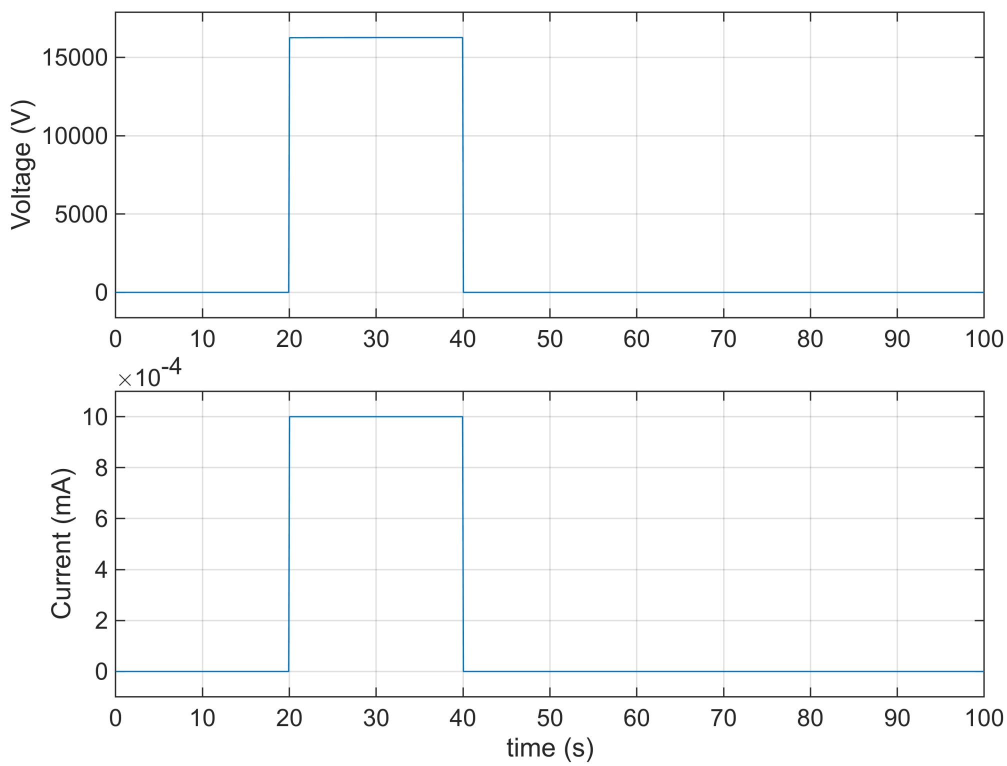
```
R_ct_a = 1.6234e+07
```

```
imshow("Randles_5a.png")
```




```
close all
% 5.a.4
% V    = IZ
% V(S) = (I/S)*(Rs+(Rct||(1/(S*Cdl))))
% V(S) = (I/S)*(Rs+(Rct/(Rct*S*Cdl+1)))
% V(S) = Rs*(I/S)+Rct*(I/S)/(Rct*S*Cdl+1)
% V(t) = I*Rs + I*Rct*(1-exp(-t/(Rct*Cdl)))

% (TODO) 5.a.5
t = linspace(0,100,1000);
cStart = 20;
cEnd = 40;
cAmp = 1e-3; % Amp
I = Iovertime(t,cStart,cEnd,cAmp);

V = I*R_S_a + I*R_ct_a.*(1-exp(-t/(R_ct_a*C_dl_a)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
plot(t,V)
grid on
```

```
ylabel("Voltage (V)"); ylim([-0.1*max(V) max(V)*1.1])

ax2 = nexttile;
plot(t,I)
grid on
xlabel("time (s)");
ylabel("Current (mA)"); ylim([-0.1*cAmp cAmp*1.1])
```




```
% Question 5b

% Since R_S is dependent on geometric surface area, decreasing the surface
% area by 10% would decrease R_s_b by 10%
R_S_b = R_S_a*0.9
```

```
R_S_b = 25200
```

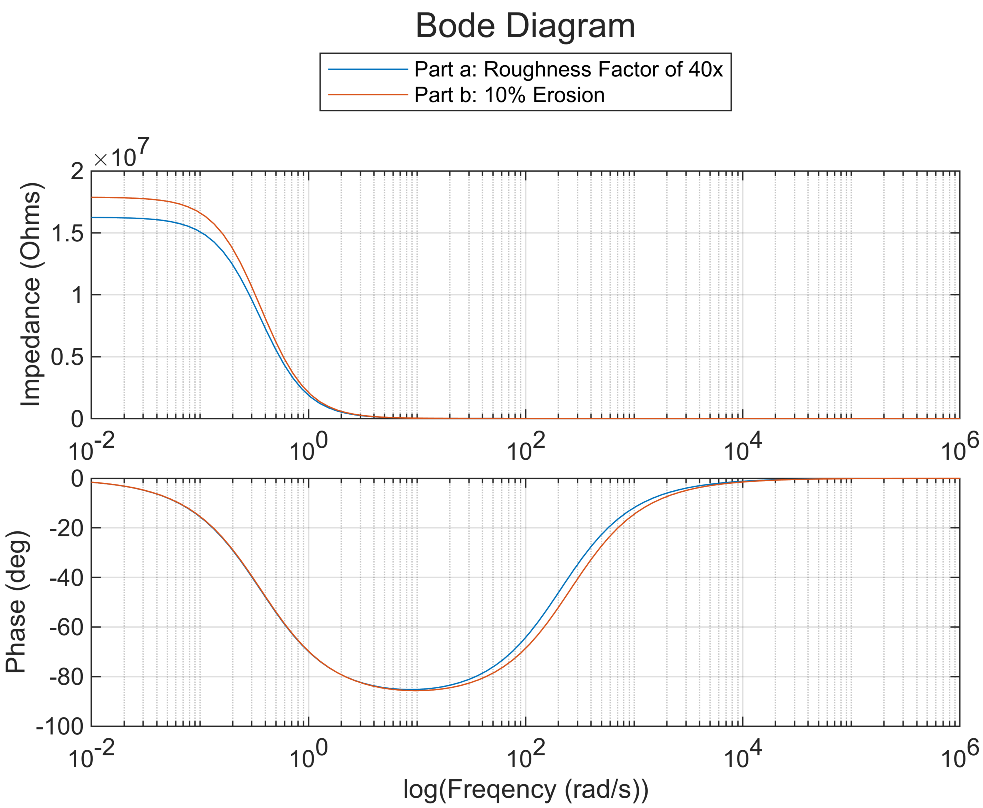
```
% Since C_dl is directly proportional to the electrode surface area,
% decreasing the surface area by 10% would decrease C_dl by 10%:
C_dl_b = C_dl_a*0.9
```

```
C_dl_b = 1.5410e-07
```

```
% Since R_ct is inversely proportional to the electrode surface area,
% decreasing the surface area by 10% would increase C_dl by 10%:
R_ct_b = R_ct_a*1.1
```

```
R_ct_b = 1.7857e+07
```

```
% Question 5c
close all

R_par_a = (R_S_a*R_ct_a)/(R_S_a+R_ct_a);
R_par_b = (R_S_b*R_ct_b)/(R_S_b+R_ct_b);

freq = logspace(-2,6,100);

Z_ct_a = R_S_a*(1i*freq+(1/(R_par_a*C_dl_a)))./(1i*freq+(1/(R_ct_a*C_dl_a)));
Z_ct_b = R_S_b*(1i*freq+(1/(R_par_b*C_dl_b)))./(1i*freq+(1/(R_ct_b*C_dl_b)));

tiledlayout(2,1,'TileSpacing','tight')

ax1 = nexttile;
semilogx(freq,real(Z_ct_a))
hold on
semilogx(freq,real(Z_ct_b))
grid on
ylabel("Impedance (Ohms)");
hold off

ax2 = nexttile;
semilogx(freq,rad2deg(angle(Z_ct_a)))
hold on
semilogx(freq,rad2deg(angle(Z_ct_b)))
grid on
xlabel("log(Freqency (rad/s))");
ylabel("Phase (deg)");
hold off

lg = legend('Part a: Roughness Factor of 40x','Part b: 10% Erosion');
lg.Layout.Tile = 'north';

sgtitle("Bode Diagram")
```


Bode Diagram
Part a: Roughness Factor of 40x
Part b: 10% Erosion
×10^7
Impedance (Ohms)
2
1.5
1
0.5
0
10^-2
10^0
10^2
10^4
10^6
Phase (deg)
0
-20
-40
-60
-80
-100
log(Freqency (rad/s))