CW003: Electromagnetics

Module: CAN209 Advanced Electric Circuits and Electromagnetics

Components: **Part 1 Calculation Problems 40%**

Part 2 MATLAB Problems 60%

Grouping: **5** students per group

Release Date: **Monday, 14th October 2024**

Deadline: **00:01 2023/10/28 softcopy only, uploaded on Core**

Group assignment (**One** submission per group)

INTRODUCTION

This coursework assessment aims to help develop your understanding and ability to handle problems relating to electromagnetism. The work is undertaken as a group of 5 members. There will be a single submission per group. The coursework has two parts and your group MUST complete all problems. Ensure that your submission complies with the formatting requirement set out on page 2.

Groups have been either pre-requested or have been randomly allocated. Please check the details in the group list provided on CORE.

LEARNING OUTCOMES

Following the completion of this assignment you should be able to:

A. Understand principles related to Electrostatics and Magnetostatics and analyse the operation of basic magnetically coupled circuits.

B. Apply Maxwell's equations in differential and integral form for engineering applications and the energy aspects of electromagnetic fields, and understand and analyse the properties of plane waves in free space.

Formatting Requirements

You must fulfil each formatting requirement listed below. Failure to meet any TWO of the formatting requirements below will lead to a reduction in mark of **10 percentage points**. A further **5%** will be lost for each additional requirement not met. Formatting penalties will not reduce your mark below 40%.

1. The entire submitted document must be created, edited (typed, not handwritten), and saved in Microsoft Office Word (.docx).
2. The assignment must have a filename in this format: Group Number.docx.

   For example: Group 3, then filename: **G03**.docx.

   Group 20, then filename: **G20**.docx
3. The main text of the assignment must use 1.5 line spacing.
4. The main text of the assignment must use Times New Roman font with the font size of 12 point.
5. The main text of the document must be aligned with 'Justify'.
6. The assignment must include correct page numbers.
7. Handwriting is not acceptable unless the question says can.
8. Use of screenshots from other sources (other than figures generated by MATLAB) is not acceptable.
9. Equations should be edited by the embedded Microsoft Equation Editor in Word or in Mathtype.
10. You MUST use the **cover page template** provided on core. **Print it out**, fill it in, sign your names, **scan it**, and then attach the scanned picture as the first page of your submission.
11. Any citations should follow IEEE referencing style.

ACADEMIC INTEGRITY

The work submitted for the group assignment **must be produced by your group**. Plagiarism, copying, collusion, dishonest use of data, or purchasing codes from others will be penalised. Penalties will follow those of the University's Academic Integrity Policy on E-bridge and can range from capped marks to expulsion from the university. Please contact the Module Leader if there is any confusion relating to academic integrity.

LATE SUBMISSION POLICY

XJTLU policy is -5% per day up to a total of 25%. Work submitted more than five working days late will receive a grade of zero.

Part 1: Calculation Problems (40%)

Q1. A vector field is given by:

$$\vec{A}(r,\varphi,z) = \frac{a}{r^2} cos^2\varphi \, \hat{r}$$

Analyse the expression and explain if this field can be a magnetic field (show your working) (10 marks).

Q2. A magnetic field in a certain source-free region is given by:

$$\vec{B}(x,y,z,t) = Acos(kz - \omega t)\hat{y}$$

If the component E_z of the related electric field is zero, determine an expression of the electric field $\vec{E}(x,y,z,t)$ (10 marks).

Hint: Faraday's Law

Q3. A circular parallel-plate capacitor has been charged and discharged by a time-varying voltage source. Determine the expression of displacement current density and electric field intensity as a function of time that would produce the following magnetic field:

$$\vec{B} = \frac{r\omega V cos(\omega t)}{2dc^2}\hat{\varphi}$$

where r is the distance from the centre of the capacitor, ω is the angular frequency of the applied voltage V, d is the plate spacing, and c is the speed of light in vacuum (20 marks).

Part 2: MATLAB Problems (60%)

A) Electric Field and Electric Potential

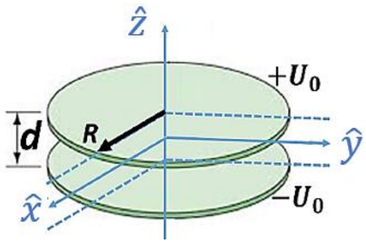
Two point charges, Q_1 = +20 nC, Q_2 = −60 nC, are separated by a distance of 1 m. Copy and paste the code in Appendix A into the MATLAB Command Window and run the script. Figure 1 demonstrates the 3D image of the potential distribution. Figure 2 shows the electric potential as equipotential contour curves. Figure 3 displays the 2D magnitude image of the E-field distribution.

A-1) With aid of the equipotential contour curves, hand-draw the electric field lines on Figure 2 with white colour (6 marks).
Note that the quantity of the electric field lines should be sufficient to show strength of the electric field around both point charges, and the direction of electric field lines should be clearly labelled.

A-2) Modify the MATLAB code to verify the results in A-1) (4 marks).
Note that please provide your MATLAB code with sufficient comments as Appendix A-2 in your submission (Code format: Arial with the font size 9, line spacing is single).

B) Parallel-plate Capacitor with Circular Plates

A capacitor comprises two parallel conductive disks of the same radius R equally and oppositely charged to absolute potentials $+U_0$ and $-U_0$, with U_0 = 1 V. They are of an infinitesimal thickness and placed a distance d apart.



Copy and paste the code in Appendix B into the MATLAB Command Window. Set the ratio d/R = {0.1~1 with step 0.1, 2, 5, 10} then run the script. The first figure demonstrates the electric potential U_e as equipotential contour curves and the E-field as the red arrowed lines. The second figure is a 3D image of the potential distribution.

Now, answer the following questions:

B-1) Run the script and set d/R = 0.5, comment on the reasons for the (almost) uniform distribution around the middle of the plates (10 marks).

B-2) Run the script and set d/R = 0.5, comment on the reasons for the E-field singularities (colossal increase in E-field) around the edges (10 marks).

B-3) Evaluate the potential value along the dotted symmetry line (z = 0) in the first figure and explain the reasons (10 marks).

B-4) Run the script and increase the ratio d/R (i.e., d/R = 1, 2, 5 and 10). Compared with the results obtained from d/R = 0.5, summarise your observed changes/differences and explain reasons (10 marks).

B-5) What happens if we put a conductive circular plate with the same radius *R* between the two parallel conductive disks? Assume the infinite conductive circular plate is inserted at a location where the distance between it and the disk ($+U_0$) is d_1 and the distance between it and the disk ($–U_0$) is d_2. The thickness of the plate is t. You should mathematically determine an expression of the new capacitance (10 marks).

Appendix A: Code for A

```
clear all
close all
clc
tic

% INPUTS

% Number of grid point [N = 10001]
   N = 1001;
% Charges
   Q = [+20, -60, 0, 0, 0] .* 1e-6;
% Radius of circular charged conductor;
   a = 0.2;
% X & Y components of position of charges   [0, 0, 0, 0, 0]
   xC = [-0.5,   0.5,   0.5, -0.5, 0];
   yC = [ 0,      0,      0,      0,     0];
% constants
   eps0 = 8.854e-12;
   kC = 1/(4*pi*eps0);
% Dimensions of region / saturation levels
%     [dimensions of region -2 to 2 / minR = 1e-6 / Esat = 1e6 / Vsat = 1e6]
   minX = -2;
   maxX =   2;
   minY = -2;
   maxY =   2;
   minR = 1e-6;
   minRx = 1e-6;
   minRy = 1e-6;
   Vsat = kC * max(abs(Q)) / a;
   Esat = kC * max(abs(Q)) / a^2;
% SETUP   ============================================================
  % fields
    V = zeros(N,N);
    Ex = zeros(N,N); Ey = zeros(N,N);
  % [2D] region
    x   = linspace(minX,maxX,N);
    y = linspace(minY, maxY,N);
  % color of charged object   +   red    /    - black
    col1 = [1 0 0];
    col2 = [0 0 0];
    %if Q(1) < 0; col1 = [0 0 0]; end;
```

```
  % grid positions
    [xG, yG] = meshgrid(x,y);

% CALCULATION: POTENTIAL & ELECTRIC FIELD
for n = 1 : 2
   Rx = xG - xC(n);
   Ry = yG - yC(n);

   index = find(abs(Rx)+ abs(Ry) == 0);
   Rx(index) = minRx;   Ry(index) = minRy;

   R = sqrt(Rx.^2 + Ry.^2);
   R(R==0) = minR;
   V = V + kC .* Q(n) ./ (R);

   R3 = R.^3;
   Ex = Ex + kC .* Q(n) .* Rx ./ R3;
   Ey = Ey + kC .* Q(n) .* Ry ./ R3;
end

   if max(max(V)) >=   Vsat; V(V > Vsat)    = Vsat; end;
   if min(min(V)) <= -Vsat; V(V < -Vsat) = -Vsat; end;

   E = sqrt(Ex.^2 + Ey.^2);
   if max(max(E)) >=   Esat; E(E >   Esat)   =   Esat; end;
   if min(min(E)) <= -Esat; E(E < -Esat)    = -Esat; end;

   if max(max(Ex)) >=   Esat; Ex(Ex >   Esat)   =   Esat; end;
   if min(min(Ex)) <= -Esat; Ex(Ex < -Esat)    = -Esat; end;

   if max(max(Ey)) >=   Esat; Ey(Ey >   Esat)   =   Esat; end;
   if min(min(Ey)) <= -Esat; Ey(Ey < -Esat)    = -Esat; end;

% GRAPHICS
figure(1)
   set(gcf,'units','normalized','position',[0.01 0.52 0.23 0.32]);
   surf(xG,yG,V./1e6);
   xlabel('x   [m]'); ylabel('y   [m]'); zlabel('V   [ V ]');
   title('potential','fontweight','normal');

   rotate3d
   view(76,32);
```

```
    set(gca,'fontsize',12)
    set(gca,'xLim',[-2, 2]); set(gca,'yLim',[-2, 2]);

    shading interp;
    h = colorbar;
    h.Label.String = 'V     [ MV ]';
    colormap(parula);
    axis square
    box on

%%
figure(2)
    set(gcf,'units','normalized','position',[0.25 0.1 0.23 0.32]);
    zP = V./1e6;
    contourf(xG,yG,zP,12);
    %set(gca,'xLim',[-5,5]); set(gca,'yLim', [-5, 5]);
    %set(gca,'xTick',-5:5); set(gca,'yTick', -5:5);
    hold on
    % charged conductors
        col = col1;
        if Q(1) < 0; col = col2; end;

        pos1 = [-a+xC(1), -a, 2*a, 2*a];
        h = rectangle('Position',pos1,'Curvature',[1,1]);
        set(h,'FaceColor',col,'EdgeColor',col);
        col = col1;
        if Q(2) < 0; col = col2; end;
        pos2 = [-a-xC(1), -a, 2*a, 2*a];
        h = rectangle('Position',pos2,'Curvature',[1,1]);
        set(h,'FaceColor',col,'EdgeColor',col);
    xlabel('x   [m]'); ylabel('y   [m]');
    title('potential','fontweight','normal');
    shading interp
    h = colorbar;
    h.Label.String = 'V     [ MV ]';
    colormap(parula);
    set(gca,'fontsize',12);
    axis square
    box on

%%
figure(3)
```

```
set(gcf,'units','normalized','position',[0.01 0.1 0.23 0.32]);
    surf(xG,yG,E./1e6);
    xlabel('x   [m]'); ylabel('y   [m]'); zlabel('E   [ V / m ]');
    title('electric field | E |','fontweight','normal');
    colorbar
    shading interp
    h =   colorbar;
    h.Label.String = '| E |     [ MV/m ]';
    rotate3d
    view(30,50);
    axis square
    set(gca,'fontsize',12)
    box on
      %%
      toc
```

Appendix B: Code for B

```
clc; close all; clear; fprintf(2,'\nAll coordinates are normalized to disk radius R\n');
fprintf(2,'\nThe normalized to R Gap d/R between disks must be chosen as\n');
fprintf(2,'\nd/R = 0.1 - 1 with step 0.1 or d/R = 2,5,10\n'); d=input('\nEnter the ratio d/R = ');
NN=1.2e2; R=1; r=linspace(0,2*R,NN); z=linspace(-4*d,4*d,NN); [RR,ZZ] = meshgrid(r,z);
if d==0.1; P=@(x) (11.170089-4.690523*x.^2-1.474409*x.^4+0.664140*x.^6-1.53822237*x.^8); end
if d==0.2; P=@(x) (6.0773646-2.373046*x.^2+0.164289*x.^4-1.6199941*x.^6+0.7925024*x.^8); end
if d==0.3; P=@(x) (4.3596859-1.507951*x.^2-0.002886*x.^4-0.7929827*x.^6+0.5076101*x.^8); end
if d==0.4; P=@(x) (3.4935288-1.072782*x.^2-0.118818*x.^4-0.2410555*x.^6+0.2211096*x.^8); end
if d==0.5; P=@(x) (2.97067-0.819293*x.^2-0.124922*x.^4-0.0114976*x.^6+0.077654494*x.^8); end
if d==0.6; P=@(x) (2.6206072-0.653164*x.^2-0.088666*x.^4+0.0576722*x.^6+0.0184320*x.^8); end
if d==0.7; P=@(x) (2.3699300-0.533814*x.^2-0.048402*x.^4+0.0639551*x.^6-0.0022945*x.^8); end
if d==0.8; P=@(x) (2.1817877-0.442585*x.^2-0.017287*x.^4+0.0511089*x.^6-0.0075254*x.^8); end
if d==0.9; P=@(x) (2.0356215-0.370213*x.^2+0.002996*x.^4+0.0358529*x.^6-0.0073136*x.^8); end
if d==1.0; P=@(x) (1.91903-0.311595*x.^2+0.014564*x.^4+0.0233527*x.^6-0.005655492*x.^8); end
if d==2.0; P=@(x) (1.41007-0.071116*x.^2+0.008674*x.^4-0.0005066*x.^6-0.0000309361*x.^8); end
if d==5; P=@(x) (1.14348-0.005373*x.^2+0.000182*x.^4); end
if d==10; P=@(x) (1.06773-0.000666*x.^2+0.000000*x.^4); end; for ii=1:length(r); for jj=1:length(z);
VV=@(x) (1./sqrt(RR(ii,jj)^2+(ZZ(ii,jj)-d/2+1i*x).^2)-1./sqrt(RR(ii,jj)^2+(ZZ(ii,jj)+d/2+1i*x).^2)).*P(x);
Int(ii,jj)=integral(VV,-1,1); end; end; Ue=real(Int)/pi; [Er Ez]=gradient(Ue,2*R/NN,8*d/NN);
C=8.854e-12*sum(sum(Er.^2+Ez.^2))*(2*R/NN)*(8*d/NN); C0=8.854e-12*pi*R^2/d;
figure('units','normalized','outerposition',[0 0 1 1]); grid minor; hold on;
hLines = streamslice(RR,ZZ,-Er,-Ez,2);set(hLines,'Color','r','LineWidth',1);
hLines = streamslice(-RR,ZZ,Er,-Ez,2);set(hLines,'Color','r','LineWidth',1);
contour(RR,ZZ,Ue,50); contour(-RR,ZZ,Ue,50); hh=colorbar;
ylabel(hh,'Electric Potential Intensity Ue(r/R,z/R)','FontWeight','Bold','FontSize',15);
xlabel('r/R-axis [m]'); ylabel('z/R-axis [m]'); r0=linspace(-R,R,200);
axis 'tight'; rectangle('Position',[-R,-d/2,2*R,4*d/NN],'FaceColor','k')
rectangle('Position',[-R,d/2,2*R,4*d/NN],'FaceColor','k');
text(0,-d/2,'Uo = -1','Color','b','FontSize',50); text(0,1.1*d/2,'Uo = +1','Color','r','FontSize',50)
%text(-2*R,4*d,['Capacitance according to (3.26) = ',num2str(C0),' [F]'],'Color','k','FontSize',40)
%text(-2*R,3.4*d,['Capacitance according to (3.27) = ',num2str(C),' [F]'],'Color','k','FontSize',40);
if d<2; plot(-2*R:0.1:2*R,0,'*m','LineWidth',4); end; if d>=2; axis square; xlim([-4*d,4*d]); end;
figure(2);hold on; meshc(RR,ZZ,Ue); meshc(-RR,ZZ,Ue); xlabel('r/R-
axis','FontSize',14,'FontWeight','bold');
ylabel('z/R-axis','FontSize',14,'FontWeight','bold'); view(84,21);
hh1=colorbar; ylabel(hh1,'Electric Potential Intensity Ue(r/R,z/R)','FontWeight','Bold','FontSize',15);
zlabel('Electric Potential Ue(r/R,z/R)','FontSize',14,'FontWeight','bold');grid minor;
title('Electric Potential Intensity in rz-plane','FontSize',12,'FontWeight','bold')
vert = [-2*R 0 -1;2*R 0 -1;2*R 0 -1;-2*R 0 -1;-2*R 0 1;2*R 0 1;2*R 0 1;-2*R 0 1];
fac = [1 2 6 5;1 2 6 5;1 2 6 5;1 2 6 5;1 2 6 5;1 2 6 5];
ph=patch('Vertices',vert,'Faces',fac,'FaceVertexCData',hsv(6),'FaceColor','flat');alpha(ph,0.2)
```