Good

200/200

11/26/07

Name: Brian Rolfe. TA:

Random Student #

Partner(s):

Lab 4 FDTD		Grd
Copy from previous lab or compute R',L',G',C' values	10	10
Compute alpha,beta, velocity of propagation, wavelength	10	10
Draw time and space FDTD grid in your lab book and explain notation	10	10
Rewrite telagrapher equations as central difference equations	30	30
Solve for the future	20	20
Tests and Observations		
a) Run and plot simulations	50	50
b) Measure and compare velocity of propagation	20	20
c) Summarize Results	20	20
d) Include printout of code	30	30
Total	**200**	200

How much time was spent on this lab?

Comments:

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BRIAN Keefe

LAB 4 - FDTD PLANE WAVE SIMULATION.

PRE-LAB

READ THE LAB.

PROCEDURE

OBJECTIVES

1) UNDERSTAND THE TELEGRAPHERS EQUATIONS

2) UNDERSTAND HOW TO USE AND IMPLEMENT THE FDTD METHOD.

3) CORRECTLY SIMULATE WAVES ON YOUR TRANSMISSION LINES.

I. INTRO TO FDTD METHOD & TELEGRAPHERS EQS.

$$-\frac{\partial V(z,t)}{\partial z} = R' I(z,t) + L' \frac{\partial I(z,t)}{\partial t} \quad (1)$$

$$-\frac{\partial I(z,t)}{\partial z} = G' V(z,t) + C' \frac{\partial V(z,t)}{\partial t} \quad (2)$$

$$f'(c) = \frac{f(b) - f(a)}{b-a}$$

$$f(c) = \frac{f(b) + f(a)}{2}$$

II FINDING RLGC VALUES.

USING PROGRAM FROM LAB 2

CHECK FOR GIVEN VALUES.

$f = 1GHz$.

AIR: SAME OR CLOSE

TEFLON: SAME OR CLOSE

SEAWATER: SAME OR CLOSE.

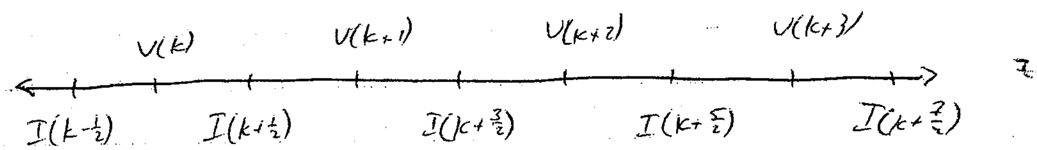
III DIFFERENTIALS VS. DIFFERENCES.

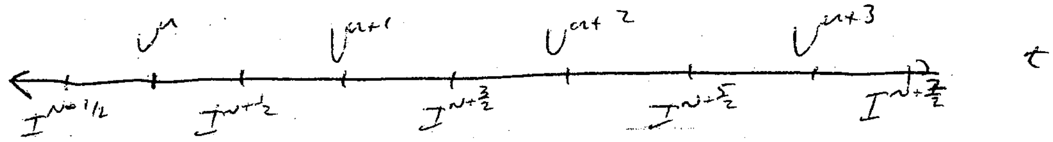
CENTRAL DIFFERENCE EQUATIONS:

$$f(c) = \frac{f(b)+f(a)}{2}$$

$$f'(c) = \frac{f(b)-f(a)}{b-a}$$

IV DISCRETIZING SPACE AND TIME





$V(k)$ = VOLTAGE AT SPACE k

$V(k+1)$ = VOLTAGE AT SPACE $k+1$

$I(k+\frac{1}{2})$ CURRENT AT SPACE $k+\frac{1}{2}$

V^n = VOLTAGE AT PRESENT TIME

$V^{n\pm k}$ = VOLTAGE IN PAST OR FUTURE.

$I^{n\pm\frac{k}{2}}$ = CURRENT IN PAST OR FUTURE.

V CONVERT FROM DERIVATIVES TO DIFFERENCES.

REWRITE TELEGRAPHERS EQ'S. WITH DIFFERENCE NOTATION.

$$\frac{\partial V(z,t)}{\partial z} = -\left(\frac{V_{k+1}^{N} - V_{k}^{N}}{dz}\right) = R'\left(\frac{I_{k+\frac{1}{2}}^{N+\frac{1}{2}} + I_{k+\frac{1}{2}}^{N+\frac{1}{2}}}{2}\right) + L'\left(\frac{I_{k+\frac{1}{2}}^{N+\frac{1}{2}} - I_{k+\frac{1}{2}}^{N-\frac{1}{2}}}{dt}\right)$$

$$\frac{\partial I(z,t)}{\partial z} = -\left(\frac{I_{k+\frac{1}{2}}^{N+\frac{1}{2}} - I_{k-\frac{1}{2}}^{N+\frac{1}{2}}}{dz}\right) = G'\left(\frac{V_{k}^{N} + V_{k}^{N+1}}{2}\right) + C'\left(\frac{V_{k}^{N+1} - V_{k}^{N}}{dt}\right)$$

VI SOLVE FOR THE FUTURE.

SOLVE EQ. 1 FROM EARLIER FOR $I_{k+\frac{1}{2}}^{N+\frac{1}{2}}$

$$-\left(\frac{V_{k+1}^{N}-V_{k}^{N}}{dz}\right)=R'\left(\frac{I_{k+\frac{1}{2}}^{N-\frac{1}{2}}+I_{k+\frac{1}{2}}^{N+\frac{1}{2}}}{2}\right)+C'\left(\frac{I_{k+\frac{1}{2}}^{N+\frac{1}{2}}-I_{k+\frac{1}{2}}^{N-\frac{1}{2}}}{dt}\right)$$

MULT THROUGH BY R' & C'

$$-\left(\frac{V_{k+1}^{N}-V_{k}^{N}}{dz}\right)=\frac{R' I_{k+\frac{1}{2}}^{N-\frac{1}{2}}}{2}+\frac{R' I_{k+\frac{1}{2}}^{N+\frac{1}{2}}}{2}+\frac{L' I_{k+\frac{1}{2}}^{N+\frac{1}{2}}}{dt}-\frac{L' I_{k+1/2}^{N-1/2}}{dt}$$

GROUP LIKE TERMS FOR I & SIMPLIFY.

$$-\left(\frac{V_{k+1}^{N}-V_{k}^{N}}{dz}\right)=I_{k+\frac{1}{2}}^{N-\frac{1}{2}}\left(\frac{R'}{2}-\frac{L'}{dt}\right)+I_{k+\frac{1}{2}}^{N+\frac{1}{2}}\left(\frac{R'}{2}+\frac{L'}{dt}\right)$$

SOLVE FOR $I_{k+1/2}^{N+1/2}$

$$* \quad I_{k+\frac{1}{2}}^{N+1/2}=\frac{-\left(\frac{V_{k+1}^{N}-V_{k}^{N}}{dz}\right)-I_{k+1/2}^{N-\frac{1}{2}}\left(\frac{R'}{2}-\frac{L'}{dt}\right)}{\left(\frac{R'}{2}+\frac{L'}{dt}\right)} \quad (3)$$

SOLVE EQ. 2 FROM EARLIER FOR V_{k}^{N+1}

$$-\left(\frac{I_{k+1/2}^{N+1/2}-I_{k-1/2}^{N+1/2}}{dz}\right)=G'\left(\frac{V_{k}^{N}+V_{k}^{N+1}}{2}\right)+C'\left(\frac{V_{k}^{N+1}-V_{k}^{N}}{dt}\right)$$

MULT THROUGH BY G' & C'

$$-\left(\frac{I_{k+1/2}^{N+1/2}-I_{k-\frac{1}{2}}^{N+1/2}}{dz}\right)=\frac{G' V_{k}^{N}}{2}+\frac{G' V_{k}^{N+1}}{2}+\frac{C' V_{k}^{N+1}}{dt}-\frac{C' V_{k}^{N}}{dt}$$

GROUP LIKE TERMS & SIMPLIFY.

$$-\left(\frac{I_{k+1/2}^{N+1/2}-I_{k-\frac{1}{2}}^{N+1/2}}{dz}\right)=V_{k}^{N}\left(\frac{G'}{2}-\frac{C'}{dt}\right)+V_{k}^{N+1}\left(\frac{G'}{2}+\frac{C'}{dt}\right)$$

$$* \quad V_{k}^{N+1}=\frac{-\left(\frac{I_{k+\frac{1}{2}}^{N+\frac{1}{2}}-I_{k-\frac{1}{2}}^{N+\frac{1}{2}}}{dz}\right)-V_{k}^{N}\left(\frac{G'}{2}-\frac{C'}{dt}\right)}{\left(\frac{G'}{2}+\frac{C'}{dt}\right)} \quad (4)$$

TO CLEAN-UP EQUATIONS.

$$A = \frac{-\frac{1}{dz}}{\frac{R'}{2} + \frac{L'}{dt}}$$

$$B = \frac{-\left(\frac{R'}{2} - \frac{L'}{dt}\right)}{\frac{R'}{2} + \frac{L'}{dt}}$$

$$D = \frac{-\frac{1}{dz}}{G'/2 + C'/dt}$$

$$E = \frac{-\left(\frac{G'}{2} - \frac{C'}{dt}\right)}{\left(G'/2 + C'/dt\right)}$$

VII

$$I(k) = A\left[V(k+1) - V(k)\right] + B\,I(k)$$

$$V(k) = D\left[I(k) - I(k-1)\right] + E\,V(k)$$

PROGRAM THE DIFFERENCE FORM OF THE TELEGRAPHERS EQUATION.

VIII $f = 1\,GHz$

$dz = \lambda/20$ (CALCULATED λ IN SECTION II)

$dt = 0.5\,dz$ / VELOCITY OF PROPAGATION (CALC. IN SECTION II)

LINE IS 2000 dz LONG.

START WITH AIR FILLED LINE.

IX PROGRAM A SOURCE.

USE V SRC AT k = 1

$V(1) = (V_0 \sin(\omega t))$

X TESTS & OBSERVATIONS

(A) ATTACHED PLOTS.

(B)

	ACTUAL	CALC.
Vp AIR	2.99728^8	$2.9972e^8$
TEFLON	2.06882^8	$2.0688e^8$
SEAWATER	$3.1007e^7$	$3.1007e^7$

THEY ARE EQUAL.

C) RESULTS. FOR IN CLASS WRITEUP
THERE IS NO WRITE-UP.

D) MATLAB ATTACHED

E) DISCUSSION & CONCLUSION

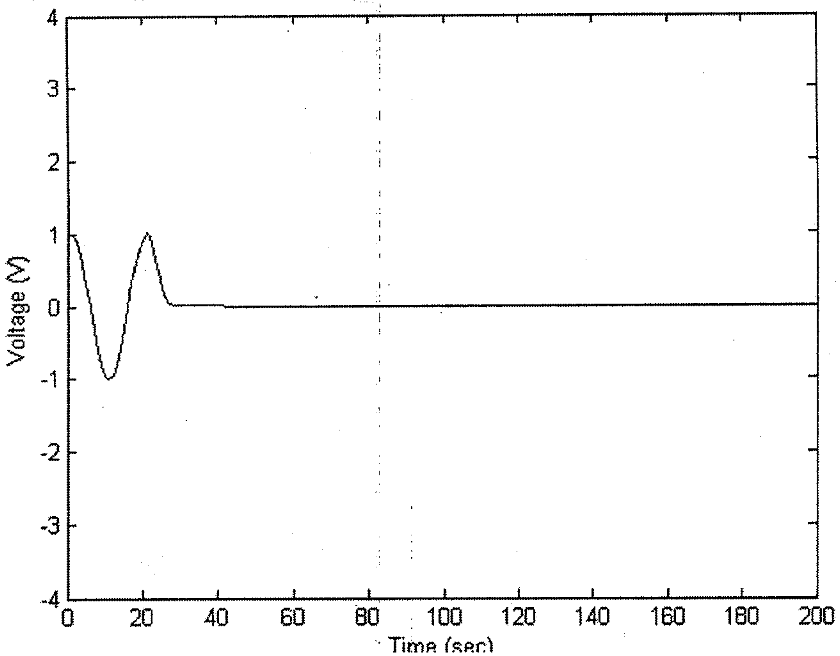
FDTD IS VERY EFFECTIVE IN SIMULATING A WAVE PROPAGATING DOWN A T-LINE. AS LONG AS YOU KNOW ALL OF YOUR SOURCES & SOURCES OF ERROR AND ARE ABLE TO ACCOUNT FOR THEM IN THE CODE. OTHERWISE IT IS JUST A GOOD APPROXIMATION FOR WHAT IS GOING TO HAPPEN BUT MAY HAVE LESS VOLTAGE A SLOWER OR FASTER UP... ETC. POSSIBLE SOURCES OF ERROR ARE ERRORS IN THE CODE, IMPROPER VALUES FOR ε_r, μ_r ETC FOR MATERIALS, WRONG SIZE OF LINE EXPECTED, CALCULATION ERRORS WHILE DERIVING EQUATIONS, ~~AND OTHERS~~ AND OTHERS. THEY CAN BE CONTROLLED BY DOUBLE CHECKING AND HAVING SOMEONE ELSE LOOK AT THE CODE FOR COMPLETENESS. THE ERRORS BETWEEN SIMULATED & ACTUAL ARE INCONSISTANT MATERIAL, INTERFERENCES IMPROPER CALCULATIONS FOR SIMULATED. ~~DIFFERENCES AND~~ OTHER ITEMS OF ENVIRONMENT & MATERIAL NOT ACCOUNTED FOR IN THE PROGRAM. THESE ARE HARDER TO CONTROL BUT COULD POSSIBLY BE DONE WITH THE ADDITION OF MORE VARIABLES. ALL IN ALL THIS METHOD WORKS WELL & WILL EVEN SHOW WHAT HAPPENS WITH EACH SUCCESSIVE REFLECTION ON THE LINE. IT IS IMPORTANT TO MAKE SURE ALL EQUATIONS ARE PROPERLY INPUT. IF NOT YOU WILL GET UNDESIRED/UNEXPECTED RESULTS LIKE WE DID. IT IS IMPORTANT TO NOTE THAT IN MOST CASES ACTUAL & CALCULATED DO VARY BUT THE MORE INTRICATE THE CODE THE LESS

OF A CHANCE OF ERROR. THE CODE MAY BE SIMPLIFIED BY KNOWING MORE ABOUT MATLAB AND USING SHORTCUTS TO REPRESENT THINGS I DID IN LONGER WAYS. ALSO IMPROVEMENTS CAN BE MADE BY TESTING AND IMPROVING & TESTING FOR DESIRED FUNCTIONALITY AGAIN UNTIL YOU HAVE SIMPLIFIED SEVERAL ITEMS INTO ONE STEP WITHOUT SACRIFICING FUNCTIONALITY.

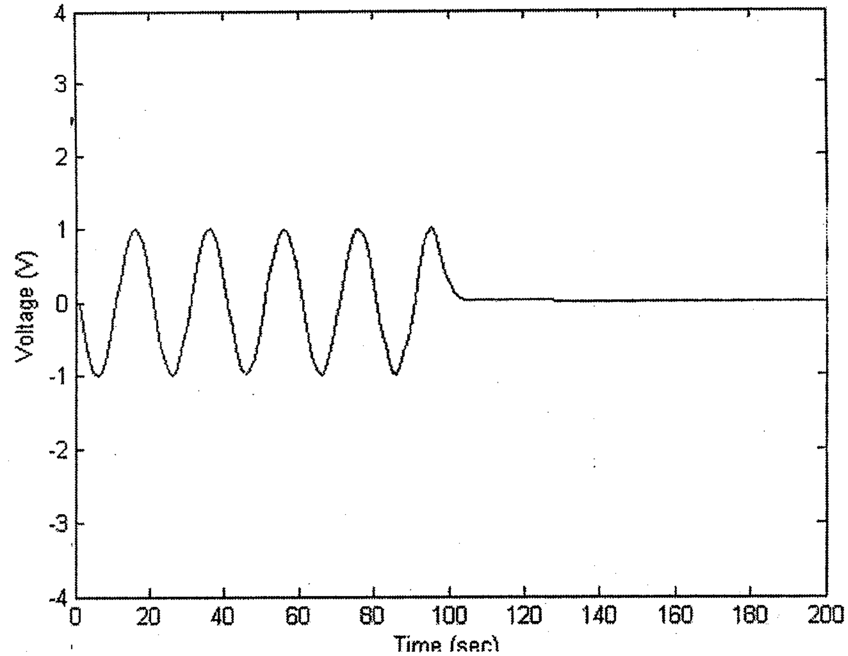
```
clear all
clc

%This is how many cells are in the transmission line.
maxZ=200;
% Maximum number of time steps in 2*maxZ before wave hits the end of the grid...?Why???
maxT=200;

% Here is a version of the FDTD program.
% parameters
F= 1e9; % Frequency
w = 2*pi*F;
Mu_not = 4*pi*(10^-7);   %H/m
Epsilon_not = 8.854*(10^-12);

% Parameters for copper conductor
Sigma_c= 5.8e7;
Mu_c= 0.999991*Mu_not;
a = 0.445*(10^-3);  % outer radius of inner conductor,m, of RG58
b = 1.765*(10^-3);  % inner radius of outer conductor,m, of RG58

% Comment out parameters not being used in current simulations
% Parameters for air
sigma= zeros(1,maxZ);
Epsilon_i= 1.0005*Epsilon_not*ones(1,maxZ);
Mu_i= Mu_c*ones(1,maxZ);

% Parameters for teflon
% sigma= 10e-15*ones(1,maxZ);
% Epsilon_i= 2.1*Epsilon_not*ones(1,maxZ);
% Mu_i= 1*Mu_not*ones(1,maxZ);

% Parameters for sea water
% sigma= 5*ones(1,maxZ);
% Epsilon_i= 72*Epsilon_not*ones(1,maxZ);
% Mu_i= 1*Mu_not*ones(1,maxZ);

% Constants computed in previous section
R_s = sqrt(pi*F.*Mu_c / Sigma_c);
R = (R_s / (2*pi))*((1/a) + (1/b))
L = (Mu_i ./ (2*pi)).*log(b/a)
G = (2*pi.*sigma) ./ (log(b/a))
C = (2*pi.*Epsilon_i) / (log(b/a))
Gamma =sqrt((R + j*w*L(1)) .* (G(1) + j*w*C(1)));
Alpha = real(Gamma)
Beta = imag(Gamma)
Lambda = (2*pi) / Beta
u_p = F * Lambda

Dz = Lambda/20;    % from section II
Dt = (1/2*Dz)/u_p;  % from section II
%l = 200*Dz;       % Line is 200 times dz long
```

```
% conversions to make equations simple
A = 1 ./ (-Dz.*(R./2 + L./Dt));
B = (-R./2 + L./Dt) ./ (R/2 + L./Dt);
D = 1 ./ (-Dz.*((G/2) + (C./Dt)));
E = (-G./2 + C./Dt) ./ (G/2 + C./Dt);

% %This is how many cells are in the transmission line.
% maxZ=200;
% % Maximum number of time steps in 2*maxZ before wave hits the end of the grid...?Why???
% maxT= 800;

% Initialize voltage and current values of transmission line.
V=zeros(1,maxZ);
I= zeros(1,maxZ);

%FDTD loops
for N=1:800;
    V(1) = sin(2*pi*F*N*Dt); % sine wave source
    for K=2:maxZ;  % find voltage everywhere on the line
        V(K)= D(K)*(I(K)-I(K-1))+E(K)*V(K);
    end

    V(maxZ)=0;
    for K=1:maxZ-1;                  % find current everywhere on the line
        I(K)= A(K)*(V(K+1)-V(K))+B(K)*I(K);
    end
plot(V)                          % plot the voltage all along the line at time N
axis([0 maxZ -4 4])    % control the axis for uniform pictures
pause(.001);                   % give the program time to plot to screen
end

title('Transmission Line with Air as the Insulation Material for n = 200')
xlabel('Time (sec)')
ylabel('Voltage (V)')
```

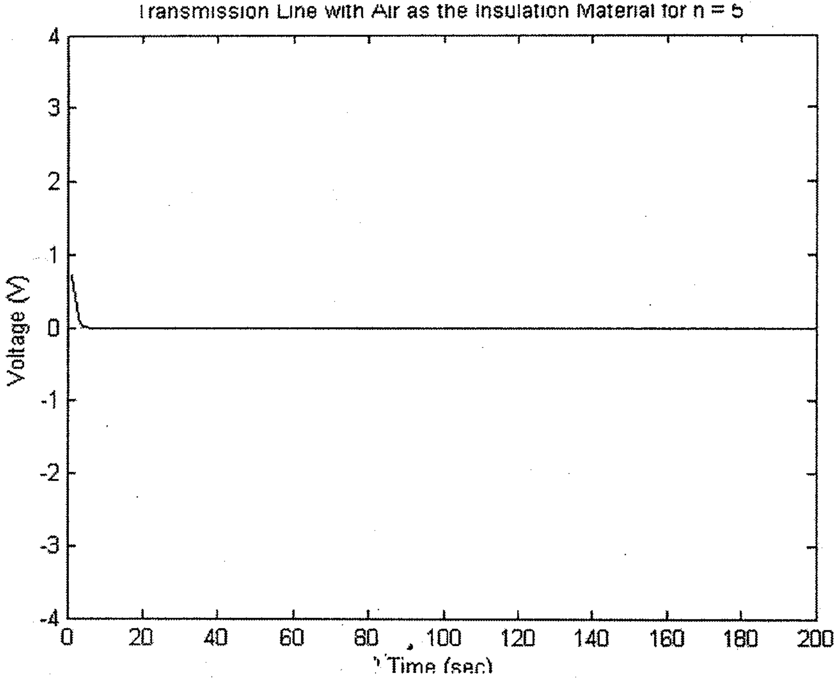
Transmission Line with Air as the Insulation Material for n = 50



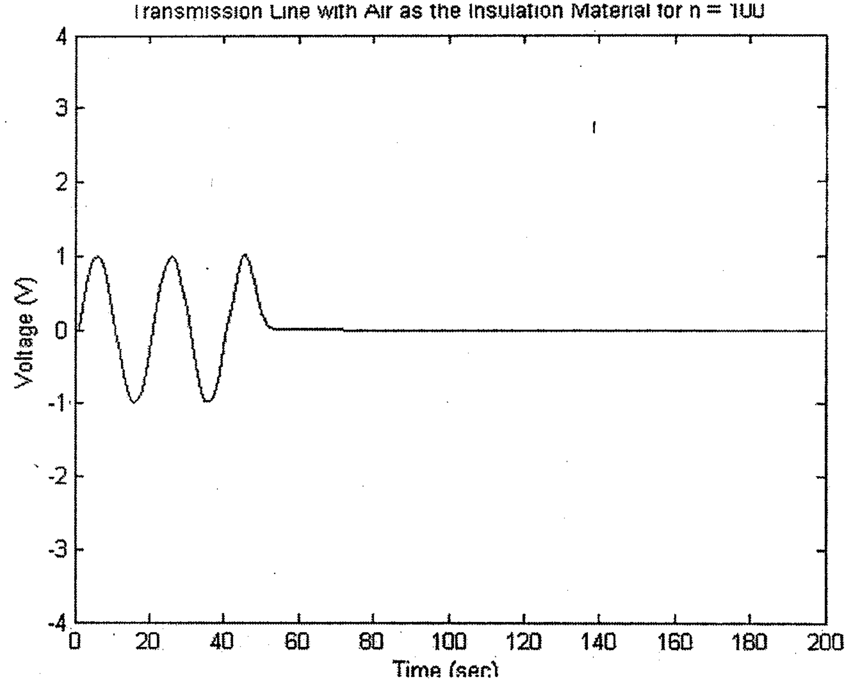
Transmission Line with Air as the Insulation Material for n = 200



Transmission Line with Air as the Insulation Material for n = 5



Transmission Line with Air as the Insulation Material for n = 100



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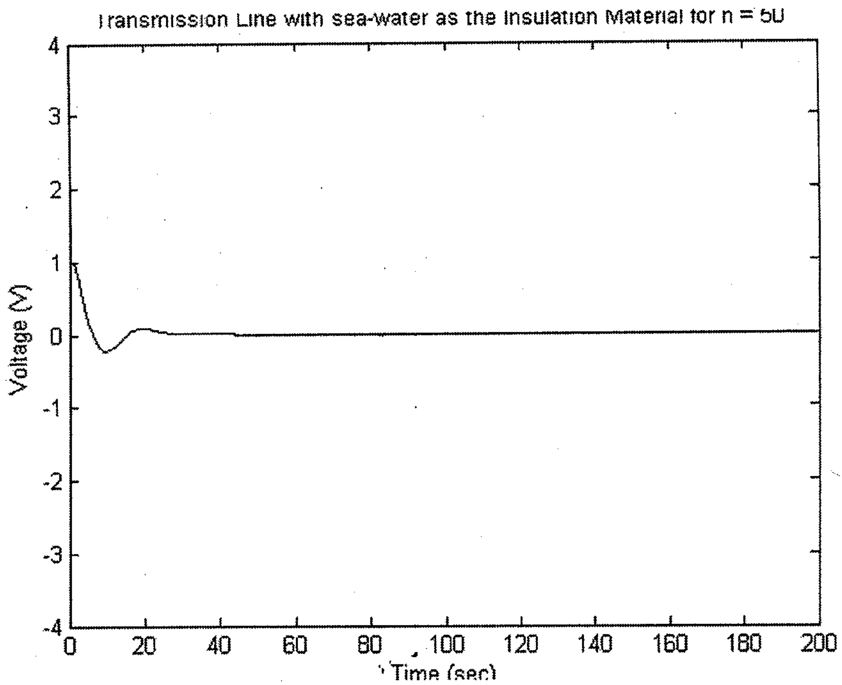
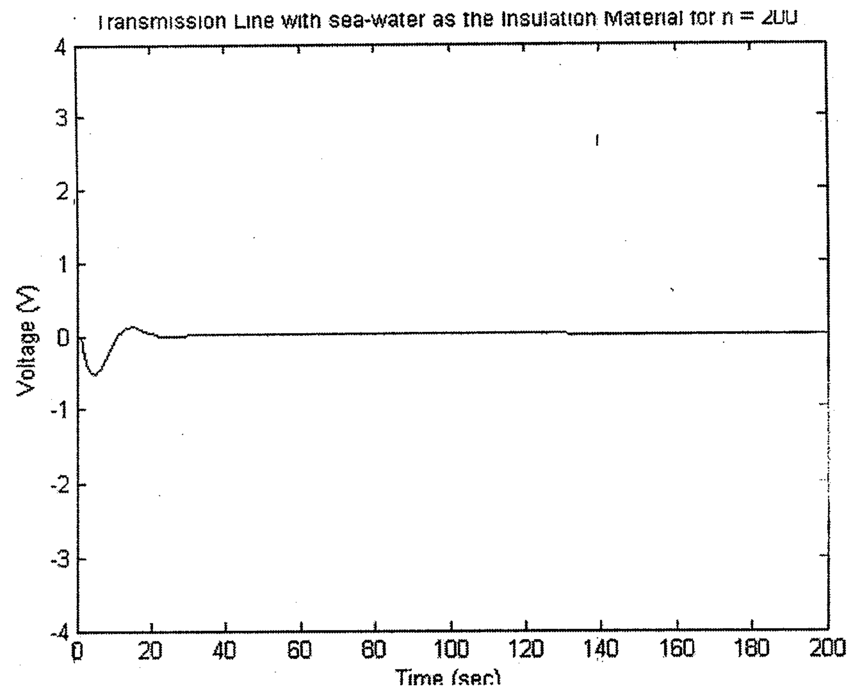
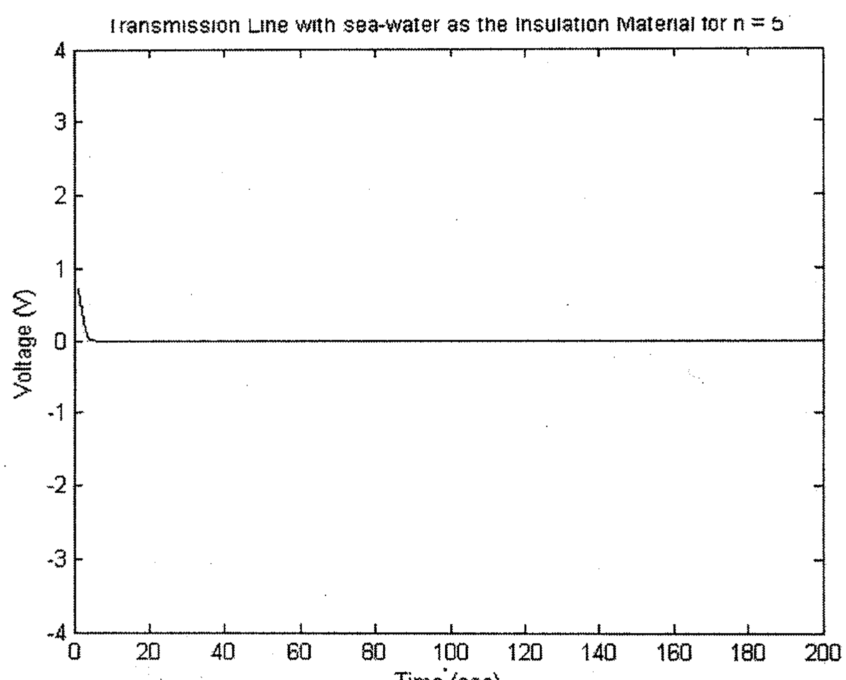


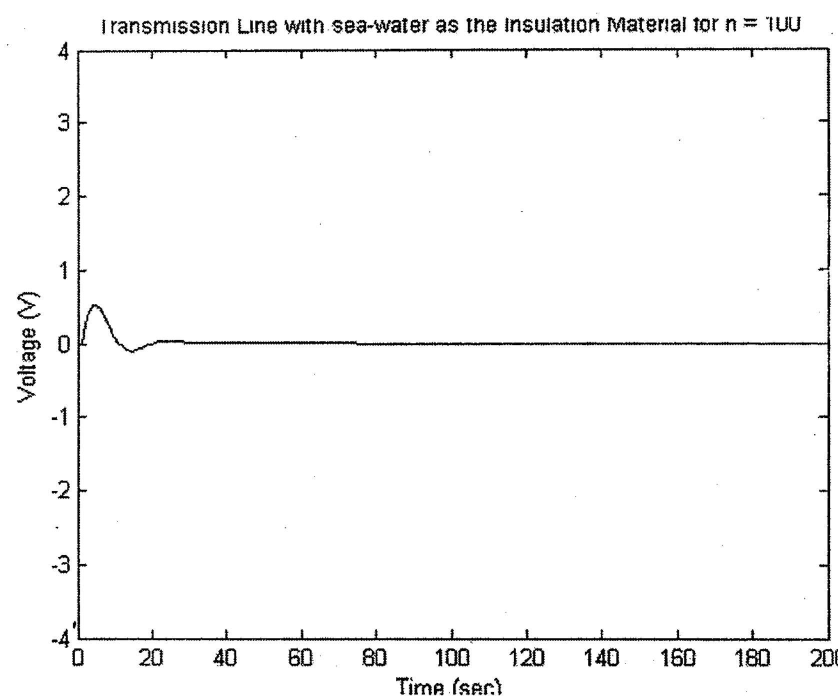
Transmission Line with sea-water as the Insulation Material for n = 50
Voltage (V)
Time (sec)



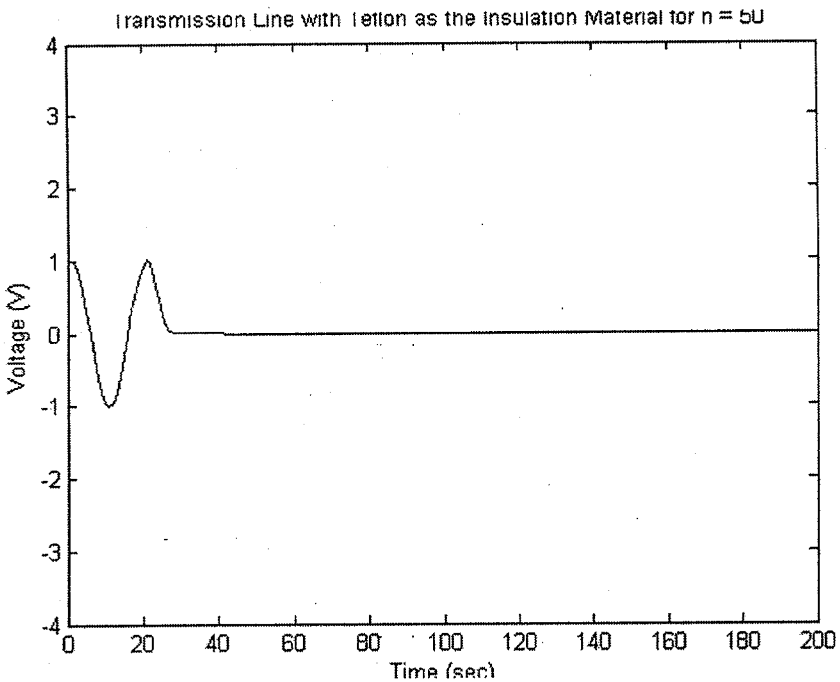
Transmission Line with sea-water as the Insulation Material for n = 200
Voltage (V)
Time (sec)

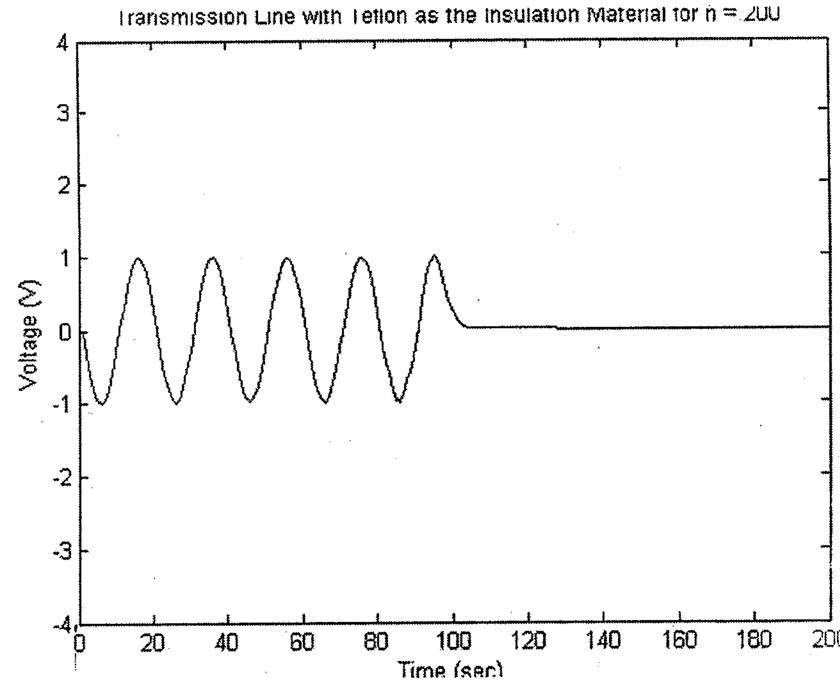


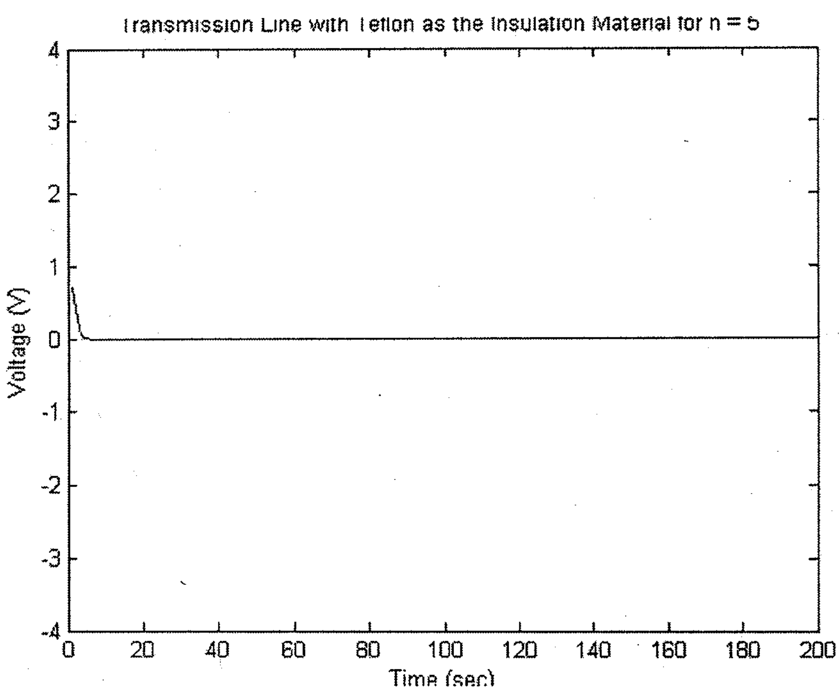
Transmission Line with sea-water as the Insulation Material for n = 5
Voltage (V)
Time (sec)

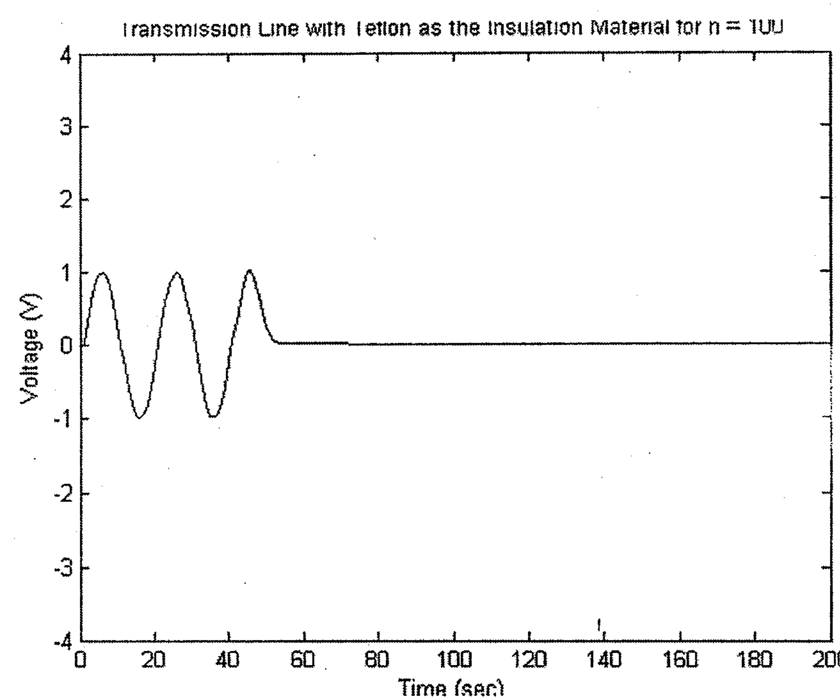


Transmission Line with sea-water as the Insulation Material for n = 100
Voltage (V)
Time (sec)


Transmission Line with Teflon as the Insulation Material for n = 50
Voltage (V)
Time (sec)


Transmission Line with Teflon as the Insulation Material for n = 200
Voltage (V)
Time (sec)


Transmission Line with Teflon as the Insulation Material for n = 5
Voltage (V)
Time (sec)


Transmission Line with Teflon as the Insulation Material for n = 100
Voltage (V)
Time (sec)