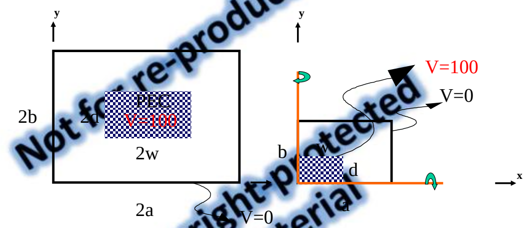
Efficient Solution of The Quasi-Static Solution of a Rectangular Coaxial Cable Geometry

Rectangular Coaxial Cable



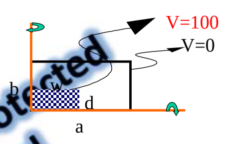
a = 2.5, b = 1.5, w = .5, d = .25, All dimensions are in mm.

Assuming $\Delta x = \Delta$[illegible]

$$V_C = \frac{1}{[\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4]}\left[V_T\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right) + V_B\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right) + V_R\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)\right]$$

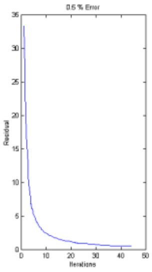
MatLab Program for the Rectangular Coaxial Cable

```
% Rect_coaxial_Potential.m    Started on September 6, 1998
% by:              Dr. Atef Z. Elsherbeni, atef@olemiss.edu
% Computation of the characteristic impedance of a rectangular coaxial cable
% Static solution
% Symmetry along x and y is used, hence, computations are for one quarter only
a = 2.5;        % outer lenght along x
b = 1.5;        % outer length along y
w = 0.5;        % center conductor length along x
d = 0.25;       % center conductor length along y
vcond = 100     % potential on the center conductor
h = .05         % incerement of segmentation
                % << watch for integer values >>

niter = 300    % number of iterations
nx = a/h; ny = b/h; nw = w/h; nd = d/h
v(1:nx+1,1:ny+1) = 0.0; % initialization of all nodes to zero

for [illegible] = 1:niter
  for i = 1:nx
    for j = 1:ny
      if      i <= nw & j <= nd
            v(i,j) = vcond;                                 % fixed potential
      elseif i == 1 & j > nd
            v(i,j) = .25*(2.*v(i+1,j)+v(i,j+1)+v(i,j-1));   % symmetry along y
      elseif j == 1 & i > nw
            v(i,j) = .25*(v(i+1,j)+v(i-1,j)+2.*v(i,j+1));   % symmetry along x
      else
            v(i,j) = .25*(v(i+1,j)+v(i-1,j)+v(i,j+1)+v(i,j-1)); % general point
      end
    end
  end
end

surfc(v');      % plot the potential distribution Note the transpose operation
axis([1 nx 1 ny]); xlabel('x Axis'); ylabel('y Axis');
title('Potential Distribution');View([-15,35]);     % plot the potential distribution
```



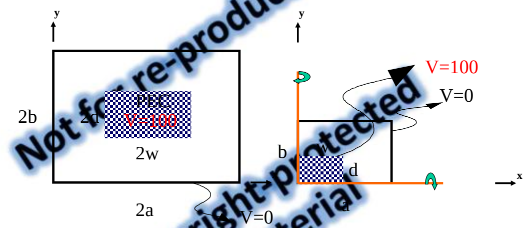
Computation of The Potential With a Specified Accuracy

```
% Rect_coaxial_Pot_Residual.m    September 20, 1999
% by:              Dr. Atef Z. Elsherbeni, atef@olemiss.edu
clear all; clf; startcpu = cputime;
a = 2.5;  b = 1.5;        % outer dimensions along x and y
w = 0.5;  d = 0.25;       % center conductor dimensions along x and y
vcond = 100;              % potential on the center conductor
h = .05;                  % incerement of segmentation << watch for integer values >>
nx = a/h; ny = b/h; nw = w/h; nd = d/h;
v(1:nx+1,1:ny+1) = 0.0;   % initialize all nodes to zero
v(1:nw,1:nd) = vcond;     % initialize the constant voltage
Maxiter = 1000;     % number of iterations
percent = .5/100; rmin = percent*vcond;  % percentage error
for k =1:Maxiter
   residual = 0.;          % initialize the residual
   for i = 1:nx
      for j = 1:ny
         if   i <= nw & j <= nd
            vnew = vcond;        % Do nothing fixed potential already defined(1)
         elseif j == 1 & i > nw
              vnew = .25*(v(i+1,j)+v(i-1,j)+2.*v(i,j+1));   % symmetry along x
            elseif i == 1 & j > nd
              vnew =.25*(2.*v(i+1,j)+v(i,j+1)+v(i,j-1));   % symmetry along y
         else
              vnew = .25*(v(i+1,j)+v(i-1,j)+v(i,j+1)+v(i,j-1));  % general point
         end
         r = abs(vnew -v(i,j));    % Check for accuracy
         if  r > residual
             residual = r;
         end
         v(i,j) = vnew;
      end
   end
   iter(k) = k;              % set the resudual and iteration number in arrays
   resid(k) = residual;
   niter = k;
   if residual < rmin
      break
   end
end
```



Rectangular Coaxial Cable

Original problem **Computational domain**



a = 2.5,b = 1.5,w = .5,d = .25, All dimensions are in mm.

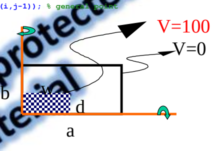
Assuming $\Delta x = \Delta y = h$

$$V_C = \frac{1}{[\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4]}\left[V_T\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right) + V_B\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right) + V_R\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)\right]$$

MatLab Program for the Rectangular Coaxial Cable

Un-Vectorized code:

```
for k = 1:niter
   for i = 1:nx
      for j = 1:ny
         if     i <= nw & j <= nd
               v(i,j) = vcond;                               % fixed potential
         elseif i == 1 & j > nd
               v(i,j) = .25*(2.*v(i+1,j)+v(i,j+1)+v(i,j-1));   % symmetry along y
         elseif j == 1 & i > nw
               v(i,j) = .25*(v(i+1,j)+v(i-1,j)+2.*v(i,j+1));   % symmetry along x
         else
               v(i,j) = .25*(v(i+1,j)+v(i-1,j)+v(i,j+1)+v(i,j-1)); % general point
         end
      end
   end
end
```

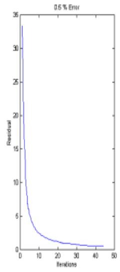


Vectorized code:

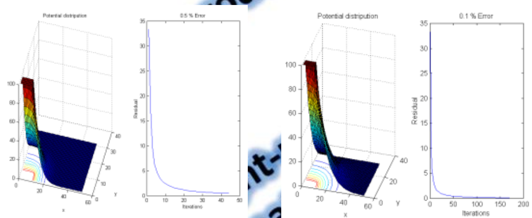
```
for k = 1:niter
    v(2:nx,2:ny) = .25*(v(3:nx+1,2:ny)+v(1:nx-1,2:ny)+v(2:nx,3:ny+1)+v(2:nx,1:ny-1)); % general case
    v(1:nw,1:nd) = vcond;                                                             % fixed potential
    v(1,nd+1:ny) = .25*(2.*v(2,nd+1:ny)+v(1,nd+2:ny+1)+v(1,nd:ny-1));                % symmetry along y
    v(nw+1:nx,1) = .25*(v(nw+2:nx+1,1)+v(nw:nx-1,1)+2.*v(nw+1:nx,2));                % symmetry along x
end
```

Computation of The Potential with a Specified Accuracy - Vectorized Code

```
% Rect_coax_Pot_Resid_Optm.m    September 20, 1999
% by:               Dr. Atef Z. Elsherbeni, atef@olemiss.edu
clear all, clf,clc;

DateTime_Start = datestr(now)
start_time=cputime;

a = 2.5;            % outer lenght along x
b = 1.5;            % outer length along y
w = 0.5;            % center conductor length along x
d = 0.25;           % center conductor length along y
vcond = 100;        % potential on the center conductor
h = .05;            % incerement of segmentation


nx = a/h; ny = b/h; nw = w/h; nd = d/h;
v(1:nx+1,1:ny+1) = 0.0;  vnew(1:nx+1,1:ny+1) = 0.0;     % initialize all nodes to zero
Maxiter = 2000;     % number of iterations
percent = .5/100; rmin = percent*vcond;                 % percentage error

for k =1:Maxiter
    vnew(2:nx,2:ny) = .25*(v(3:nx+1,2:ny)+v(1:nx-1,2:ny)+v(2:nx,3:ny+1)+v(2:nx,1:ny-1)); % general case
    vnew(1:nw,1:nd) = vcond;                                        % fixed potential
    vnew(1,nd+1:ny) = .25*(2.*v(2,nd+1:ny)+v(1,nd+2:ny+1)+v(1,nd:ny-1));     % symmetry along y
    vnew(nw+1:nx,1) = .25*(v(nw+2:nx+1,1)+v(nw:nx-1,1)+2.*v(nw+1:nx,2));     % symmetry along x

    residual = max(max(abs(vnew-v)));     % Check for accuracy
    if residual < rmin
        break
    end
    v = vnew;
    iter(k) = k;                          % set the resudual and iteration number in arrays
    resid(k) = residual;
end
```

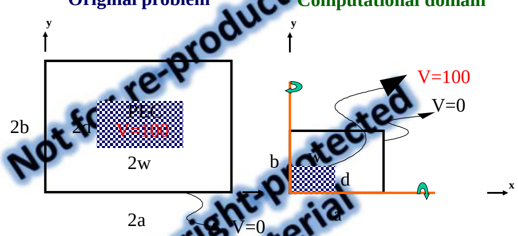


Number of Iterations Based on Solution Accuracy



Rectangular Coaxial Cable

Original problem **Computational domain**



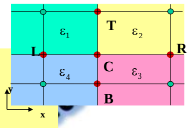
$a = 2.5, b = 1.5, w = .5, d = .25$, All dimensions are in mm.

Assuming $\Delta x = \Delta y = h$

$$V_C = \frac{1}{[\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4]}\left[V_T\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right) + V_B\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right) + V_R\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)\right]$$

Coefficients Procedure for Potential Calculation

with $\Delta x = \Delta y = h$



$$V_C = \frac{1}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]}\begin{bmatrix} V_T\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)+V_L\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right) \\ +V_B\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right)+V_R\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)\end{bmatrix}$$

$$V_C = C_T V_T + C_L V_L + C_B V_B + C_R V_R$$

$$C_T = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]}, \quad C_L = \frac{\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]}$$

$$C_B = \frac{\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]}, \quad C_R = \frac{\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]}$$

Appropriate coefficients should be used for the symmetry and asymmetry conditions.

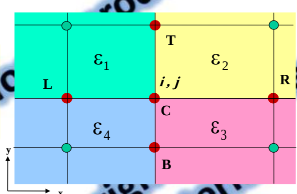
Re-naming of the Potentials and the Media Properties in Terms of the Node Coordinates

$\varepsilon_1(i,j) = \varepsilon_{(i-1,j)}$

$\varepsilon_2(i,j) = \varepsilon_{(i,j)}$

$\varepsilon_3(i,j) = \varepsilon_{(i,j-1)}$

$\varepsilon_4(i,j) = \varepsilon_{(i-1,j-1)}$



$V_C = V_{(i,j)}$

$V_T = V_{(i,j+1)}$

$V_B = V_{(i,j-1)}$

$V_R = V_{(i+1,j)}$

$V_L = V_{(i-1,j)}$

$$V_C = C_T V_T + C_L V_L + C_B V_B + C_R V_R$$

$$\Downarrow$$

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

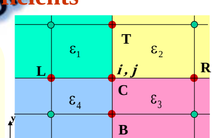
Assignment of Coefficients

$$C_T(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]} = \frac{[\varepsilon_{(i-1,j)}+\varepsilon_{(i,j)}]/2}{[\varepsilon_{(i-1,j)}+\varepsilon_{(i,j)}+\varepsilon_{(i,j-1)}+\varepsilon_{(i-1,j-1)}]}$$

$$C_L(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]} = \frac{[\varepsilon_{(i-1,j)}+\varepsilon_{(i-1,j-1)}]/2}{[\varepsilon_{(i-1,j)}+\varepsilon_{(i,j)}+\varepsilon_{(i,j-1)}+\varepsilon_{(i-1,j-1)}]}$$

$$C_B(i,j) = \frac{\left(\frac{\varepsilon_4+\varepsilon_3}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]} = \frac{[\varepsilon_{(i-1,j-1)}+\varepsilon_{(i,j-1)}]/2}{[\varepsilon_{(i-1,j)}+\varepsilon_{(i,j)}+\varepsilon_{(i,j-1)}+\varepsilon_{(i-1,j-1)}]}$$

$$C_R(i,j) = \frac{\left(\frac{\varepsilon_3+\varepsilon_2}{2}\right)}{[\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4]} = \frac{[\varepsilon_{(i,j-1)}+\varepsilon_{(i,j)}]/2}{[\varepsilon_{(i-1,j)}+\varepsilon_{(i,j)}+\varepsilon_{(i,j-1)}+\varepsilon_{(i-1,j-1)}]}$$



$V_C = V_{(i,j)}$ $\quad \varepsilon_1(i,j) = \varepsilon_{(i-1,j)}$

$V_T = V_{(i,j+1)}$ $\quad \varepsilon_2(i,j) = \varepsilon_{(i,j)}$

$V_B = V_{(i,j-1)}$ $\quad \varepsilon_3(i,j) = \varepsilon_{(i,j-1)}$

$V_R = V_{(i+1,j)}$ $\quad \varepsilon_4(i,j) = \varepsilon_{(i-1,j-1)}$

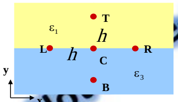
$V_L = V_{(i-1,j)}$

$$\begin{aligned} V(i,j) &= C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) \\ &\quad + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j) \end{aligned}$$

Potential at The Interfaces Between Two Media With Uniform Discretization Along *x* and *y* Directions

Horizontal boundary

$$V_C = \frac{1}{2[\varepsilon_1+\varepsilon_3]}\left[V_T\varepsilon_1 + V_L\left(\tfrac{\varepsilon_1+\varepsilon_3}{2}\right) + V_B\varepsilon_3 + V_R\left(\tfrac{\varepsilon_1+\varepsilon_3}{2}\right)\right]$$

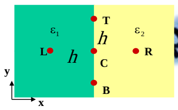


$$C_T(i,j) = \frac{\varepsilon_1}{2[\varepsilon_1+\varepsilon_3]} \;,\; C_L(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)}{2[\varepsilon_1+\varepsilon_3]}$$

$$C_B(i,j) = \frac{\varepsilon_3}{2[\varepsilon_1+\varepsilon_3]} \;,\; C_R(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)}{2[\varepsilon_1+\varepsilon_3]}$$

Vertical boundary

$$V_C = \frac{1}{2[\varepsilon_1+\varepsilon_2]}\left[V_T\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\varepsilon_1 + V_B\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right) + V_R\varepsilon_2\right]$$



$$C_T(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{2[\varepsilon_1+\varepsilon_2]} \;,\; C_L(i,j) = \frac{\varepsilon_1}{2[\varepsilon_1+\varepsilon_2]}$$

$$C_B(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{2[\varepsilon_1+\varepsilon_2]} \;,\; C_R(i,j) = \frac{\varepsilon_2}{2[\varepsilon_1+\varepsilon_2]}$$

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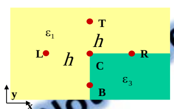
Potential at Top Corners With Uniform Discretization Along *x* and *y* Directions

Left top corner

$$V_C = \frac{1}{[3\varepsilon_1+\varepsilon_3]}\left[V_T\varepsilon_1 + V_L\varepsilon_1 + V_B\left(\tfrac{\varepsilon_1+\varepsilon_3}{2}\right) + V_R\left(\tfrac{\varepsilon_1+\varepsilon_3}{2}\right)\right]$$

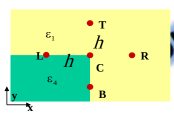


$$C_T(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_3]} \;,\; C_L(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_3]}$$

$$C_B(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)}{[3\varepsilon_1+\varepsilon_3]} \;,\; C_R(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)}{[3\varepsilon_1+\varepsilon_3]}$$

Right top corner

$$V_C = \frac{1}{[3\varepsilon_1+\varepsilon_4]}\left[V_T\varepsilon_1 + V_L\left(\tfrac{\varepsilon_1+\varepsilon_4}{2}\right) + V_B\left(\tfrac{\varepsilon_1+\varepsilon_4}{2}\right) + V_R\varepsilon_1\right]$$



$$C_T(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_4]} \;,\; C_L(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right)}{[3\varepsilon_1+\varepsilon_4]}$$

$$C_B(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_4}{2}\right)}{[3\varepsilon_1+\varepsilon_4]} \;,\; C_R(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_4]}$$

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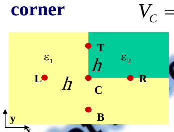
Potential at Bottom Corners With Uniform Discretization Along *x* and *y* Directions

Right bottom corner

$$V_C = \frac{1}{[3\varepsilon_1+\varepsilon_2]}\left[V_T\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\varepsilon_1 + V_B\varepsilon_1 + V_R\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right)\right]$$

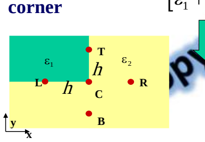


$$C_T(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[3\varepsilon_1+\varepsilon_2]} \;,\; C_L(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_2]}$$

$$C_B(i,j) = \frac{\varepsilon_1}{[3\varepsilon_1+\varepsilon_2]} \;,\; C_R(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[3\varepsilon_1+\varepsilon_2]}$$

Left bottom corner

$$V_C = \frac{1}{[\varepsilon_1+3\varepsilon_2]}\left[V_T\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right) + V_L\left(\tfrac{\varepsilon_1+\varepsilon_2}{2}\right) + V_B\varepsilon_2 + V_R\varepsilon_2\right]$$



$$C_T(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[\varepsilon_1+3\varepsilon_2]} \;,\; C_L(i,j) = \frac{\left(\frac{\varepsilon_1+\varepsilon_2}{2}\right)}{[\varepsilon_1+3\varepsilon_2]}$$

$$C_B(i,j) = \frac{\varepsilon_2}{[\varepsilon_1+3\varepsilon_2]} \;,\; C_R(i,j) = \frac{\varepsilon_2}{[\varepsilon_1+3\varepsilon_2]}$$

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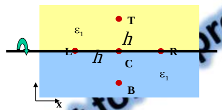
Potential at point on Lines of Symmetry

Symmetry w.r.t. horizontal line



$$\frac{\partial V}{\partial y} = 0 = \frac{V_T - V_B}{2h} \rightarrow V_T = V_B$$

$$V_C = \frac{1}{4}\left[2V_B + V_L + V_R\right]$$

$C_T(i,j) = 0$, $C_L(i,j) = \frac{1}{4}$

$C_B(i,j) = \frac{1}{2}$, $C_R(i,j) = \frac{1}{4}$

$$V_C = \frac{1}{4}\left[2V_T + V_L + V_R\right]$$

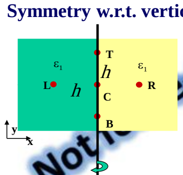
$C_T(i,j) = \frac{1}{2}$, $C_L(i,j) = \frac{1}{4}$

$C_B(i,j) = 0$, $C_R(i,j) = \frac{1}{4}$

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

Potential at point on Lines of Symmetry

Symmetry w.r.t. vertical line



$$\frac{\partial V}{\partial x} = 0 = \frac{V_R - V_L}{2h} \rightarrow V_R = V_L$$

$$V_C = \frac{1}{4}\left[V_T + 2V_L + V_B\right]$$

$C_T(i,j) = \frac{1}{4}$, $C_L(i,j) = \frac{1}{2}$

$C_B(i,j) = \frac{1}{4}$, $C_R(i,j) = 0$

$$V_C = \frac{1}{4}\left[V_T + 2V_R + V_B\right]$$

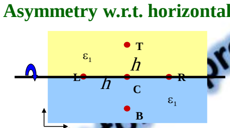
$C_T(i,j) = \frac{1}{4}$, $C_L(i,j) = 0$

$C_B(i,j) = \frac{1}{4}$, $C_R(i,j) = \frac{1}{2}$

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

Potential at point on Lines of Anti-Symmetry

Asymmetry w.r.t. horizontal line



$$V_T = -V_B$$

$$V_C = \frac{1}{4}\left[V_L + V_R\right]$$

$$V_C = \frac{1}{4}\left[V_L + V_R\right]$$

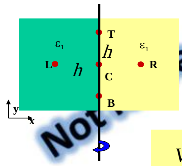
$C_T(i,j) = 0$, $C_L(i,j) = \frac{1}{4}$

$C_B(i,j) = 0$, $C_R(i,j) = \frac{1}{4}$

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

Potential at point on Lines of Anti-Symmetry

Asymmetry w.r.t. vertical line



$$V_R = -V_L$$

$$V_C = \frac{1}{4}[V_T + V_B]$$

$$V_C = \frac{1}{4}[V_T + V_B]$$

$$C_T(i,j) = \frac{1}{4} \quad , \quad C_L(i,j) = 0$$

$$C_B(i,j) = \frac{1}{4} \quad , \quad C_R(i,j) = 0$$

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

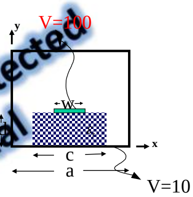
Home Work # 4: Alternative Procedure for Potential Calculation

$$V(i,j) = C_T(i,j)V(i,j+1) + C_L(i,j)V(i-1,j) + C_B(i,j)V(i,j-1) + C_R(i,j)V(i+1,j)$$

Based on the above equation, develop a program to solve for the potential at all the points in the computational domain using the minimum number of code lines for the potential iterative expression (no loops except for the iteration process).

Use the symmetry whenever is possible.

Compare the CPU time based on this coefficient expression procedure with the CPU time if your solution is not based on the coefficient procedure but using the vectorized code.



a = 10, b = 6, c = 7, d = 2, w = 1.5, $\varepsilon_r = 9$
Thickness of the strip =.05
All dimensions are in mm.