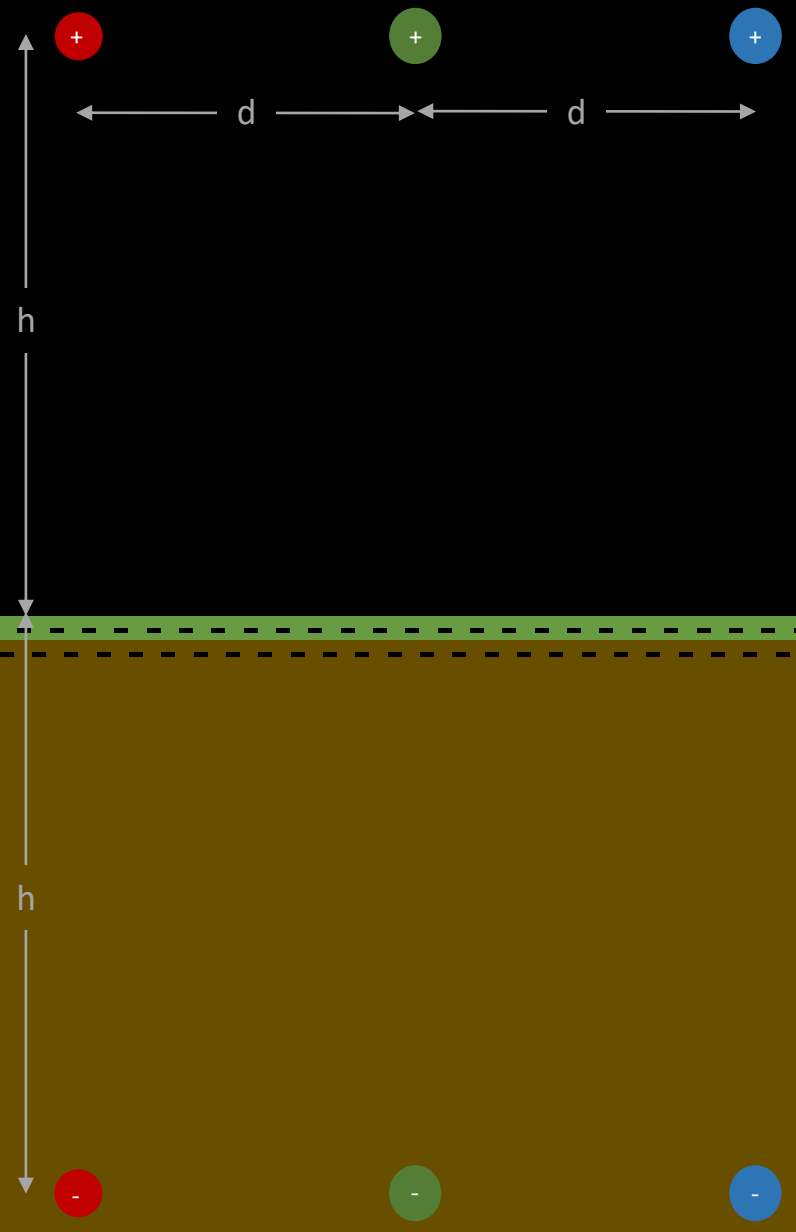
Calculating 3Φ T-Line Electric Fields

(Horizontal Configuration)

consider a 3Φ circuit with infinity long straight conductors
and some height above ground

For this problem, the effects of earth need to be considered.
Since the earth is a good conductor of electric current…
It will be modeled as a conducting plane at the surface.

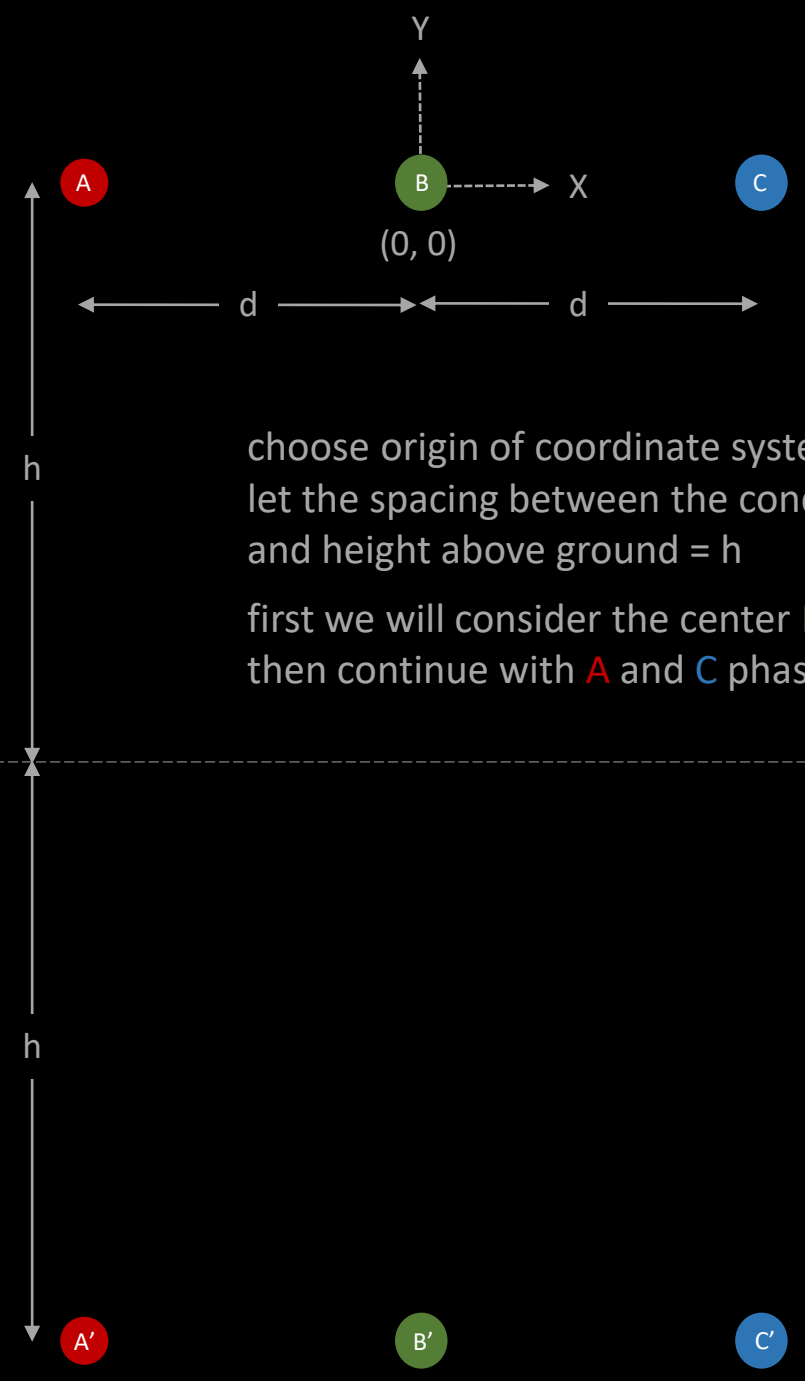


The electric charge on the lines will create electric fields.
The electric fields will Induce an opposite charge near the earth's surface.

The concept of "image conductors" are used to calculate the net electric field around the overhead transmission lines.

Calculating 3Φ T-Line Electric Fields

(Horizontal Configuration)



choose origin of coordinate system at center of B phase conductor
let the spacing between the conductors = d
and height above ground = h

first we will consider the center B phase conductor
then continue with A and C phase using superposition

Calculating 3Φ T-Line Electric Fields

Let the instantaneous current flowing in the conductor = i where positive current is "out" of the page
consider the electric field at some arbitrary point = (x, y) that is a distance r away from the B conductor

permeability of free space

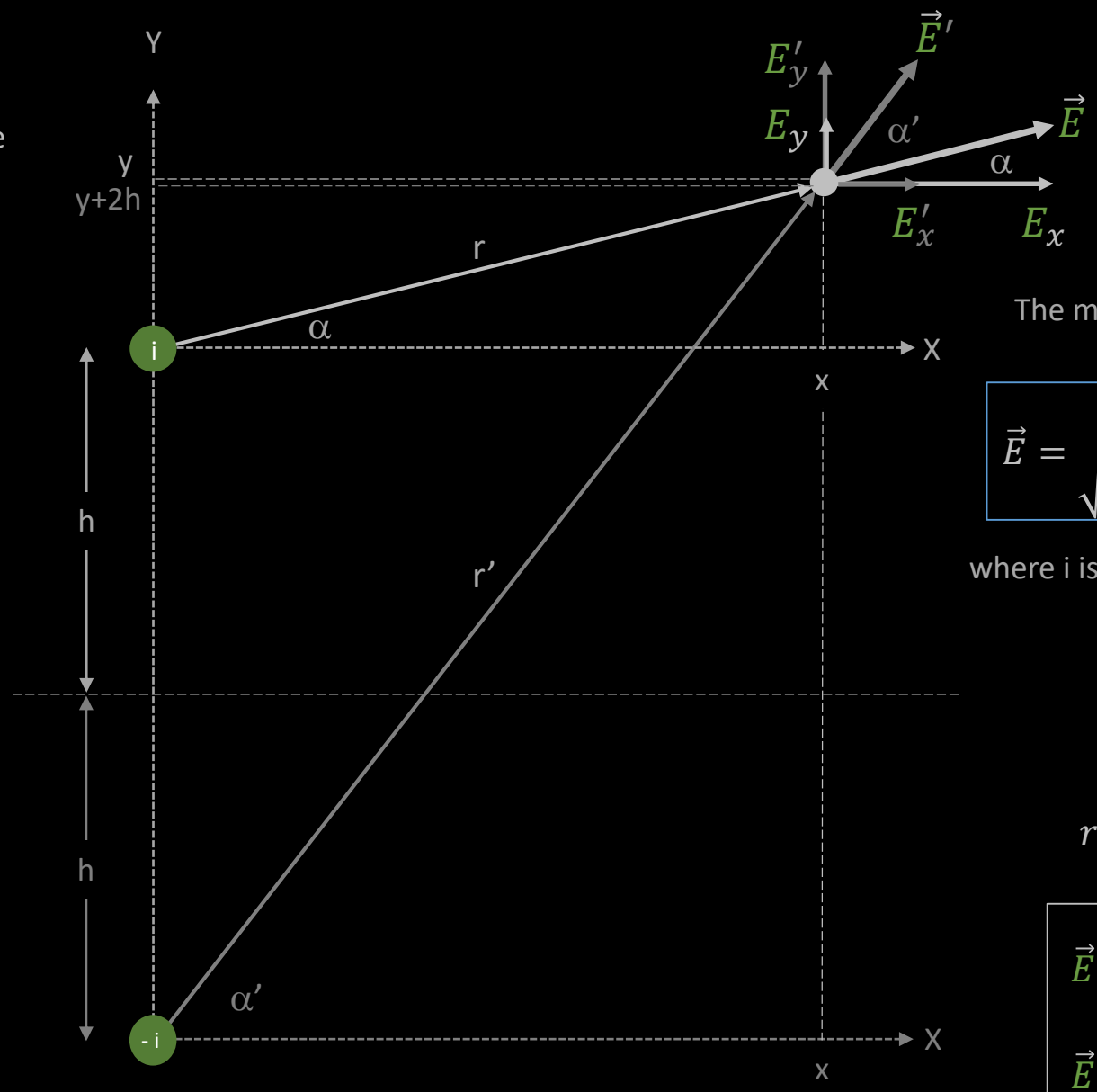
$$\mu_0 = 4\pi \times 10^{-7} \frac{H}{m}$$

permittivity of free space

$$\varepsilon_0 = 8.854 \times 10^{-12} \frac{F}{m}$$

line charge density

$$\rho = i\sqrt{\mu_0 \varepsilon_0}$$



The magnitude of the electric field is given as

$$\boxed{\vec{E} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \frac{i}{2\pi r} = \frac{120\pi i}{2\pi r} = \frac{60i}{r}\hat{r}}$$

where i is the instantaneous RMS current

calculate r

$$r = \sqrt{x^2 + y^2}$$

calculate r'

$$r = \sqrt{x^2 + [y + 2h]^2}$$

$$\boxed{\begin{aligned} \vec{E} &= \frac{60 i_B}{\sqrt{x^2 + y^2}} \\ \vec{E}' &= \frac{-60 i_B}{\sqrt{x^2 + [y + 2h]^2}} \end{aligned}}$$

Note: when the current is negative or "into" the page, the E field will point in the opposite direction

Calculating 3Φ T-Line Electric Fields

next we want to know the horizontal and vertical components of E and E' for B phase

$$\vec{E} = \frac{60 i_B}{\sqrt{x^2 + y^2}}$$

$$E_x = \frac{60 i_B}{\sqrt{x^2 + y^2}} \cos\alpha$$

$$E_y = \frac{60 i_B}{\sqrt{x^2 + y^2}} \sin\alpha$$

$where$:

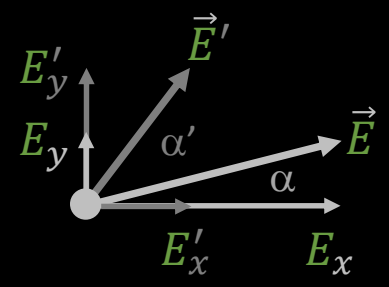
$$\cos\alpha = \frac{x}{r} = \frac{x}{\sqrt{x^2 + y^2}}$$

$$\sin\alpha = \frac{y}{r} = \frac{y}{\sqrt{x^2 + y^2}}$$

$\therefore$

$$E_x = \frac{60 i_B x}{[x^2 + y^2]}$$

$$E_y = \frac{60 i_B y}{[x^2 + y^2]}$$



$$\vec{E}' = \frac{-60 i_B}{\sqrt{x^2 + [y + 2h]^2}}$$

$$E'_x = \frac{-60 i_B}{\sqrt{x^2 + [y + 2h]^2}} \cos\alpha'$$

$$E'_y = \frac{-60 i_B}{\sqrt{x^2 + [y + 2h]^2}} \sin\alpha'$$

$where$:

$$\cos\alpha' = \frac{x}{r'} = \frac{x}{\sqrt{x^2 + [y + 2h]^2}}$$

$$\sin\alpha' = \frac{y + 2h}{r'} = \frac{y + 2h}{\sqrt{x^2 + [y + 2h]^2}}$$

$\therefore$

$$E'_x = \frac{-60 i_B x}{[x^2 + [y + 2h]^2]}$$

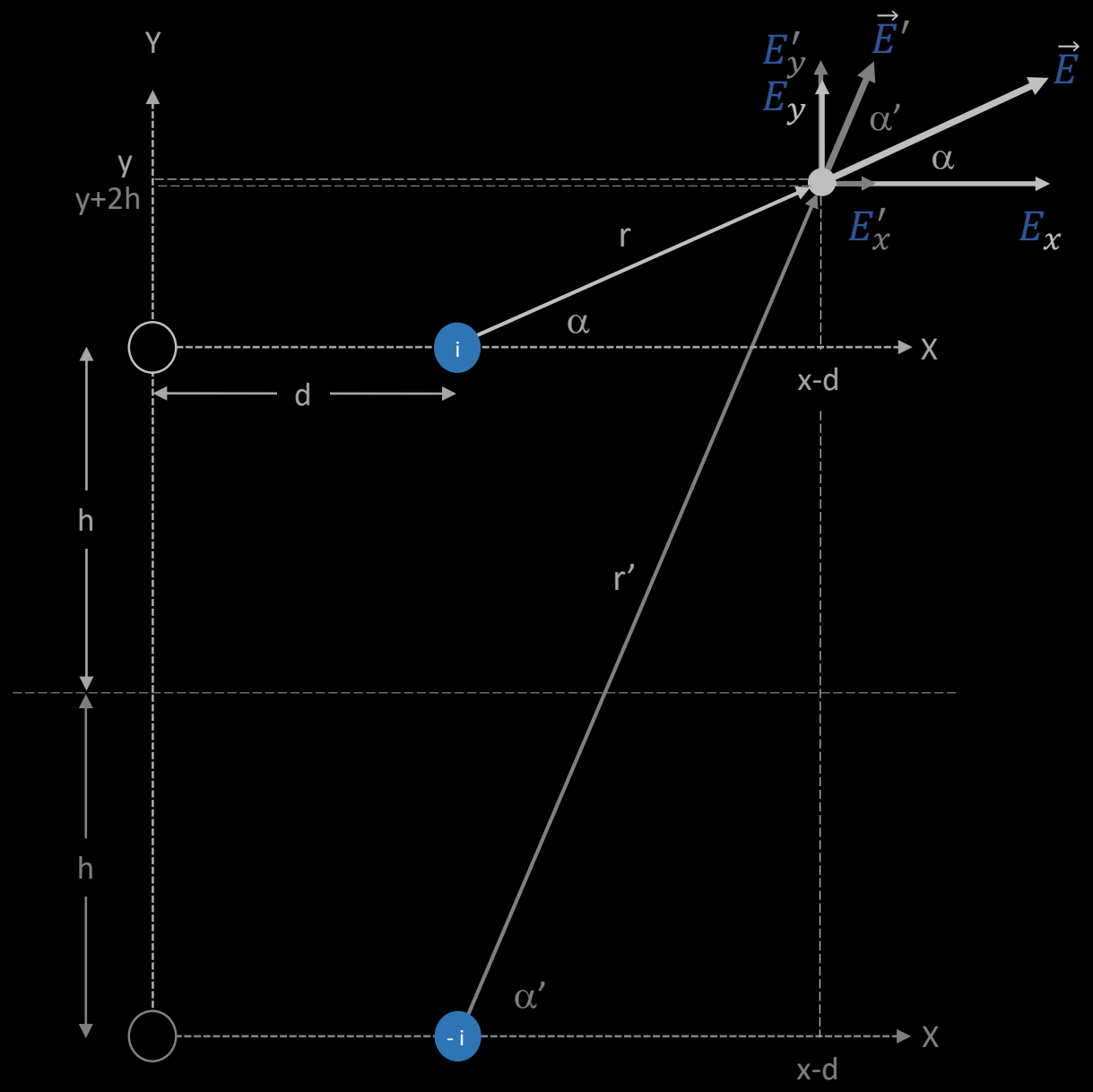
$$E'_y = \frac{-60 i_B [y + 2h]}{[x^2 + [y + 2h]^2]}$$

Since this calculation was for the center B phase...
modify the notation slightly and write the total B phase electric field

$$\boxed{\begin{aligned} E_{Bx} &= \frac{60 i_B x}{[x^2 + y^2]} - \frac{60 i_B x}{[x^2 + [y + 2h]^2]} \\ E_{By} &= \frac{60 i_B y}{[x^2 + y^2]} - \frac{60 i_B [y + 2h]}{[x^2 + [y + 2h]^2]} \end{aligned}}$$

Calculating 3Φ T-Line Electric Fields

repeat for the far right or C phase



$$\vec{E} = \frac{60i}{r}\hat{r}$$

calculate r

$$r = \sqrt{[x-d]^2 + y^2}$$

calculate r'

$$r = \sqrt{[x-d]^2 + [y+2h]^2}$$

$$\boxed{\begin{aligned} \vec{E} &= \frac{60i_C}{\sqrt{[x-d]^2 + y^2}} \\ \vec{E}' &= \frac{-60i_C}{\sqrt{[x-d]^2 + [y+2h]^2}} \end{aligned}}$$

Calculating 3Φ T-Line Electric Fields

get the horizontal and vertical components of C phase

$$\vec{E} = \frac{\sqrt{\mu_0}\sqrt{2}}{\sqrt{\varepsilon_0}2\pi}\frac{60i_C}{\sqrt{[x-d]^2+y^2}}$$

$$E_x = \frac{\sqrt{\mu_0}\sqrt{2}}{\sqrt{\varepsilon_0}2\pi}\frac{60i_C}{\sqrt{[x-d]^2+y^2}}\cos\alpha$$

$$E_y = \frac{\sqrt{\mu_0}\sqrt{2}}{\sqrt{\varepsilon_0}2\pi}\frac{60i_C}{\sqrt{[x-d]^2+y^2}}\sin\alpha$$

where:

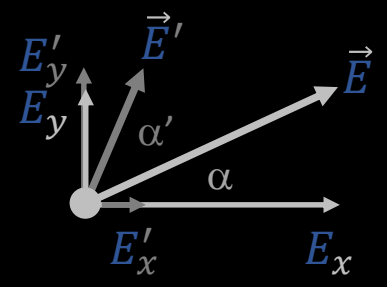
$$\cos\alpha = \frac{x-d}{r} = \frac{x-d}{\sqrt{[x-d]^2+y^2}}$$

$$\sin\alpha = \frac{y}{r} = \frac{y}{\sqrt{[x-d]^2+y^2}}$$

$\therefore$

$$E_x = \frac{60i_C[x-d]}{[[x-d]^2+y^2]}$$

$$E_y = \frac{60i_C y}{[[x-d]^2+y^2]}$$



$$\vec{E}' = \frac{-60i_C}{\sqrt{[x-d]^2+[y+2h]^2}}$$

$$E'_x = \frac{-60i_C}{\sqrt{[x-d]^2+[y+2h]^2}}\cos\alpha'$$

$$E'_y = \frac{-60i_C}{\sqrt{[x-d]^2+[y+2h]^2}}\sin\alpha'$$

where:

$$\cos\alpha' = \frac{x-d}{r'} = \frac{x-d}{\sqrt{[x-d]^2+[y+2h]^2}}$$

$$\sin\alpha' = \frac{y+2h}{r'} = \frac{y+2h}{\sqrt{[x-d]^2+[y+2h]^2}}$$

$\therefore$

$$E'_x = \frac{-60i_C[x-d]}{[[x-d]^2+[y+2h]^2]}$$

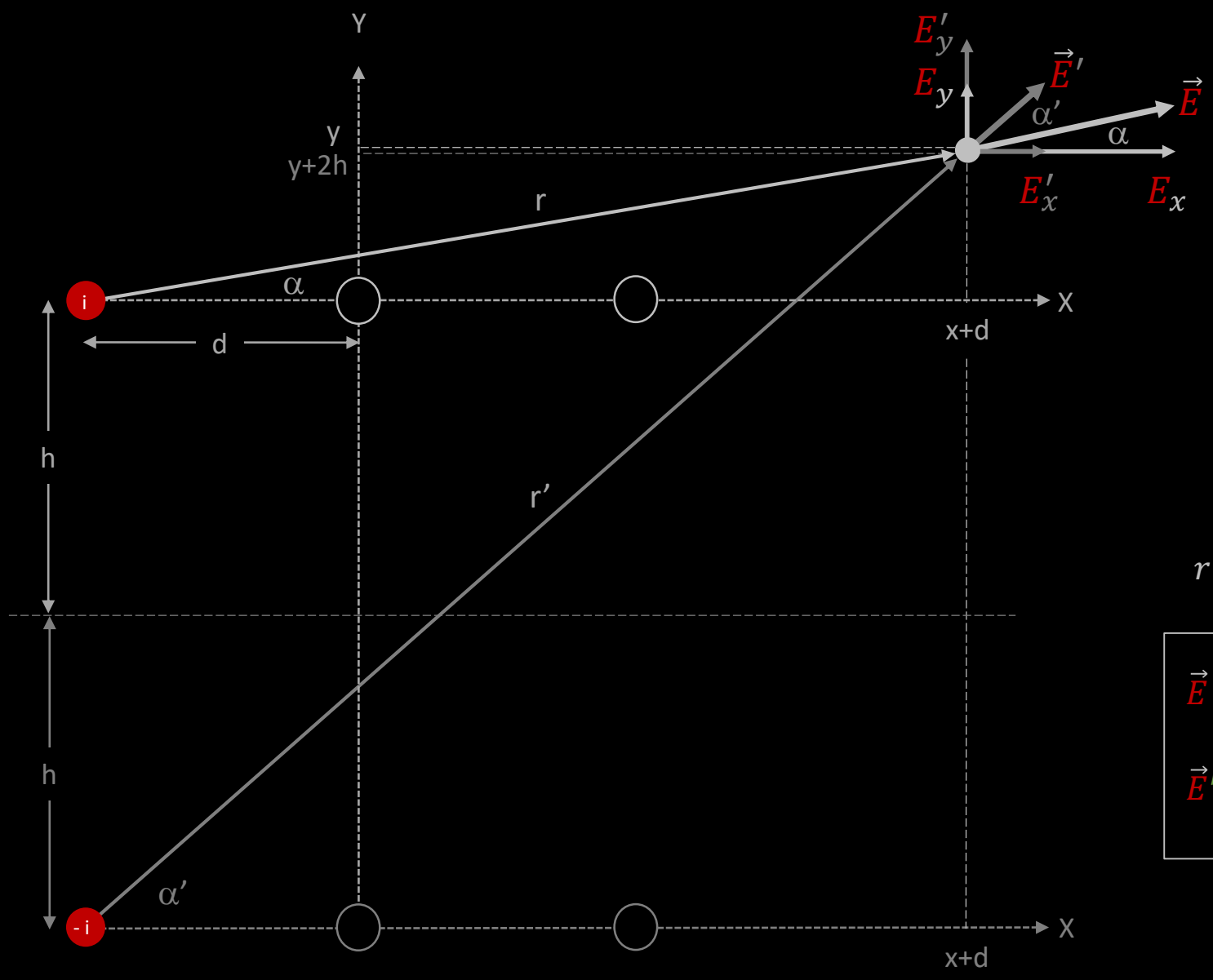
$$E'_y = \frac{-60\mathrm{i}_C[y+2h]}{[[x-d]^2+[y+2h]^2]}$$

Since this calculation was for the C phase...
modify the notation slightly and write the total C phase electric field

$$\boxed{\begin{aligned} E_{Cx} &= \frac{60i_C[x-d]}{[[x-d]^2+y^2]} - \frac{60i_C[x-d]}{[[x-d]^2+[y+2h]^2]} \\ E_{Cy} &= \frac{60i_C y}{[[x-d]^2+y^2]} - \frac{60i_C[y+2h]}{[[x-d]^2+[y+2h]^2]} \end{aligned}}$$

Calculating 3Φ T-Line Electric Fields

repeat for the far left or A phase



$$\vec{E} = \frac{60i}{r}\hat{r}$$

calculate r

$$r = \sqrt{[x+d]^2 + y^2}$$

calculate r'

$$r = \sqrt{[x+d]^2 + [y+2h]^2}$$

$$\boxed{\begin{aligned} \vec{E} &= \frac{60i_A}{\sqrt{[x+d]^2 + y^2}} \\ \vec{E}' &= \frac{-60i_A}{\sqrt{[x+d]^2 + [y+2h]^2}} \end{aligned}}$$

Calculating 3Φ T-Line Electric Fields

get the horizontal and vertical components of A phase

$$\vec{E} = \frac{60i_A}{\sqrt{[x+d]^2 + y^2}}$$

$$E_x = \frac{60i_A}{\sqrt{[x+d]^2 + y^2}} \cos\alpha$$

$$E_y = \frac{60i_A}{\sqrt{[x+d]^2 + y^2}} \sin\alpha$$

where:

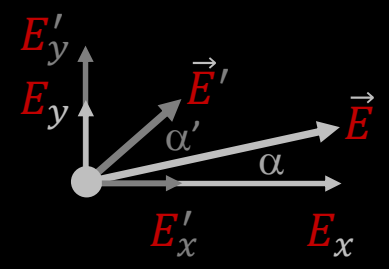
$$\cos\alpha = \frac{x+d}{r} = \frac{x+d}{\sqrt{[x+d]^2 + y^2}}$$

$$\sin\alpha = \frac{y}{r} = \frac{y}{\sqrt{[x+d]^2 + y^2}}$$

$\therefore$

$$E_x = \frac{60i_A[x+d]}{[[x+d]^2 + y^2]}$$

$$E_y = \frac{60i_A y}{[[x+d]^2 + y^2]}$$



$$\vec{E}' = \frac{-60i_A}{\sqrt{[x+d]^2 + [y+2h]^2}}$$

$$E'_x = \frac{-60i_A}{\sqrt{[x+d]^2 + [y+2h]^2}} \cos\alpha'$$

$$E'_y = \frac{-60i_A}{\sqrt{[x+d]^2 + [y+2h]^2}} \sin\alpha'$$

where:

$$\cos\alpha' = \frac{x+d}{r'} = \frac{x+d}{\sqrt{[x+d]^2 + [y+2h]^2}}$$

$$\sin\alpha' = \frac{y+2h}{r'} = \frac{y+2h}{\sqrt{[x+d]^2 + [y+2h]^2}}$$

$\therefore$

$$E'_x = \frac{-60i_A[x+d]}{[[x+d]^2 + [y+2h]^2]}$$

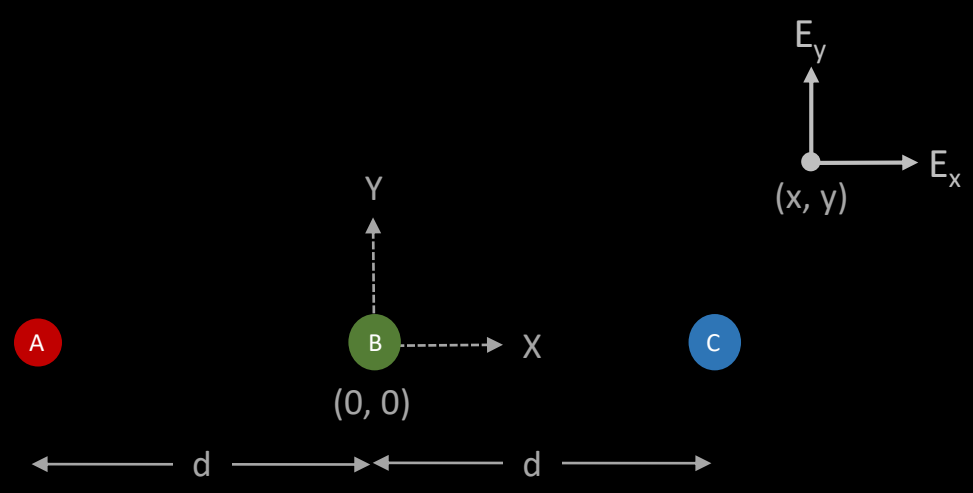
$$E'_y = \frac{-60\mathrm{i}_A[y+2h]}{[[x+d]^2 + [y+2h]^2]}$$

Since this calculation was for the A phase...
modify the notation slightly and write the total A phase electric field

$$\boxed{\begin{aligned} E_{Ax} &= \frac{60i_A[x+d]}{[[x+d]^2 + y^2]} - \frac{60i_A[x+d]}{[[x+d]^2 + [y+2h]^2]} \\ E_{Ay} &= \frac{60i_A y}{[[x+d]^2 + y^2]} - \frac{60i_A[y+2h]}{[[x+d]^2 + [y+2h]^2]} \end{aligned}}$$

Calculating 3Φ T-Line Electric Fields

so far we have the E field at any arbitrary point at single instant in time…



substitute the time dependent AC current for each phase

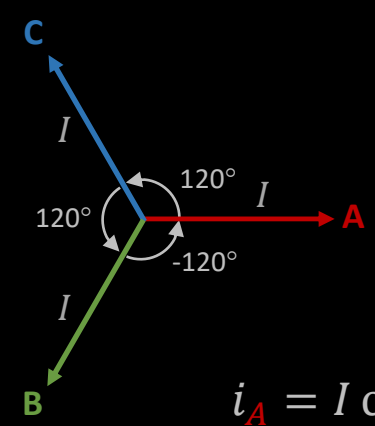
for a balanced 3Φ system in positive sequence…
all three phases have the same RMS current amplitude = I
rotating counter clockwise
and are out of phase by $\frac{2\pi}{3}$ radians

$$i_A = I\cos[\theta] \qquad \theta_A = \theta$$

$$i_B = I\cos\left[\theta - \frac{2\pi}{3}\right] \qquad \theta_B = \theta - \frac{2\pi}{3}$$

$$i_C = I\cos\left[\theta + \frac{2\pi}{3}\right] \qquad \theta_C = \theta + \frac{2\pi}{3}$$

$$\theta = \omega t = 2\pi f t$$



A-B-C-A-B-C-A

$$i_A = I\cos\theta_A$$
$$i_B = I\cos\theta_B$$
$$i_C = I\cos\theta_C$$
$$\theta = \omega t$$

Calculating 3Φ T-Line Electric Fields

substitute alternating phase currents

$$i_A = I\cos\theta_A \qquad i_B = I\cos\theta_B \qquad i_C = I\cos\theta_C$$

Horizontal Components

$$E_{Ax} = 60I\left[\frac{[x+d]\cos\theta_A}{[[x+d]^2+y^2]} - \frac{[x+d]\cos\theta_A}{[[x+d]^2+[y+2h]^2]}\right]$$

$$E_{Bx} = 60I\left[\frac{x\cos\theta_B}{[x^2+y^2]} - \frac{x\cos\theta_B}{[x^2+[y+2h]^2]}\right]$$

$$E_{Cx} = 60I\left[\frac{[x-d]\cos\theta_C}{[[x-d]^2+y^2]} - \frac{[x-d]\cos\theta_C}{[[x-d]^2+[y+2h]^2]}\right]$$

Vertical Components

$$E_{Ay} = 60I\left[\frac{y\cos\theta_A}{[[x+d]^2+y^2]} - \frac{[y+2h]\cos\theta_A}{[[x+d]^2+[y+2h]^2]}\right]$$

$$E_{By} = 60I\left[\frac{y\cos\theta_B}{[x^2+y^2]} - \frac{[y+2h]\cos\theta_B}{[x^2+[y+2h]^2]}\right]$$

$$E_{Cy} = 60I\left[\frac{y\cos\theta_C}{[[x-d]^2+y^2]} - \frac{[y+2h]\cos\theta_C}{[[x-d]^2+[y+2h]^2]}\right]$$

Calculating 3Φ T-Line Electric Fields

now add A B C phase contributions together to get total E field at any point (x, y) and any time

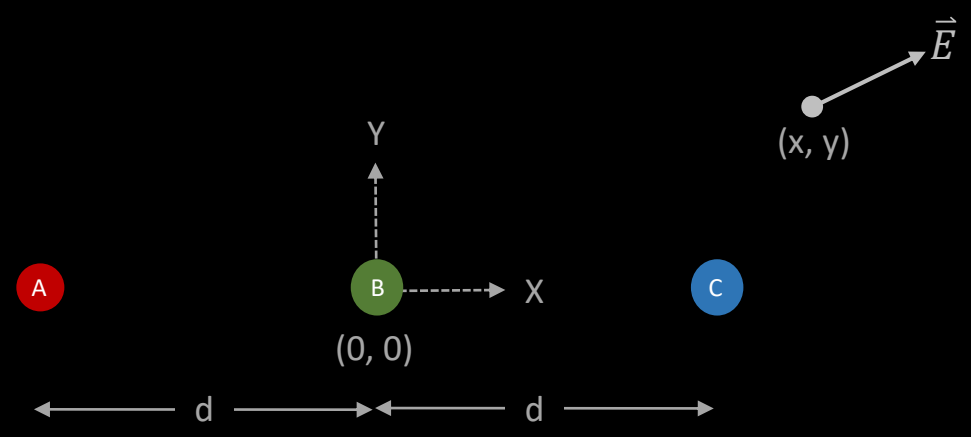
$$E_x = E_{Ax} + E_{Bx} + E_{Cx}$$

$$\boxed{E_x = 60I\left[\frac{[x+d]\cos\theta_A}{[x+d]^2+y^2} + \frac{x\cos\theta_B}{x^2+y^2} + \frac{[x-d]\cos\theta_C}{[x-d]^2+y^2} - \frac{[x+d]\cos\theta_A}{[x+d]^2+[y+2h]^2} - \frac{x\cos\theta_B}{x^2+[y+2h]^2} - \frac{[x-d]\cos\theta_C}{[x-d]^2+[y+2h]^2}\right]}$$

$$E_y = E_{Ay} + E_{By} + E_{Cy}$$

$$\boxed{E_y = 60I\left[\frac{y\cos\theta_A}{[x+d]^2+y^2} + \frac{y\cos\theta_B}{x^2+y^2} + \frac{y\cos\theta_C}{[x-d]^2+y^2} - \frac{[y+2h]\cos\theta_A}{[x+d]^2+[y+2h]^2} - \frac{[y+2h]\cos\theta_B}{x^2+[y+2h]^2} - \frac{[y+2h]\cos\theta_C}{[x-d]^2+[y+2h]^2}\right]}$$

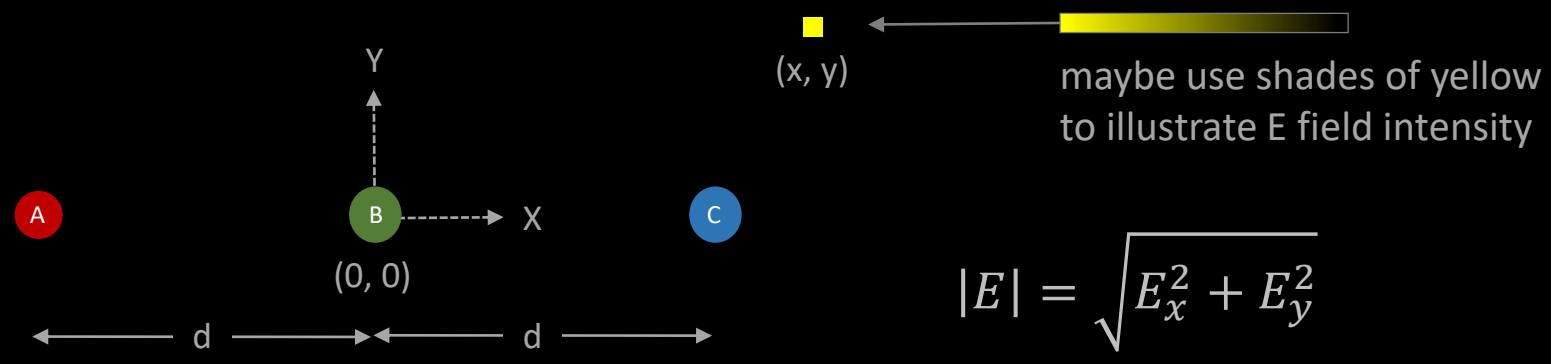
$$\boxed{\vec{E} = E_x\hat{x} + E_y\hat{y}}$$



You could plot the E field vectors for any number of points in space for any instant in time.
The length of the vector would indicate the electric field magnitude.
The direction of the vector would indicate if the field is positive or negative.
This method of illustrating fields is not very exciting…. Let's consider another way

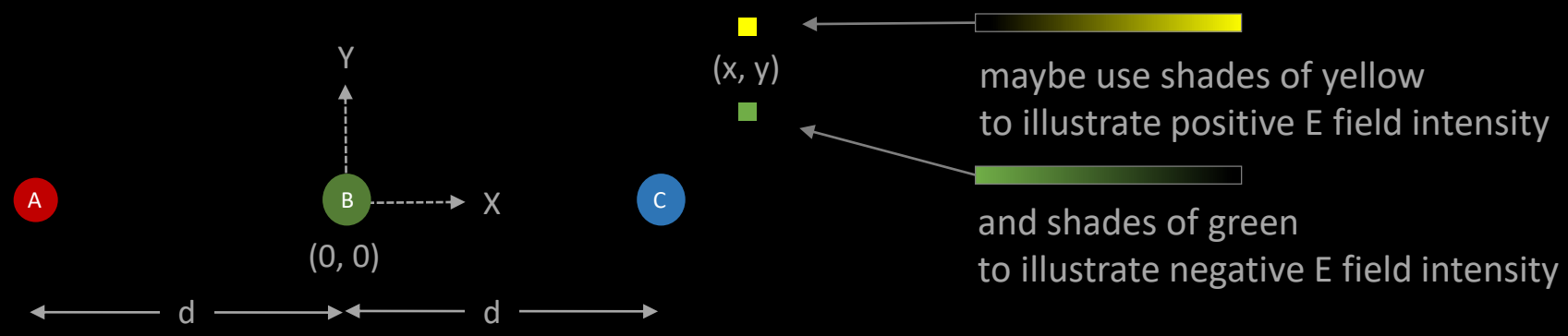
Animating 3Φ T-Line Electric Fields

For this exercise we would like to animate the magnitude of the E field = $|E|$



$$|E| = \sqrt{E_x^2 + E_y^2}$$

The above method would be a good start but it would not give an indication of the polarity or direction of the field. We want to illustrate positive field intensity with one color and negative field intensity with another color



Animating 3Φ T-Line Electric Fields

It would seem that we have all the information we need to determine the polarity, But …
the E field magnitude has no sign.
If there were only one conductor…
we could use the sign or direction of the current.
We need to:

1) find the contribution (with sign) from each phase
2) use superposition to add up the contributions
3) determine if the net contribution is positive or negative

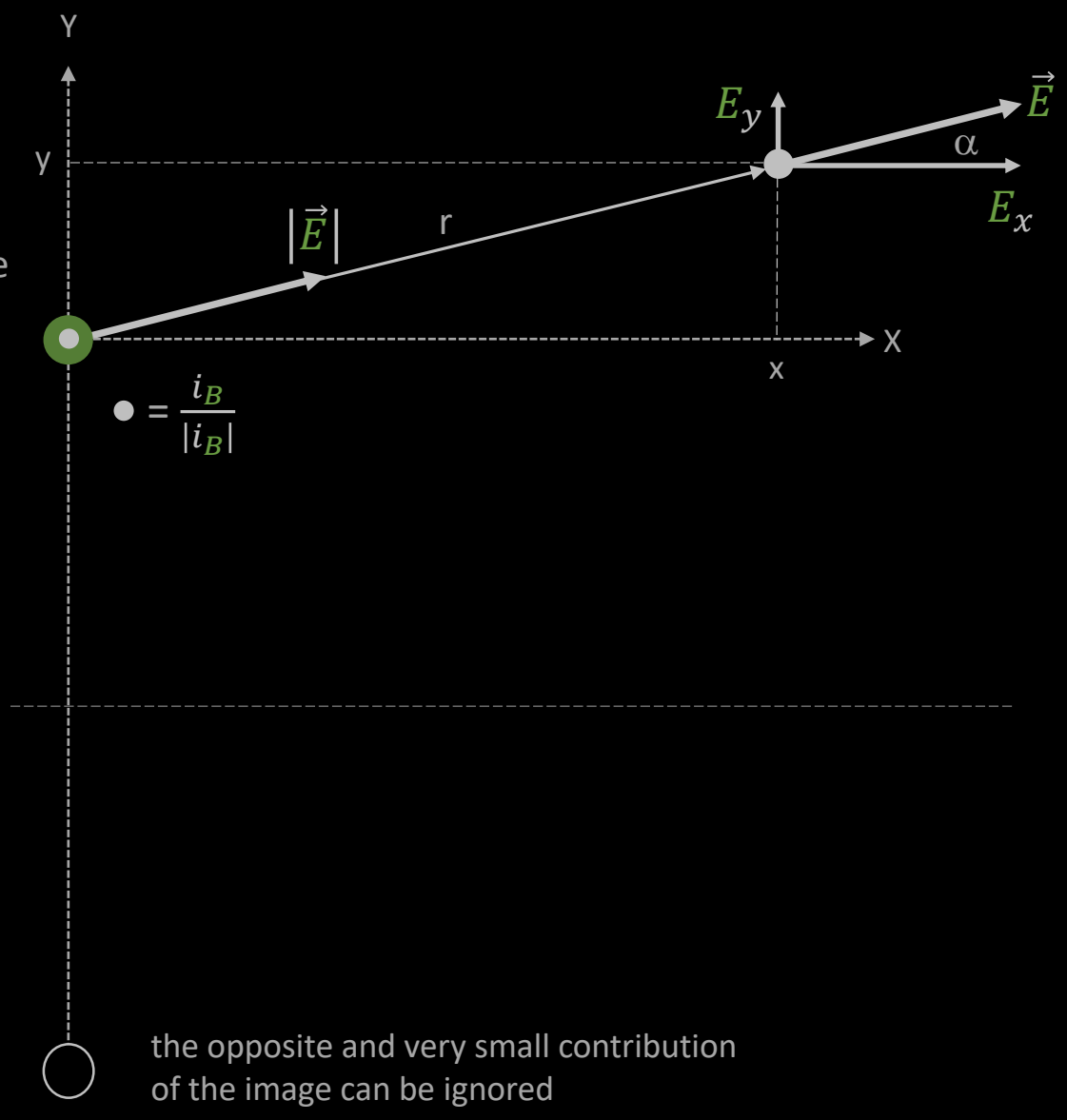
Returning to the previous derivation…
and using the center B phase conductor as and example:
We could use the product of the magnitude of E and ± 1 (depending on current direction) to determine the contribution of the E field to polarity or direction.
we can get ± 1 with $\frac{i_B}{|i_B|}$

$$let\ \delta_B = contribution\ of\ \vec{E}\ to\ polarity\ or\ direction$$

$$\therefore\ \delta_B = |\vec{E}|\frac{i_B}{|i_B|}$$

Since this calculation was for the center B phase…
modify the notation slightly:

$$\delta_B = |\vec{E}_B|\frac{i_B}{|i_B|}$$



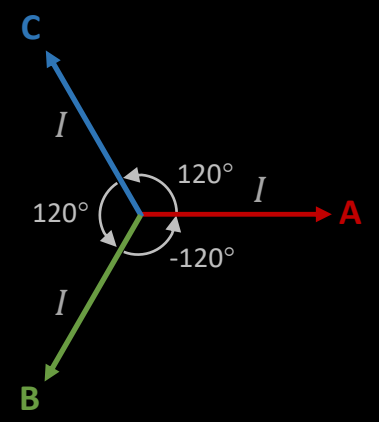
Animating 3Φ T-Line Electric Fields

continue with the sign or polarity of A and C phase

$$i_A = I\cos[\theta]$$
$$i_B = I\cos\left[\theta - \frac{2\pi}{3}\right]$$
$$i_C = I\cos\left[\theta + \frac{2\pi}{3}\right]$$
$$\theta = \omega t = 2\pi f t$$

$$\theta_A = \theta$$
$$\theta_B = \theta - \frac{2\pi}{3}$$
$$\theta_C = \theta + \frac{2\pi}{3}$$

$$i_A = I\cos\theta_A$$
$$i_B = I\cos\theta_B$$
$$i_C = I\cos\theta_C$$
$$\theta = \omega t$$



substituting ABC alternating phase currents…

$$\delta_A = |\vec{E}_A|\frac{i_A}{|i_A|} = |\vec{E}_A|\frac{I\cos\theta_A}{|I\cos\theta_A|} = |\vec{E}_A|\frac{\cos\theta_A}{|\cos\theta_A|}$$

$$\delta_B = |\vec{E}_B|\frac{i_B}{|i_B|} = |\vec{E}_B|\frac{I\cos\theta_B}{|I\cos\theta_B|} = |\vec{E}_B|\frac{\cos\theta_B}{|\cos\theta_B|}$$

$$\delta_C = |\vec{E}_C|\frac{i_C}{|i_C|} = |\vec{E}_C|\frac{I\cos\theta_C}{|I\cos\theta_C|} = |\vec{E}_C|\frac{\cos\theta_C}{|\cos\theta_C|}$$

$$\delta_A = |\vec{E}_A|\frac{\cos\theta_A}{|\cos\theta_A|} \qquad \delta_B = |\vec{E}_B|\frac{\cos\theta_B}{|\cos\theta_B|} \qquad \delta_C = |\vec{E}_C|\frac{\cos\theta_C}{|\cos\theta_C|}$$

Animating 3Φ T-Line Electric Fields

get the total contribution to the E field

$$\delta_A = |\vec{E}_A| \frac{\cos\theta_A}{|\cos\theta_A|} \qquad \delta_B = |\vec{E}_B| \frac{\cos\theta_B}{|\cos\theta_B|} \qquad \delta_C = |\vec{E}_C| \frac{\cos\theta_C}{|\cos\theta_C|}$$

total contribution to the resulting $\vec{\mathrm{E}}$ field $= \delta_A + \delta_B + \delta_C$

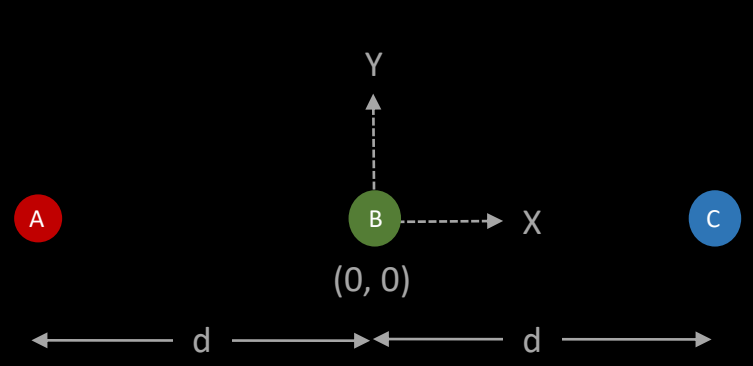
but we are only interested in the sign (± 1) of the total contribution

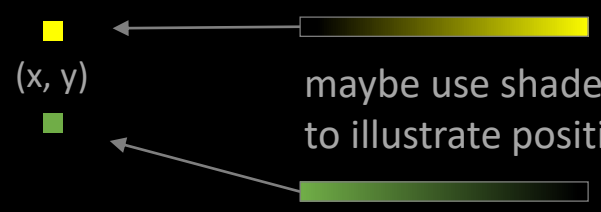
the sign (± 1) of the total contributionto the resulting $\vec{\mathrm{E}}$ field $= \dfrac{\delta_A + \delta_B + \delta_C}{|\delta_A + \delta_B + \delta_C|}$

now we can add the polarity or direction to the magnitude of the E field

$$|\vec{E}| = \sqrt{E_x^2 + E_y^2} \qquad \vec{E}_{polarity} = \frac{\delta_A + \delta_B + \delta_C}{|\delta_A + \delta_B + \delta_C|}$$

we can now plot $E(x, y, d, h, \theta) = \dfrac{\delta_A + \delta_B + \delta_C}{|\delta_A + \delta_B + \delta_C|} \sqrt{E_x^2 + E_y^2}$





maybe use shades of yellow
to illustrate positive E field intensity

and shades of green
to illustrate negative E field intensity

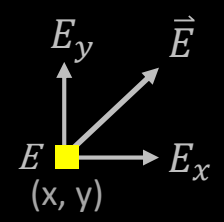
$$E = \frac{\delta_A + \delta_B + \delta_C}{|\delta_A + \delta_B + \delta_C|} \sqrt{E_x^2 + E_y^2}$$

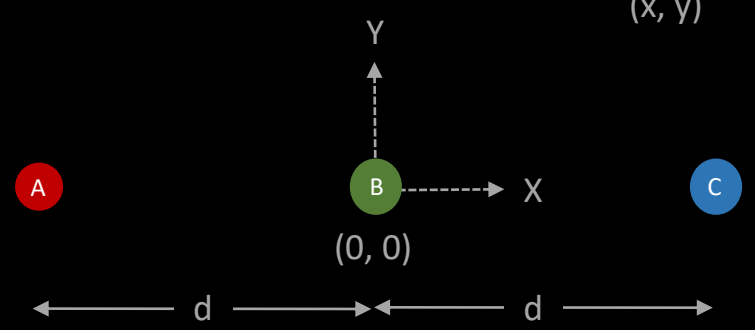
Summary So Far

$$E_x = \underbrace{60I}_{\text{drop and normalize}}\left[\underbrace{\frac{[x+d]\cos\theta_A}{[x+d]^2+y^2}}_{E_{Ax}} + \underbrace{\frac{x\cos\theta_B}{x^2+y^2}}_{E_{Bx}} + \underbrace{\frac{[x-d]\cos\theta_C}{[x-d]^2+y^2}}_{E_{Cx}} - \underbrace{\frac{[x+d]\cos\theta_A}{[x+d]^2+[y+2h]^2}}_{E'_{Ax}} - \underbrace{\frac{x\cos\theta_B}{x^2+[y+2h]^2}}_{E'_{Bx}} - \underbrace{\frac{[x-d]\cos\theta_C}{[x-d]^2+[y+2h]^2}}_{E'_{Cx}}\right]$$

$$E_y = 60I\left[\underbrace{\frac{y\cos\theta_A}{[x+d]^2+y^2}}_{E_{Ay}} + \underbrace{\frac{y\cos\theta_B}{x^2+y^2}}_{E_{By}} + \underbrace{\frac{y\cos\theta_C}{[x-d]^2+y^2}}_{E_{Cy}} - \underbrace{\frac{[y+2h]\cos\theta_A}{[x+d]^2+[y+2h]^2}}_{E'_{Ay}} - \underbrace{\frac{[y+2h]\cos\theta_B}{x^2+[y+2h]^2}}_{E'_{By}} - \underbrace{\frac{[y+2h]\cos\theta_C}{[x-d]^2+[y+2h]^2}}_{E'_{Cy}}\right]$$

$$\delta_A = |\vec{E}_A|\frac{\cos\theta_A}{|\cos\theta_A|} \qquad \delta_B = |\vec{E}_B|\frac{\cos\theta_B}{|\cos\theta_B|} \qquad \delta_C = |\vec{E}_C|\frac{\cos\theta_C}{|\cos\theta_C|}$$





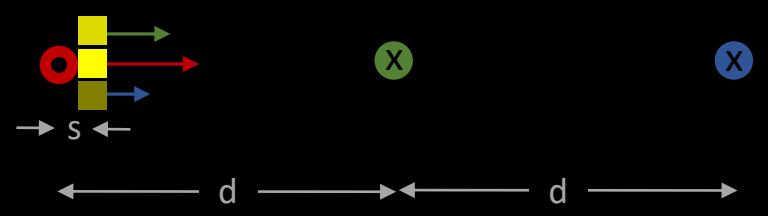
$$\boxed{E = \frac{\delta_A + \delta_B + \delta_C}{|\delta_A + \delta_B + \delta_C|}\frac{\sqrt{E_x^2 + E_y^2}}{E_{Base}}}$$

now lets find the “Base” to normalize on

Animating 3Φ T-Line Electric Fields

find the maximum E field for normalizing

consider A phase:
assume theta = 0° (max A phase current)
x = -d at the center of the A phase conductor
take a very small step in the x direction (y=0)
(on the order of conductor radius, only inches!)
call this very small step = s
the x coordinate of interest is x = -d + s



$$E_x = \frac{[x+d]\cos\theta_A}{[x+d]^2+y^2} + \frac{x\cos\theta_B}{x^2+y^2} + \frac{[x-d]\cos\theta_C}{[x-d]^2+y^2} - \underbrace{\frac{[x+d]\cos\theta_A}{[x+d]^2+[y+2h]^2} - \frac{x\cos\theta_B}{x^2+[y+2h]^2} - \frac{[x-d]\cos\theta_C}{[x-d]^2+[y+2h]^2}}_{\text{ignore contribution from image conductors}}$$

$$E_x = \frac{[-d+s+d]}{[-d+s+d]^2} + \frac{-0.5[-d+s]}{[-d+s]^2} + \frac{-0.5[-d+s-d]}{[-d+s-d]^2}$$

$$E_x = \frac{s}{s^2} + \frac{0.5[d-s]}{[d-s]^2} + \frac{0.5[2d-s]}{[2d-s]^2}$$

$$E_x = \frac{1}{s} + \frac{1}{2[d-s]} + \frac{1}{2[2d-s]}$$

$$E_y = \frac{y\cos\theta_A}{[x+d]^2+y^2} + \frac{y\cos\theta_B}{x^2+y^2} + \frac{y\cos\theta_C}{[x-d]^2+y^2} - \underbrace{\frac{[y+2h]\cos\theta_A}{[x+d]^2+[y+2h]^2} - \frac{[y+2h]\cos\theta_B}{x^2+[y+2h]^2} - \frac{[y+2h]\cos\theta_C}{[x-d]^2+[y+2h]^2}}_{\text{ignore contribution from image conductors}}$$

$$E_y = \frac{0}{[s]^2} + \frac{0}{[s-d]^2} + \frac{0}{[2d-s]^2}$$

$$E_y = 0.0$$

$$E_x^2 = \left[\frac{1}{s} + \frac{1}{2[d-s]} + \frac{1}{2[2d-s]}\right]^2$$

$$E_y^2 = 0.0$$

$$|E|_{max} = \sqrt{E_x^2 + E_y^2} = \frac{1}{s} + \frac{1}{2[d-s]} + \frac{1}{2[2d-s]}$$

"Base" electric field for normalizing → $\boxed{E_{Base} = |E|_{max} = \frac{1}{s} + \frac{1}{2[d-s]} + \frac{1}{2[2d-s]}}$

pseudo code for animating T-Line Electric Fields

```
d = 20.0                                          # define conductor spacing
h = 60.0                                          # define height above ground of lowest phase
Ebase = f(d,s)                                    # calculate the max field (for normalizing)

for angle in range(0,361)                         # loop current angles (phase A is reference)
    for x in range(-60,60,0.2)                    # loop x coordinates from -3*d to 3*d in steps of d/100
        for y in range(-60,60,0.2)                # loop y coordinates from -3*d to 3*d in steps of d/100
            angle_a = angle                       # get phase A angle (phase A is reference)
            angle_b = angle_a-120                 # get phase B angle
            angle_c = angle_a+120                 # get phase C angle
            Eax = f(x,y,d,h,angle_a)              # calculate A phase field in x direction
            Ebx = f(x,y,d,h,angle_b)              # calculate B phase field in x direction
            Ecx = f(x,y,d,h,angle_c)              # calculate C phase field in x direction
            Eay = f(x,y,d,h,angle)                # calculate A phase field in y direction
            Eby = f(x,y,d,h,angle_b)              # calculate B phase field in y direction
            Ecy = f(x,y,d,h,angle_c)              # calculate C phase field in y direction
            |Ea| = pow(Eax^2+Eay^2,0.5)           # calculate magnitude A phase field
            |Eb| = pow(Ebx^2+Eby^2,0.5)           # calculate magnitude B phase field
            |Ec| = pow(Ecx^2+Ecy^2,0.5)           # calculate magnitude C phase field
            da = |Ea|*cos(angle_a)/abs(cos(angle_a))  # calculate A phase contribution
            db = |Eb|*cos(angle_b)/abs(cos(angle_b))  # calculate B phase contribution
            dc = |Ec|*cos(angle_c)/abs(cos(angle_c))  # calculate C phase contribution
            polarity = (da+db+dc)/abs(da+db+dc)   # get the sign of the magnetic field
            Ex = Eax+Ebx+Ecx                      # get net field in x direction
            Ey = Eay+Eby+Ecy                      # get net field in y direction
            |B| = pow(Ex^2+Ey^2,0.5)              # get magnitude of net field
            B = polarity*|E|/Ebase                # report normalized field magnitude, with sign

            # this nested loop will give you the field at one (x,y) coordinate at one current angle
            # we recommend looking into matplotlib and seaborn for generating xy grid and using heatmaps
```

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Questions or Comments …

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