Test case: spring equinox $\theta_{E0} = 0$

$\phi_{LL} = \frac{\pi}{2}$

$\theta_{LL} = \pi$

P: $A_1^{es} = \cancel{r_{E0}(\sin\phi_E(0) - 0 - 0) = 0}$

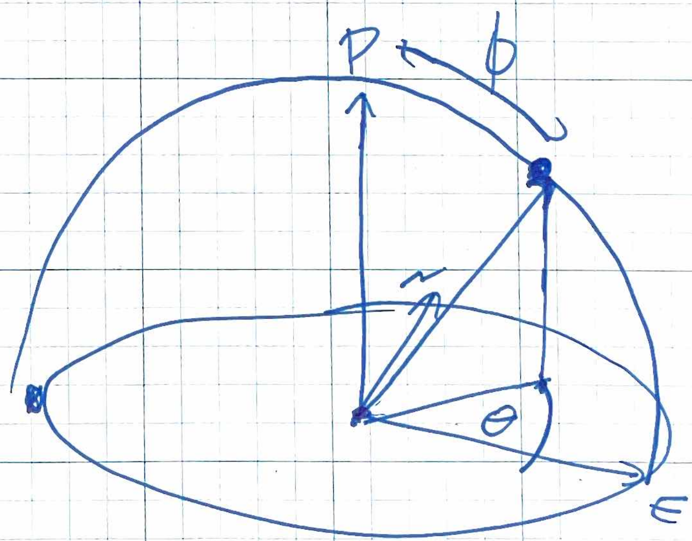
$A_1^{es} = r_{E0}(0 - 0 - (1)(-1)(1)) - r_E = r_{E0} - r_E$

$A_2^{es} = r_{E0}(0 + 0 + 0) = 0 \Rightarrow (r_{E0} - r_E,\ 0,\ 0)$

$A_3^{es} = r_{E0}(0 - 0) = 0$

$$\phi = \cos^{-1}\left(\frac{r_{E0} - r_E}{r_{E0} - r_E}\right) = 0$$

$$\theta = \tan^{-1}\left(\frac{0}{0}\right) \rightarrow \text{undefined.}$$



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$r = 0 \rightarrow 1$

$\theta = 0$

$\phi = \frac{\pi}{2}$

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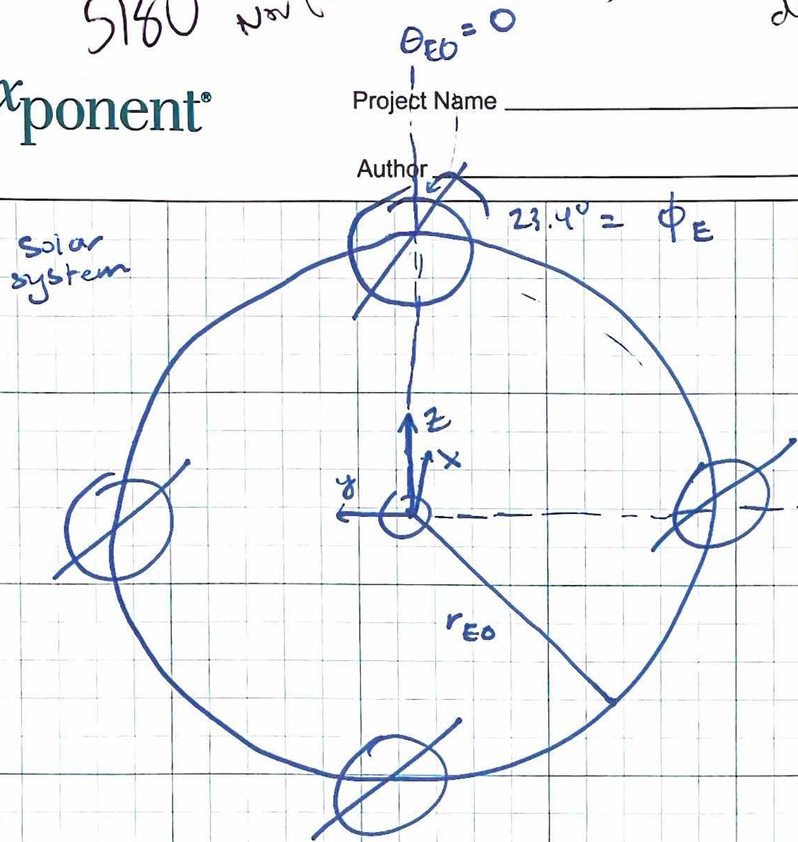
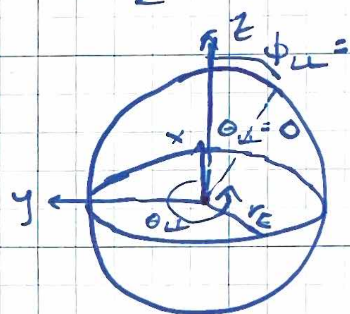


$$\theta_{LL} = \frac{2\pi}{360} L_o + \frac{2\pi}{t_{day}} t + \pi$$

$$\phi_{LL} = \frac{\pi}{2} - \frac{2\pi}{360} LA$$

$$\theta_{EO} = \frac{2\pi}{t_{year}} t$$



$A_{S \to EC}$: $A_x = r_{EO} \cos\theta_{EO}$ $A_y = r_{EO} \sin\theta_{EO}$ $A_z = 0$

Transform to earth coordinates: Basis of earth vectors: $(1, 0, 0)$ $(0, -\sin\phi_E, \cos\phi_E)$ $(0, \cos\phi_E, \sin\phi_E)$ $\sin\phi =$

$A^e_{S \to EC}$ = $A^e_x = r_{EO} \cos\theta_{EO}$ $A^e_y = r_{EO} \sin\theta_{EO} \cos\phi_E$ $A^e_z = -r_{EO} \sin\theta_{EO} \sin\phi_E$

Add vector from EC → ES to $A^e_{S \to EC}$ and invert

$$A^e_{EC \to ES} = (r_E \cos\theta_{LL} \sin\phi_{LL},\ r_E \sin\theta_{LL} \sin\phi_{LL},\ r_E \cos\phi_{LL})$$

$$A^e_{ES \to S} = (-(r_{EO} \cos\theta_{EO} + r_E \cos\theta_{LL} \sin\phi_{LL}),\ -(r_{EO} \sin\theta_{EO} \cos\phi_E + r_E \sin\theta_{LL} \sin\phi_{LL}),\ (r_{EO} \sin\theta_{EO} \sin\phi_E - r_E \cos\phi_{LL}))$$

Transform to ES coordinates

ES basis vectors: $P: (\cos\theta_{LL} \sin\phi_{LL},\ \sin\theta_{LL} \sin\phi_{LL},\ \cos\phi_{LL})$

$N: (-\cos(\theta_{LL}) \cos\phi_{LL},\ -\sin\theta_{LL} \cos\phi_{LL},\ \sin\phi_{LL})$

$E: (-\sin\theta_{LL},\ \cos\theta_{LL},\ 0)$

Perp: $A^{es}_1 = r_{EO}(\sin\phi_E \sin\theta_{EO} \cos\phi_{LL} - \cos\phi_E \sin\theta_{EO} \sin\theta_{LL} \sin\phi_{LL} - \cos\theta_{EO} \cos\theta_{LL} \sin\phi_{LL}) - r_E$

North: $A^{es}_2 = r_{EO}(\sin\phi_E \sin\theta_{EO} \sin\phi_{LL} + \cos\phi_E \sin\theta_{EO} \sin\theta_{LL} \cos\phi_{LL} + \cos\theta_{EO} \cos\theta_{LL} \cos\phi_{LL})$

East: $A^{es}_3 = r_{EO}(\cos\theta_{EO} \sin\theta_{LL} - \cos\phi_E \sin\theta_{EO} \cos\theta_{LL})$

$$\theta = \tan^{-1}\left(\frac{A^{es}_2}{A^{es}_3}\right) \qquad \phi = \cos^{-1}\left(\frac{A^{es}_1}{r}\right)$$

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$$A_1^{cs} = -(r_{EO}\cos\theta_{EO} + r_E\cos\theta_{LL}\sin\phi_{LL})(\cos\theta_{LL}\sin\phi_{LL}) +$$
$$-(r_{EO}\sin\theta_{EO}\cos\phi_E + r_E\sin\theta_{LL}\sin\phi_{LL})(\sin\theta_{LL}\sin\phi_{LL}) +$$
$$+(r_{EO}\sin\theta_{EO}\sin\phi_E - r_E\cos\phi_{LL})(\cos\phi_{LL})$$

$$= r_{EO}(-\cos\theta_{EO}\cos\theta_{LL}\sin\phi_{LL} - \cos\phi_E\sin\theta_{EO}\sin\theta_{LL}\sin\phi_{LL} + \sin\phi_E\sin\theta_{EO}\cos\phi_{LL})$$
$$+ r_E(-\cos^2\theta_{LL}\sin^2\phi_{LL} - \sin^2\theta_{LL}\sin^2\phi_{LL} - \cos^2\phi_{LL})$$

$$= \boxed{r_{EO}(\sin\phi_E\sin\theta_{EO}\cos\phi_{LL} - \cos\phi_E\sin\theta_{EO}\sin\theta_{LL}\sin\phi_{LL} - \cos\theta_{EO}\cos\theta_{LL}\sin\phi_{LL}) - r_E}$$

$$A_2^{cs} = -(r_{EO}\cos\theta_{EO} + r_E\cos\theta_{LL}\sin\phi_{LL})(-\cos\theta_{LL}\cos\phi_{LL}) +$$
$$-(r_{EO}\sin\theta_{EO}\cos\phi_E + r_E\sin\theta_{LL}\sin\phi_{LL})(-\sin\theta_{LL}\cos\phi_{LL}) +$$
$$(r_{EO}\sin\theta_{EO}\sin\phi_E - r_E\cos\phi_{LL})(\sin\phi_{LL})$$

$$= \boxed{r_{EO}(\cos\theta_{EO}\cos\theta_{LL}\cos\phi_{LL} + \cos\phi_E\sin\theta_{EO}\sin\theta_{LL}\cos\phi_{LL} + \sin\phi_E\sin\theta_{EO}\sin\phi_{LL})}$$
$$+ r_E\underbrace{\cancel{(\cos^2\theta_{LL}\sin\phi_{LL}\cos\phi_{LL} + \sin^2\theta_{LL}\sin\phi_{LL}\cos\phi_{LL} - \sin\phi_{LL}\cos\phi_{LL})}}_{0}$$

$$A_3^{cs} = -(r_{EO}\cos\theta_{EO} + r_E\cos\theta_{LL}\sin\phi_{LL})(-\sin\theta_{LL}) +$$
$$-(r_{EO}\sin\theta_{EO}\cos\phi_E + r_E\sin\theta_{LL}\sin\phi_{LL})(\cos\theta_{LL}) +$$
$$(r_{EO}\sin\theta_{EO}\sin\phi_E - r_E\cos\phi_{LL})(0)$$

$$= \boxed{r_{EO}(\cos\theta_{EO}\sin\theta_{LL} - \cos\phi_E\sin\theta_{EO}\cos\theta_{LL}) + 0}$$
$$r_E\underbrace{\cancel{(\sin\theta_{LL}\cos\theta_{LL}\sin\phi_{LL} - \sin\theta_{LL}\cos\theta_{LL}\sin\phi_{LL})}}_{0}$$