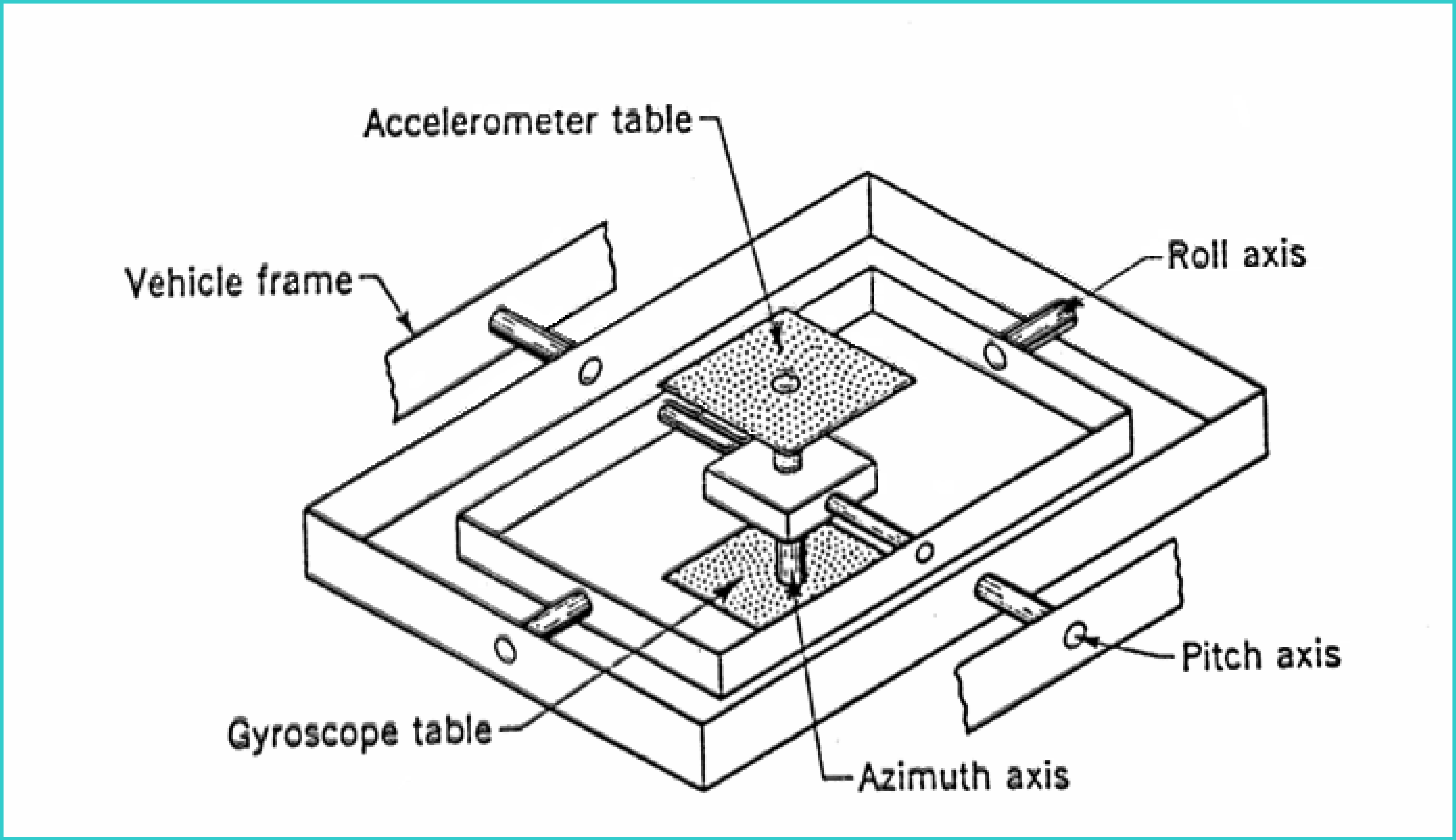
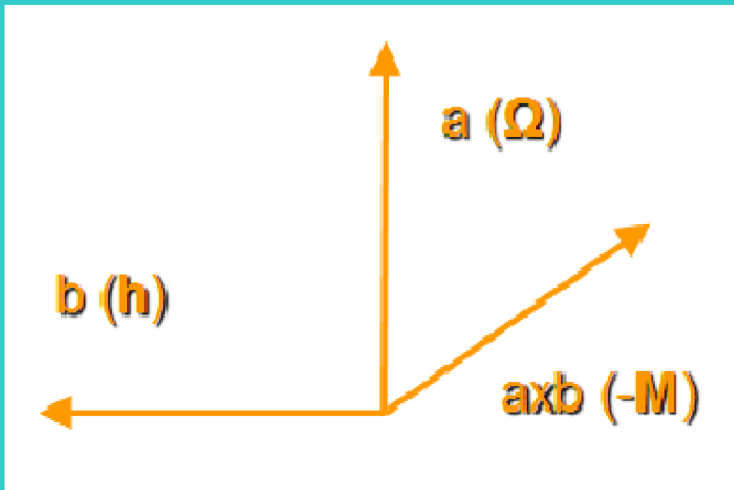
Piattaforma inerziale girostabilizzata

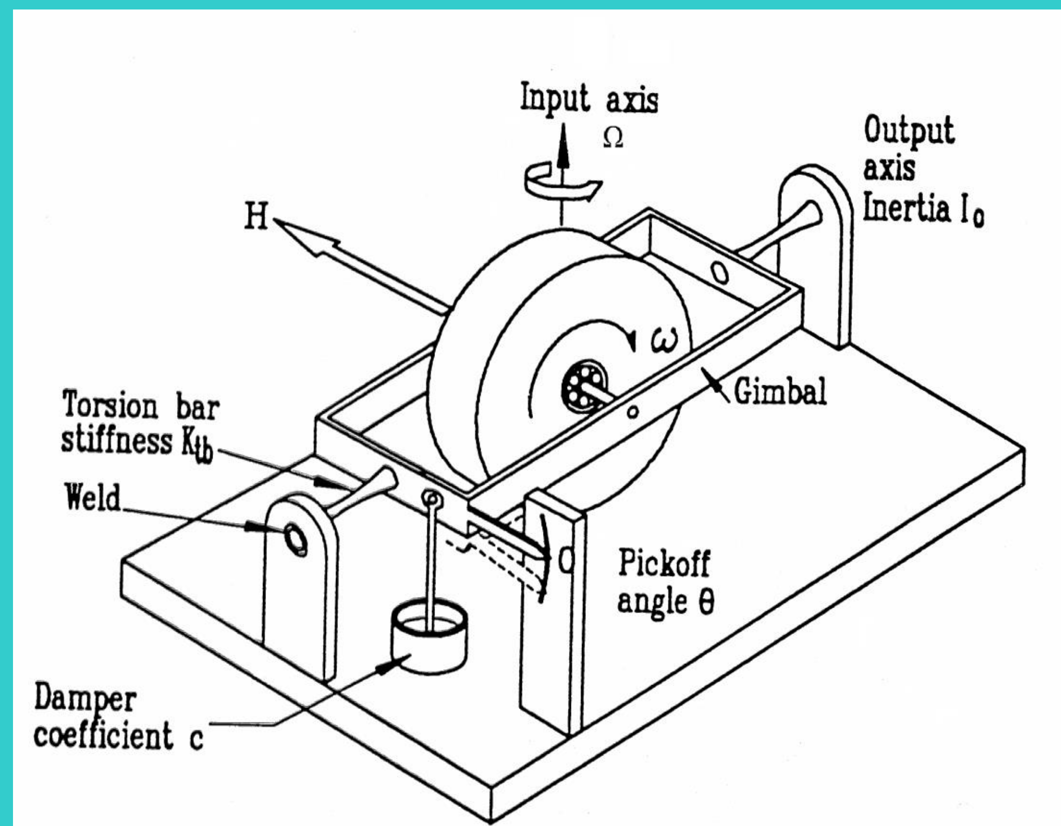


Rate gyro



$$\bar{\mathbf{M}} = -\left(\bar{\Omega} \times \bar{\mathbf{h}}\right) \quad \text{dove} \quad \bar{\mathbf{h}} = \mathbf{J}\bar{\omega}_{\mathbf{SPIN}}$$

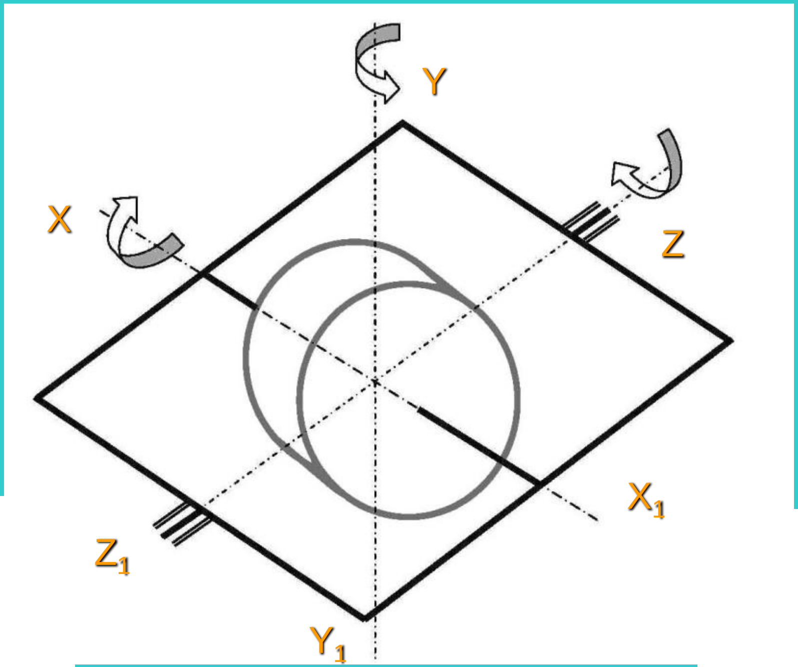
$$\bar{\mathbf{M}} = -\left(\bar{\Omega} \times \mathbf{J}\bar{\omega}_{\mathbf{SPIN}}\right)$$



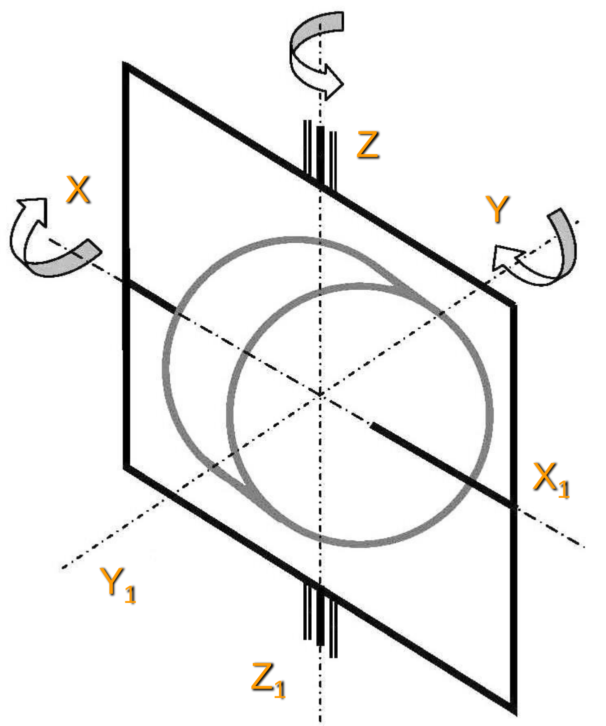
X-X_1 spin axis
Y-Y_1 input axis
Z-Z_1 output axis

North

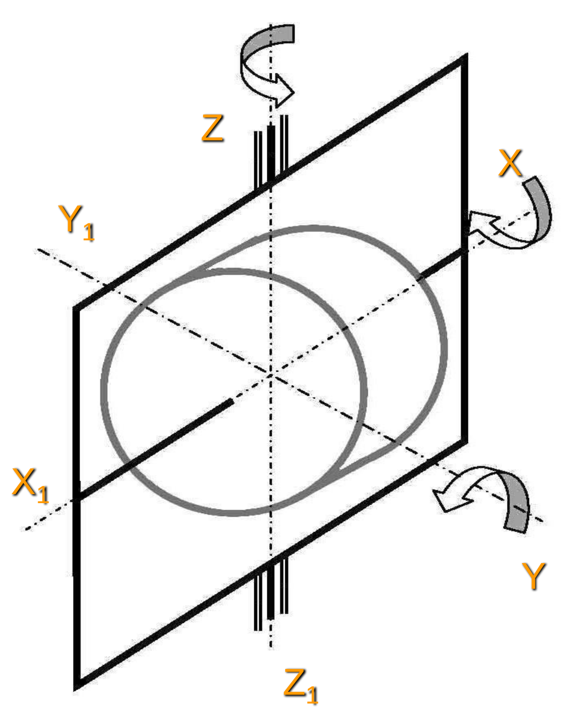
FWD



Z (Azimuth) Gyro

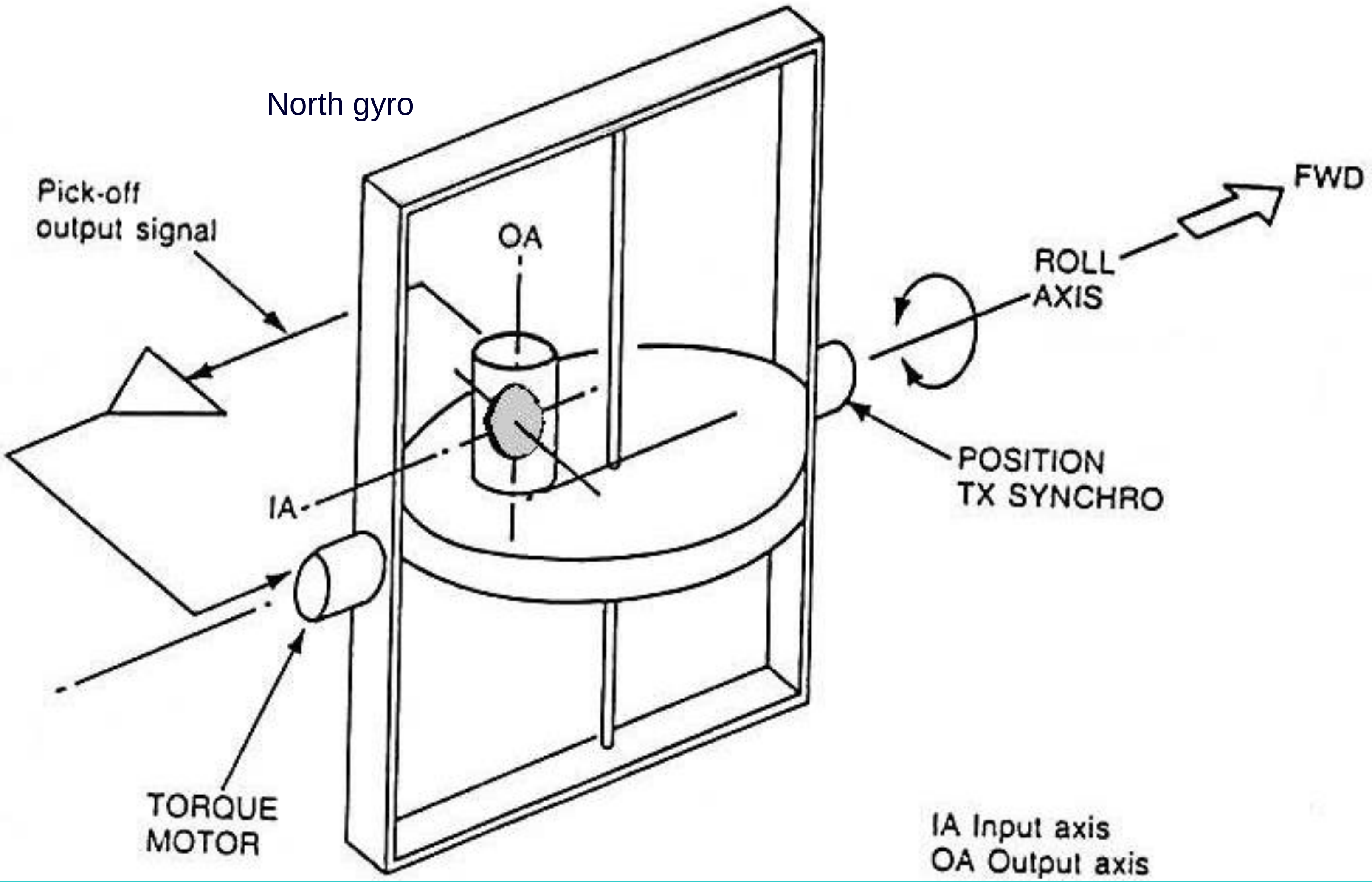


Y (North) gyro

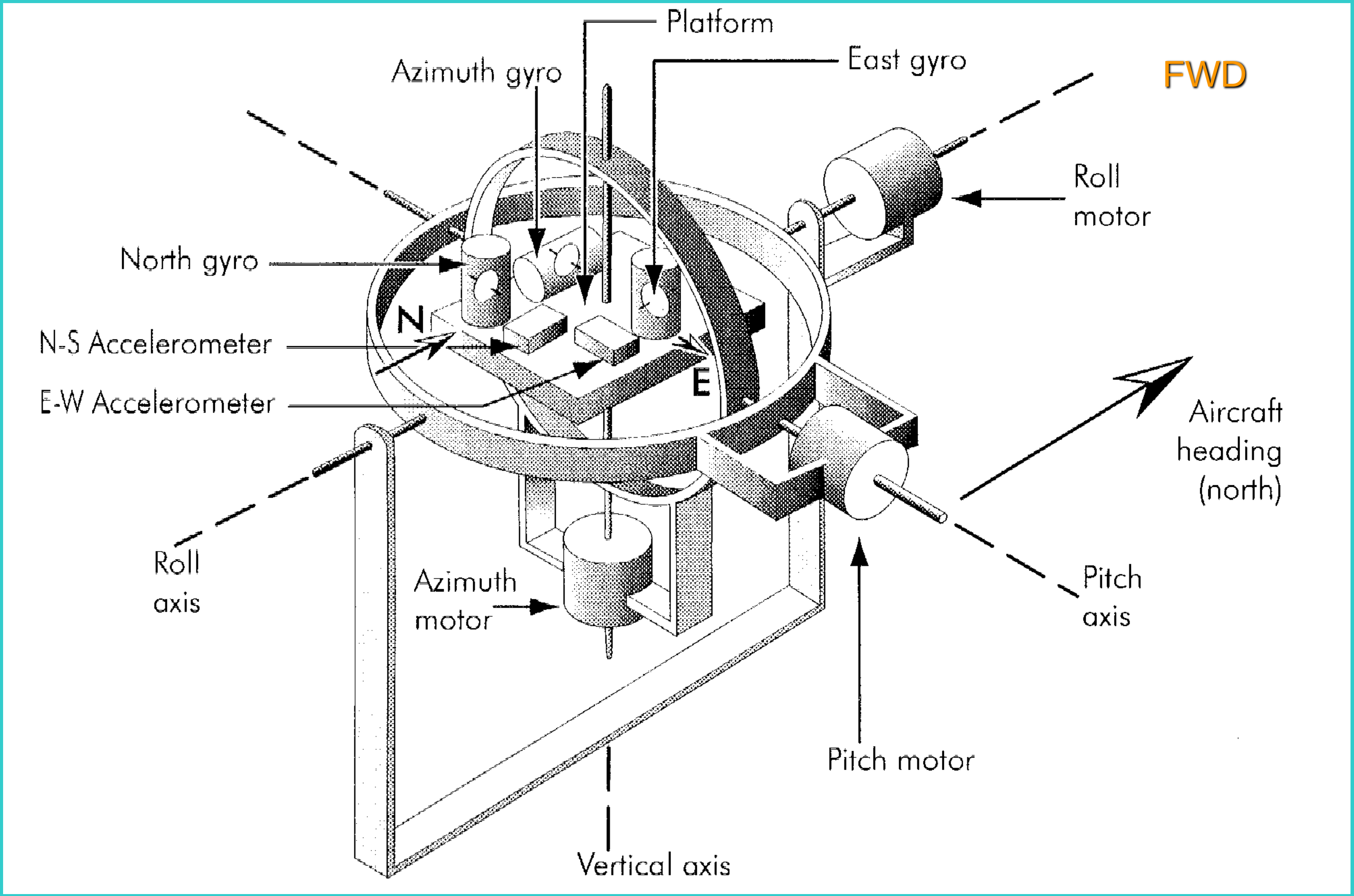


X (East) gyro

North gyro



Pick-off
output signal
OA
FWD
ROLL
AXIS
POSITION
TX SYNCHRO
IA
TORQUE
MOTOR
IA Input axis
OA Output axis


Platform
Azimuth gyro
East gyro
FWD
Roll
motor
North gyro
N
N-S Accelerometer
E-W Accelerometer
E
Aircraft
heading
(north)
Roll
axis
Azimuth
motor
Pitch
axis
Pitch motor
Vertical axis

Stabilization servo loop

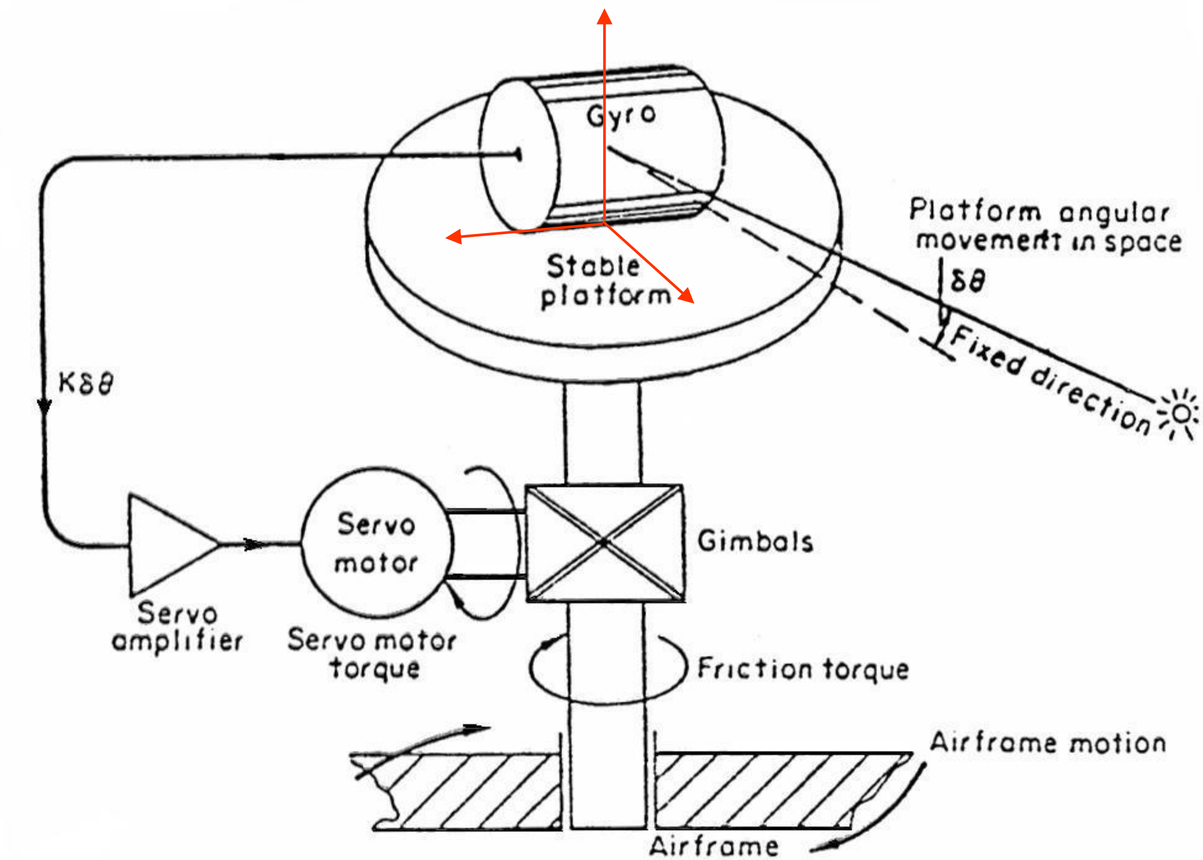
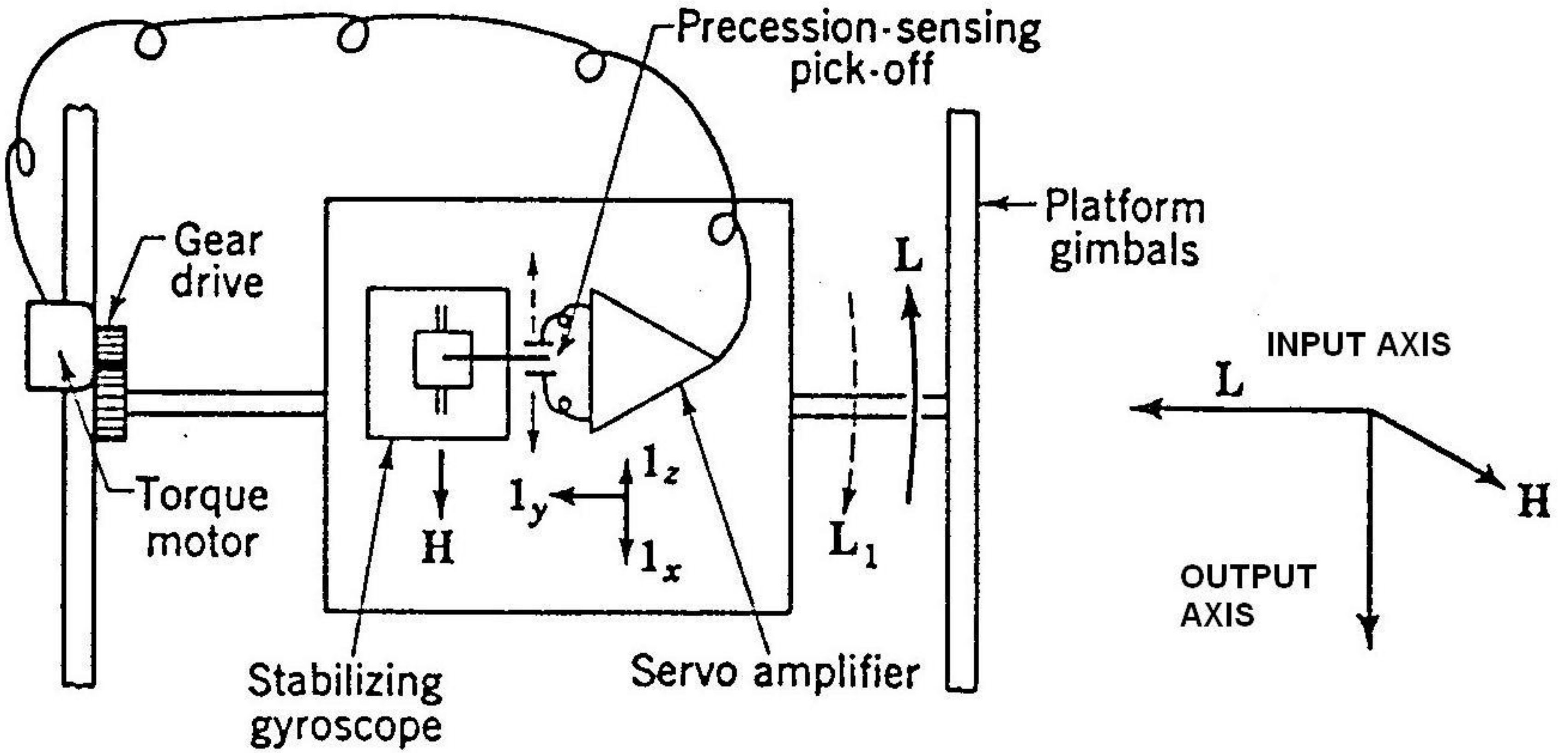
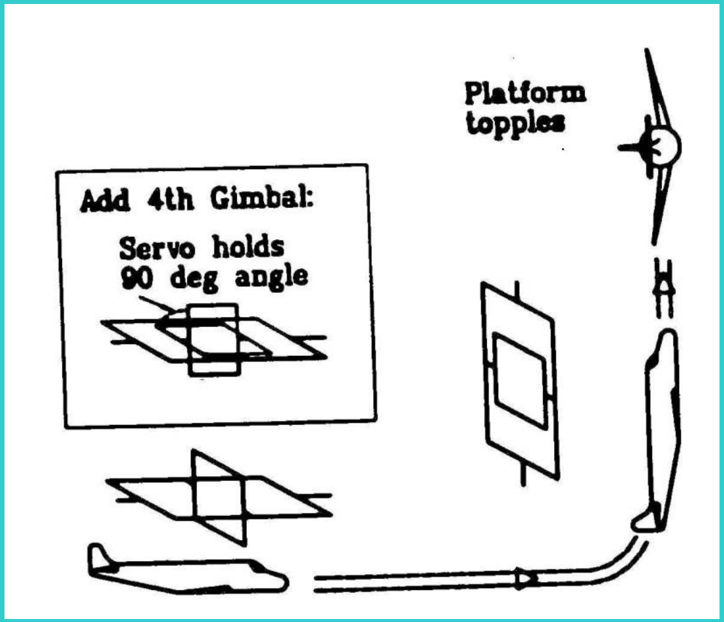


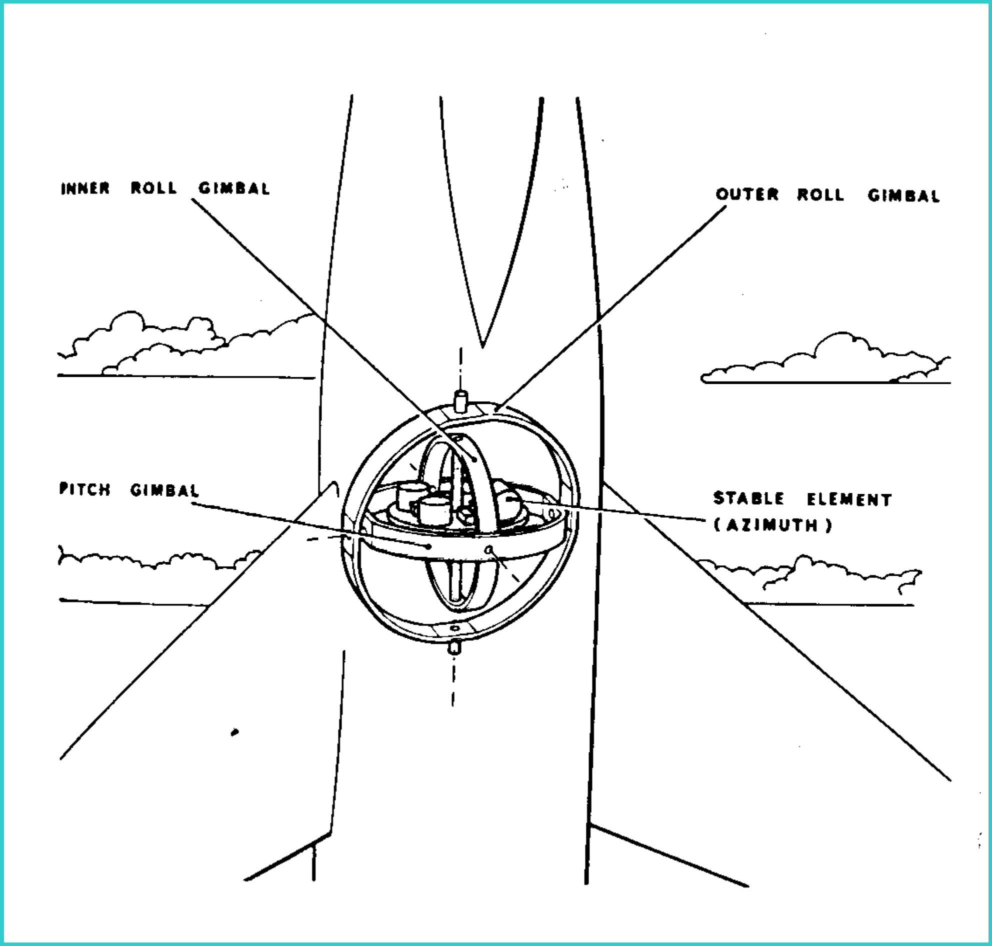
Fig. 8.4. Single axis space stabilization servo loop

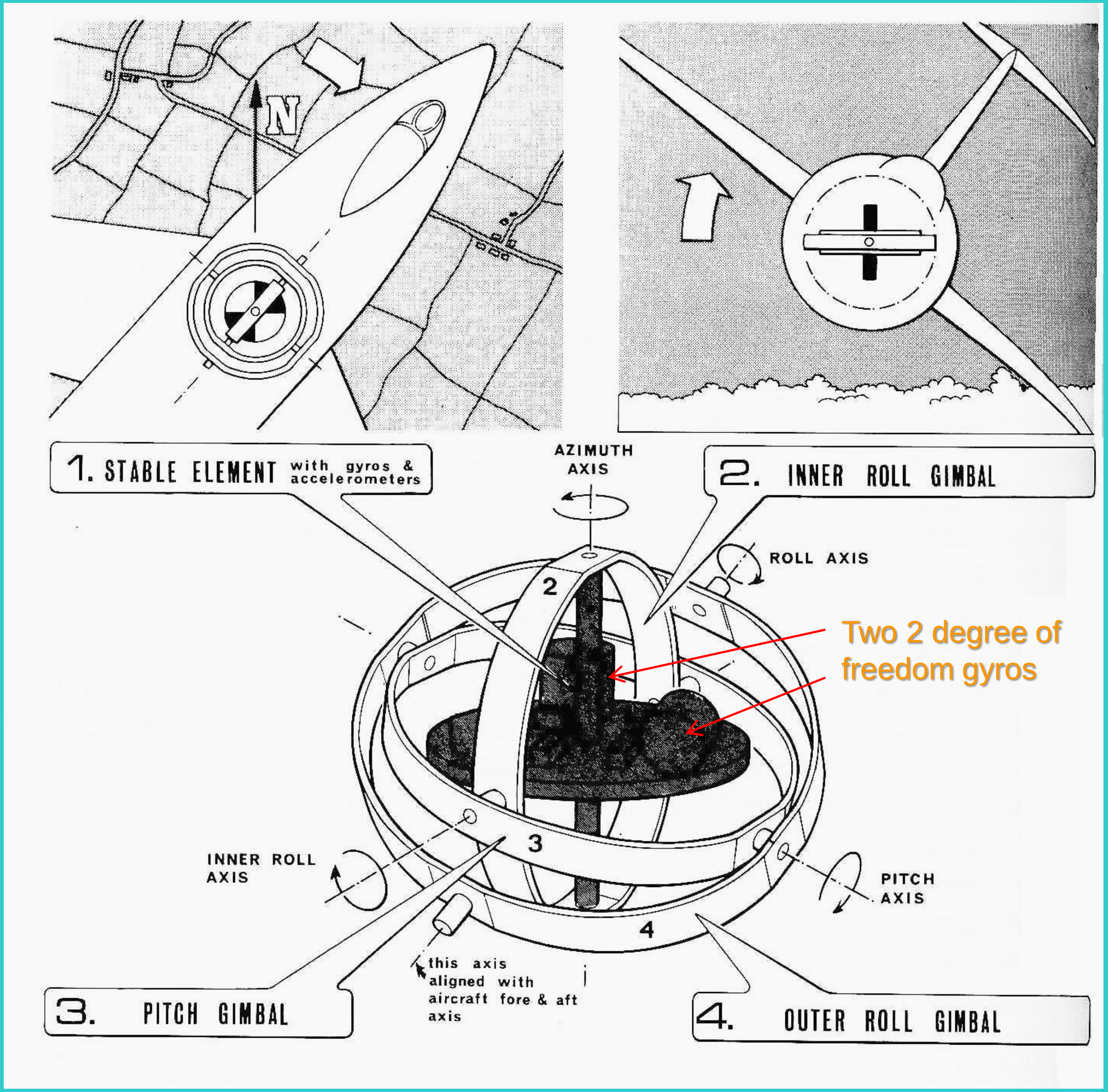
Airframe movement causes gimbal friction torque to try to drag platform to follow airframe motion, although opposed by platform inertia The gyro senses platform displacement $\delta\theta$ from fixed direction in space and via servo amplifier causes servo motor to exert a torque to oppose friction torque and restore $\delta\theta$ to near zero (servo gain is very high).


Precession-sensing pick-off
Gear drive
Platform gimbals
L
INPUT AXIS
L
Torque motor
H
1_y
1_z
1_x
L_1
H
OUTPUT AXIS
Stabilizing gyroscope
Servo amplifier

Gimbal lock

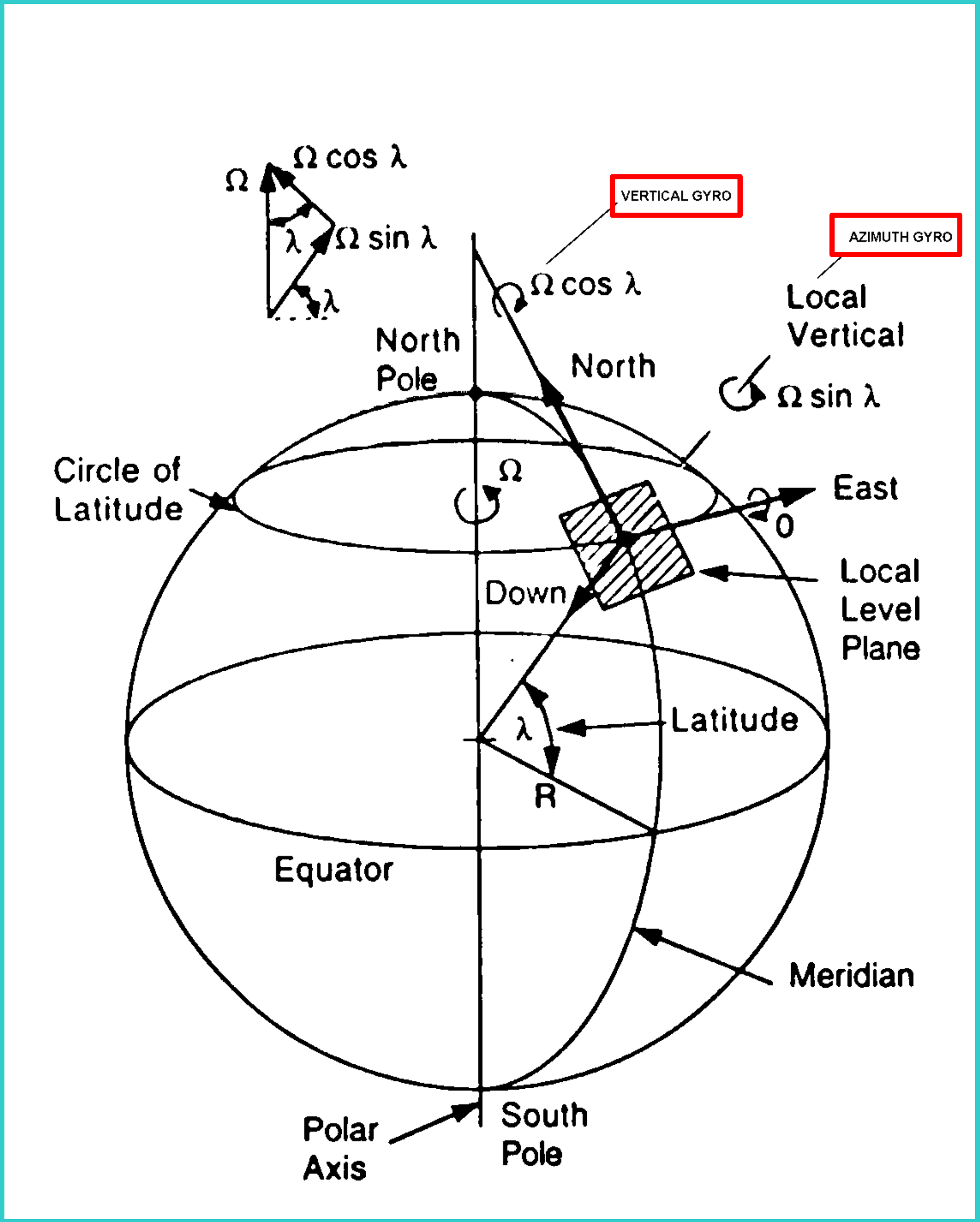

Platform
topples
Add 4th Gimbal:
Servo holds
90 deg angle


INNER ROLL GIMBAL
OUTER ROLL GIMBAL
PITCH GIMBAL
STABLE ELEMENT
(AZIMUTH)


N
1. STABLE ELEMENT with gyros & accelerometers
AZIMUTH AXIS
2. INNER ROLL GIMBAL
ROLL AXIS
Two 2 degree of freedom gyros
2
3
4
INNER ROLL AXIS
PITCH AXIS
this axis aligned with aircraft fore & aft axis
3. PITCH GIMBAL
4. OUTER ROLL GIMBAL

Influenza della velocità di rotazione della terra

X e Y gyro sono anche detti vertical gyro in quanto deputati a mantenere l’orizzontalità della piattaforma



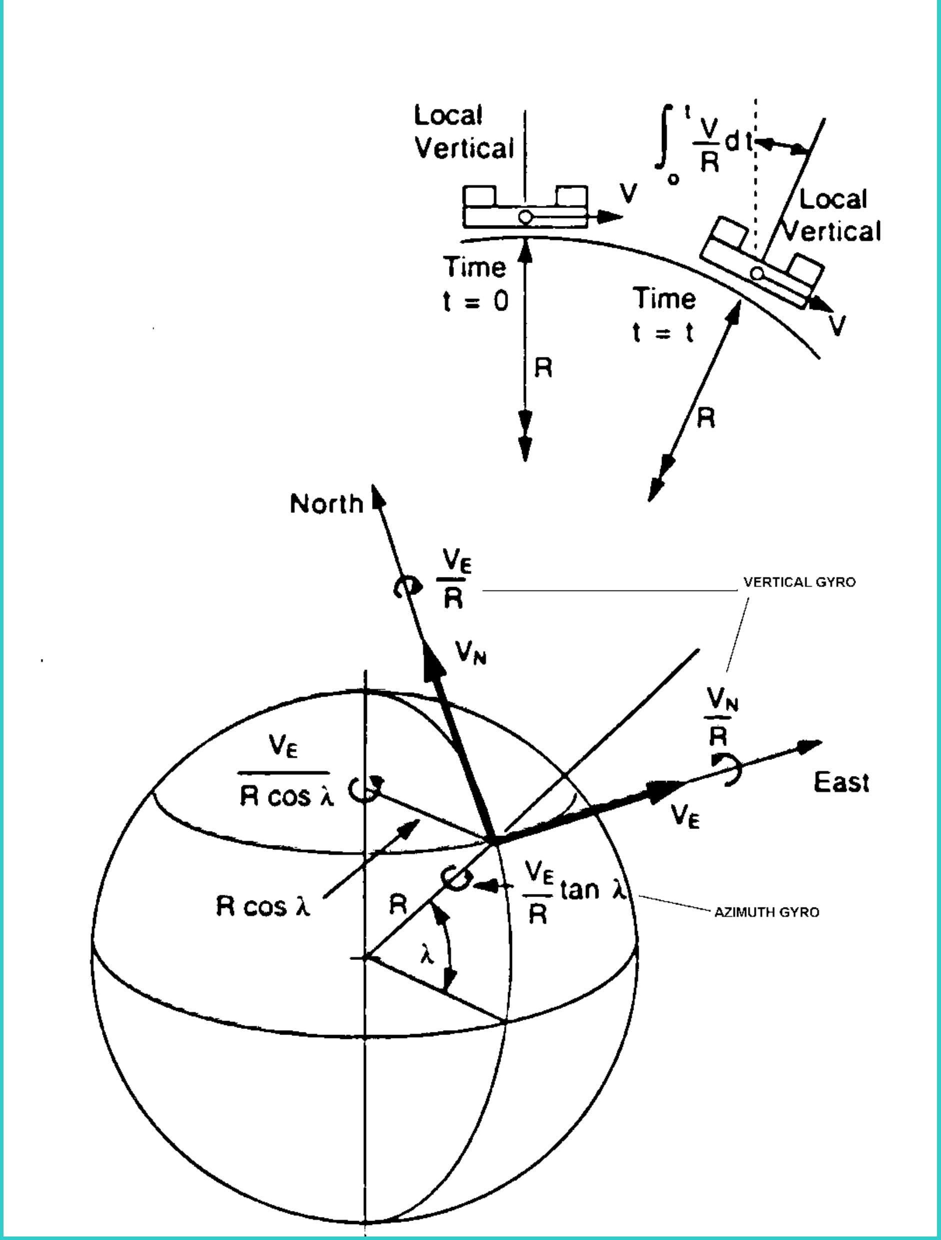
Influenza del moto sulla terra

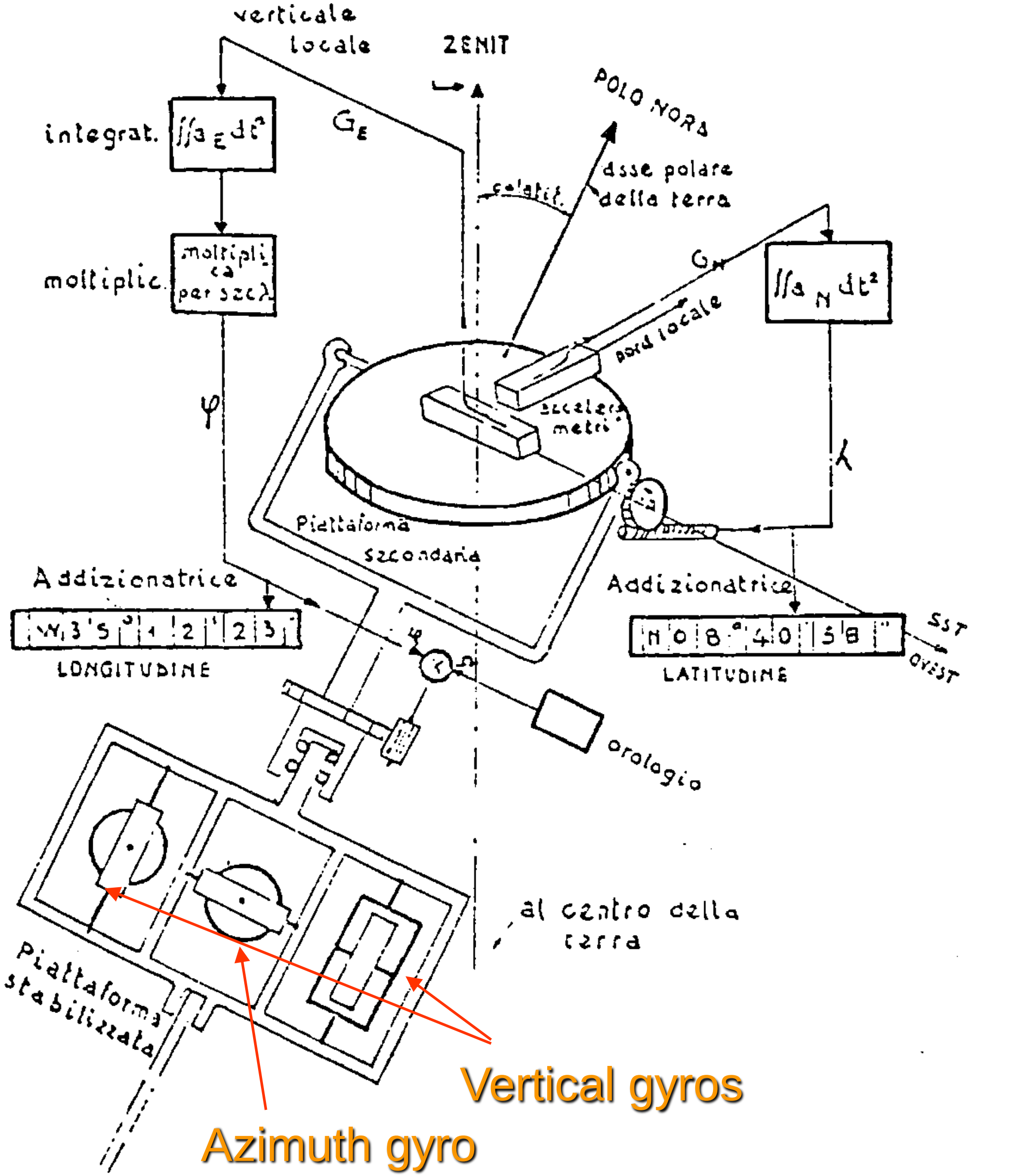
AZIMUTH GYRO

$$\frac{V_E}{R\cos\lambda}\,\mathbf{sen}\lambda = \frac{V_E}{R}\,\mathbf{tan}\,\lambda$$

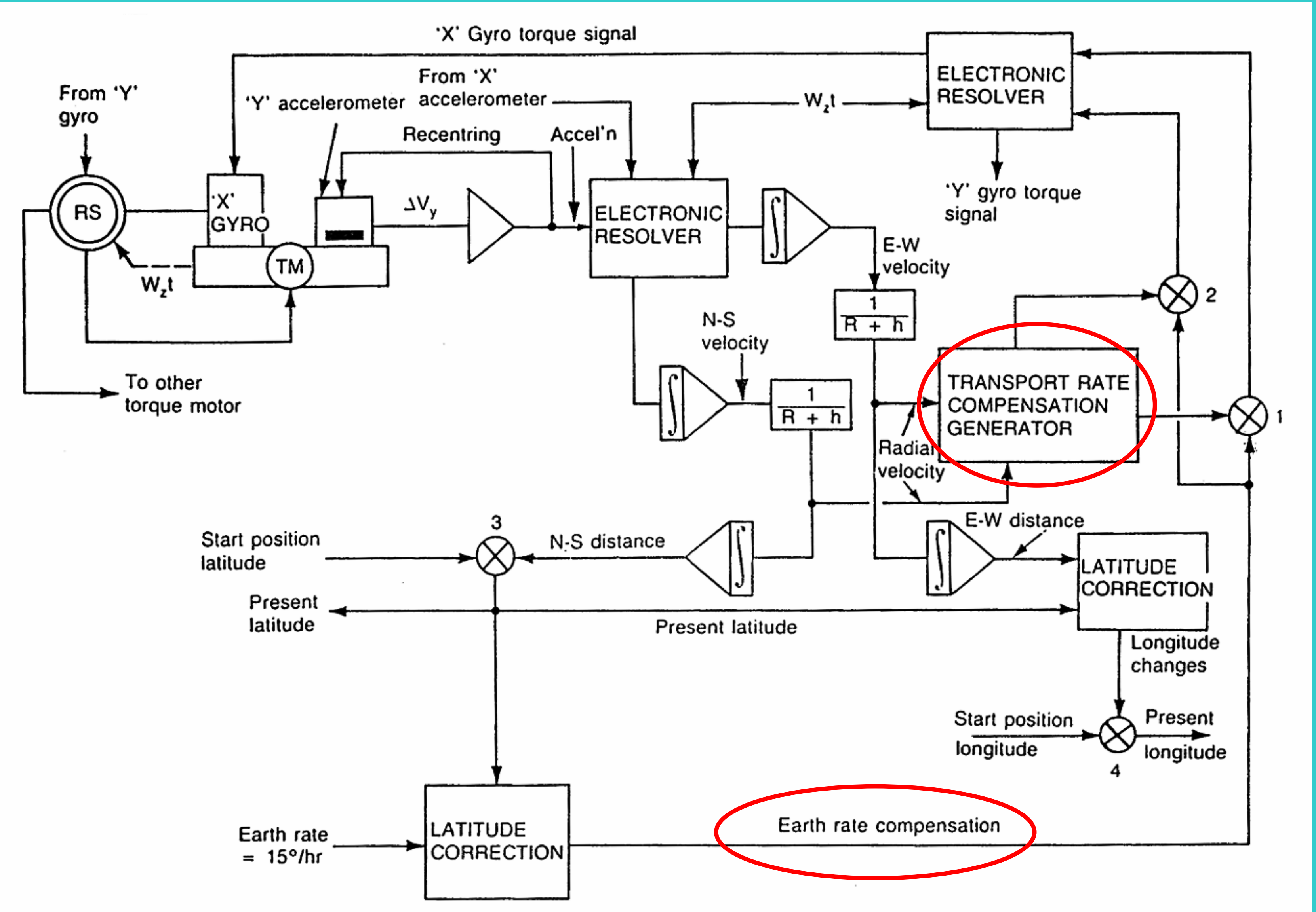
complessivamente

$$\left(\Omega + \frac{V_E}{R\cos\lambda}\right)\mathbf{sen}\lambda$$

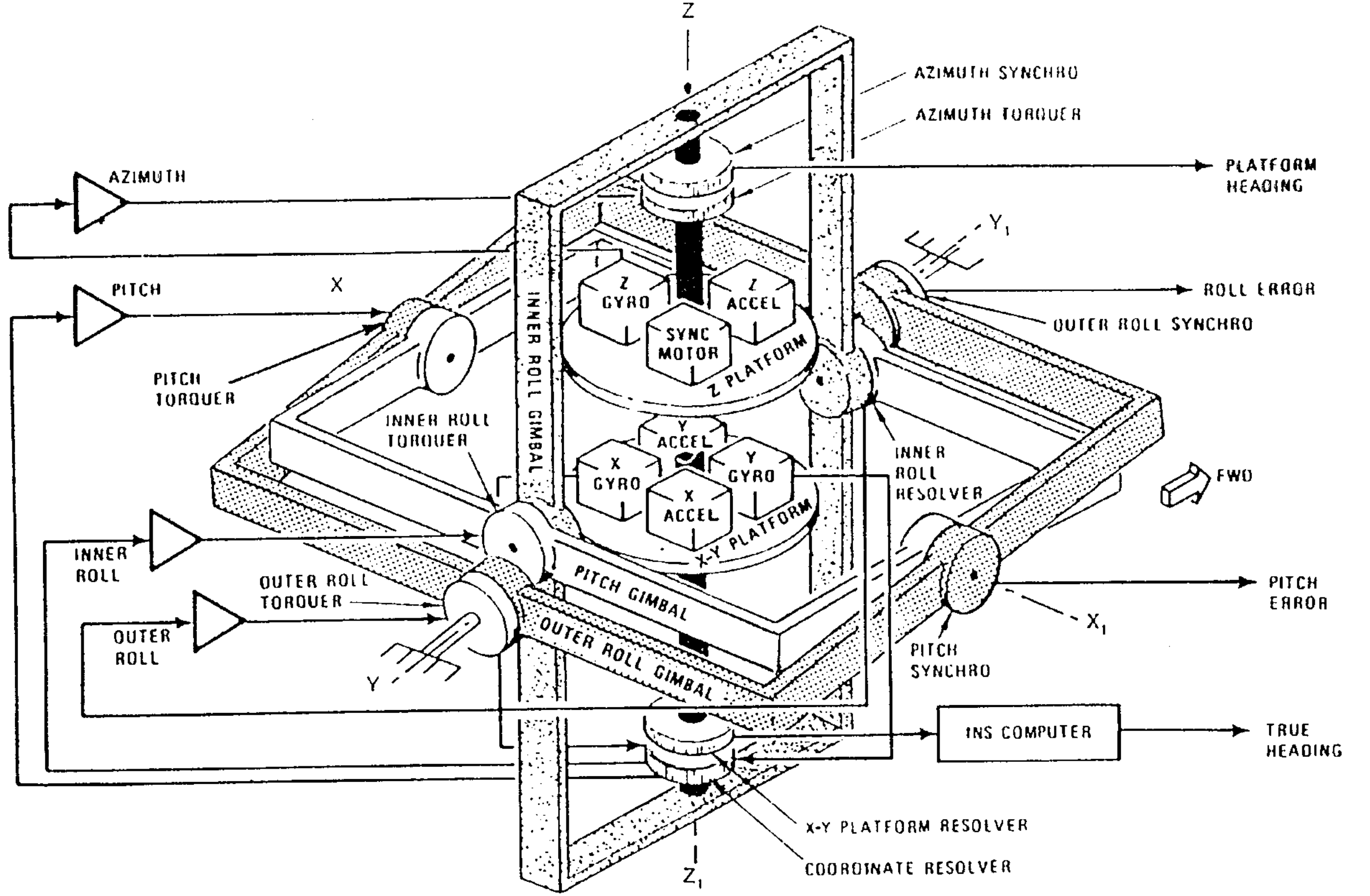




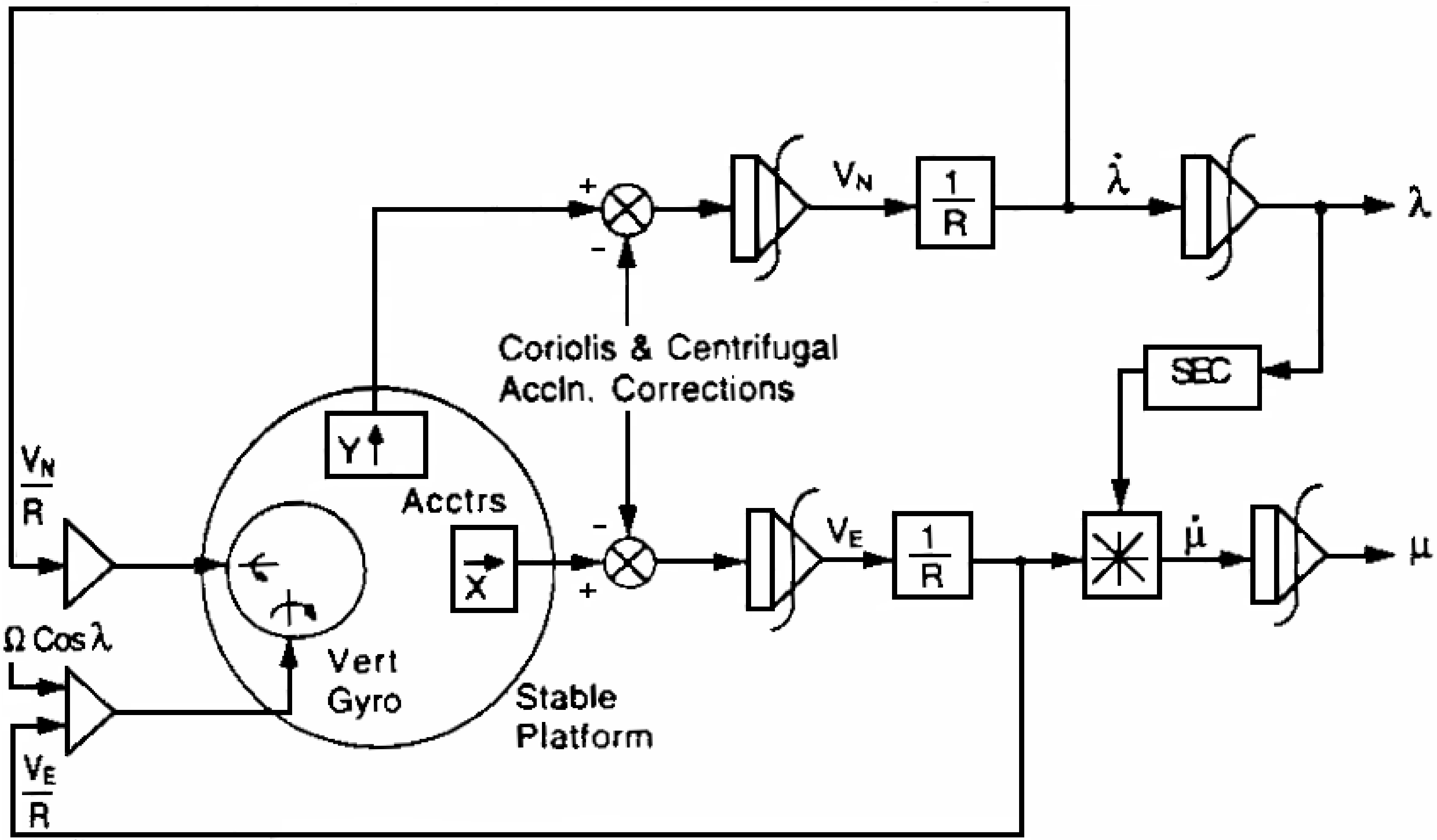
verticale locale
ZENIT
POLO NORD
integrat.
$\iint a_E dt^2$
G_E
asse polare della terra
colatit.
G_N
$\iint a_N dt^2$
moltiplic.
moltiplica per sec λ
posiz locale
accelerometri
φ
λ
Piattaforma secondaria
Addizionatrice
Addizionatrice
W 3 5° 1 2' 2 3"
LONGITUDINE
N 0 8° 4 0' 5 8"
LATITUDINE
EST
OVEST
orologio
al centro della terra
Piattaforma stabilizzata
Vertical gyros
Azimuth gyro



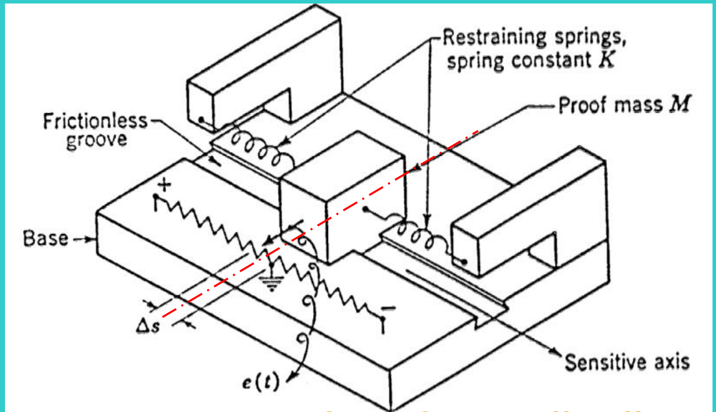
'X' Gyro torque signal
From 'Y' gyro
'Y' accelerometer
From 'X' accelerometer
$W_z t$
ELECTRONIC RESOLVER
Recentring
Accel'n
'X' GYRO
RS
TM
$W_z t$
ΔV_y
ELECTRONIC RESOLVER
'Y' gyro torque signal
E-W velocity
$\frac{1}{R + h}$
2
To other torque motor
N-S velocity
$\frac{1}{R + h}$
TRANSPORT RATE COMPENSATION GENERATOR
1
Radial velocity
3
Start position latitude
N-S distance
E-W distance
LATITUDE CORRECTION
Present latitude
Present latitude
Longitude changes
Start position longitude
Present longitude
4
Earth rate = 15°/hr
LATITUDE CORRECTION
Earth rate compensation


Z
AZIMUTH SYNCHRO
AZIMUTH TORQUER
PLATFORM HEADING
AZIMUTH
Y1
PITCH
X
ROLL ERROR
Z GYRO
Z ACCEL
SYNC MOTOR
OUTER ROLL SYNCHRO
PITCH TORQUER
INNER ROLL GIMBAL
Z PLATFORM
INNER ROLL TORQUER
Y ACCEL
X GYRO
Y GYRO
X ACCEL
INNER ROLL RESOLVER
FWD
X-Y PLATFORM
INNER ROLL
PITCH GIMBAL
PITCH ERROR
OUTER ROLL TORQUER
OUTER ROLL
X1
OUTER ROLL GIMBAL
PITCH SYNCHRO
Y
INS COMPUTER
TRUE HEADING
X-Y PLATFORM RESOLVER
COORDINATE RESOLVER
Z1

Vertical Gyros Stabilization

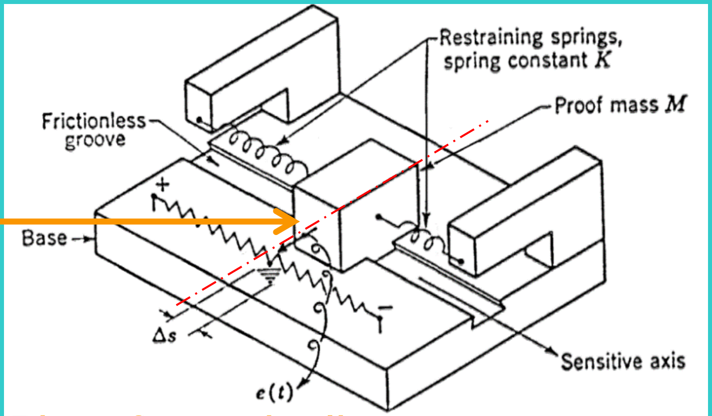


Oscillazioni della piattaforma

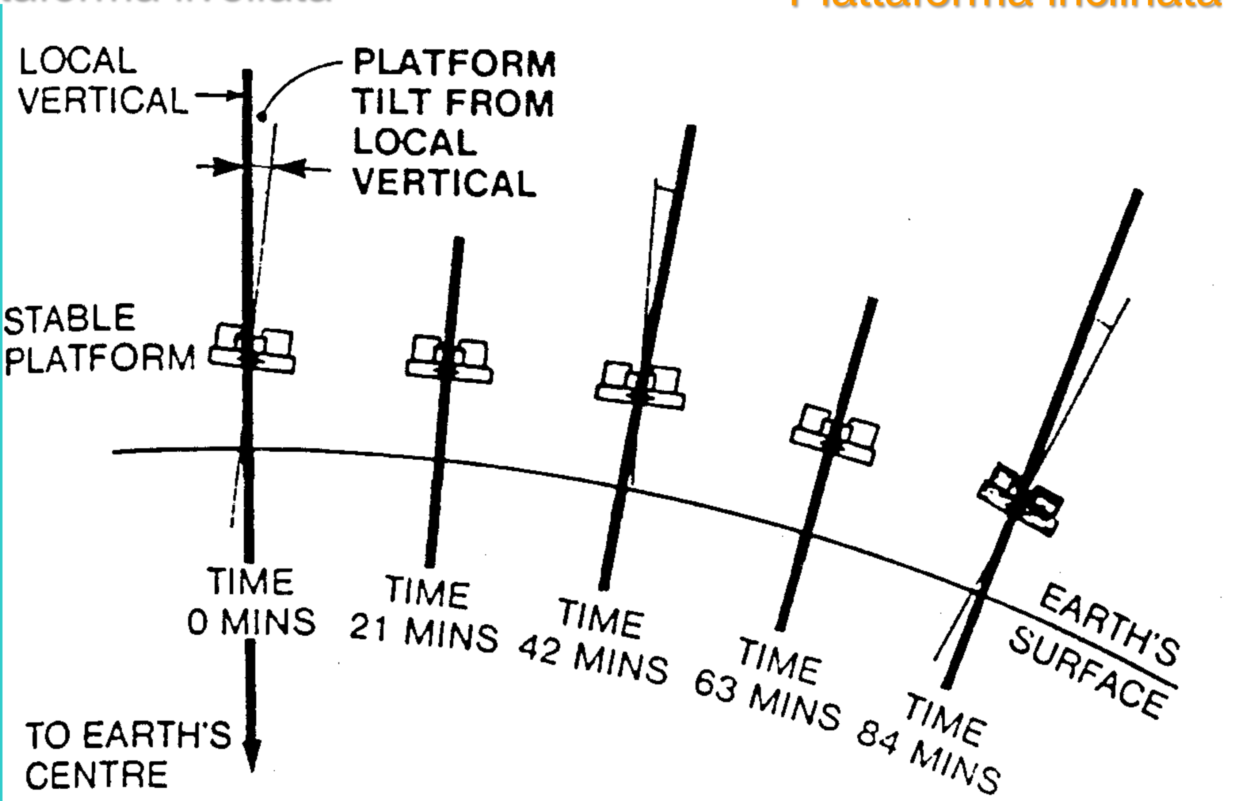


Piattaforma livellata

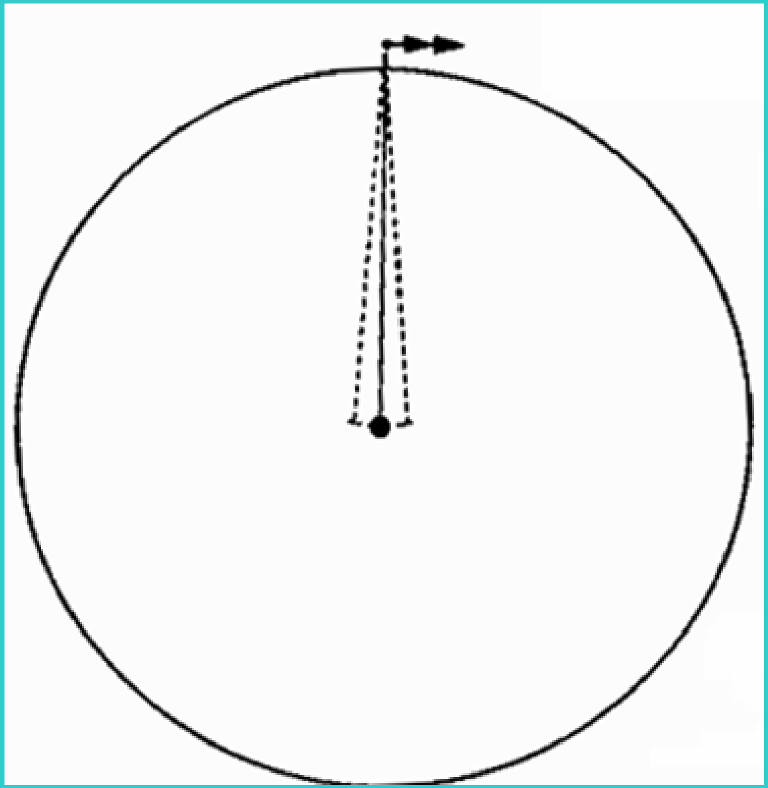
Spostamento iniziale dovuto alla componente della gravità



Piattaforma inclinata

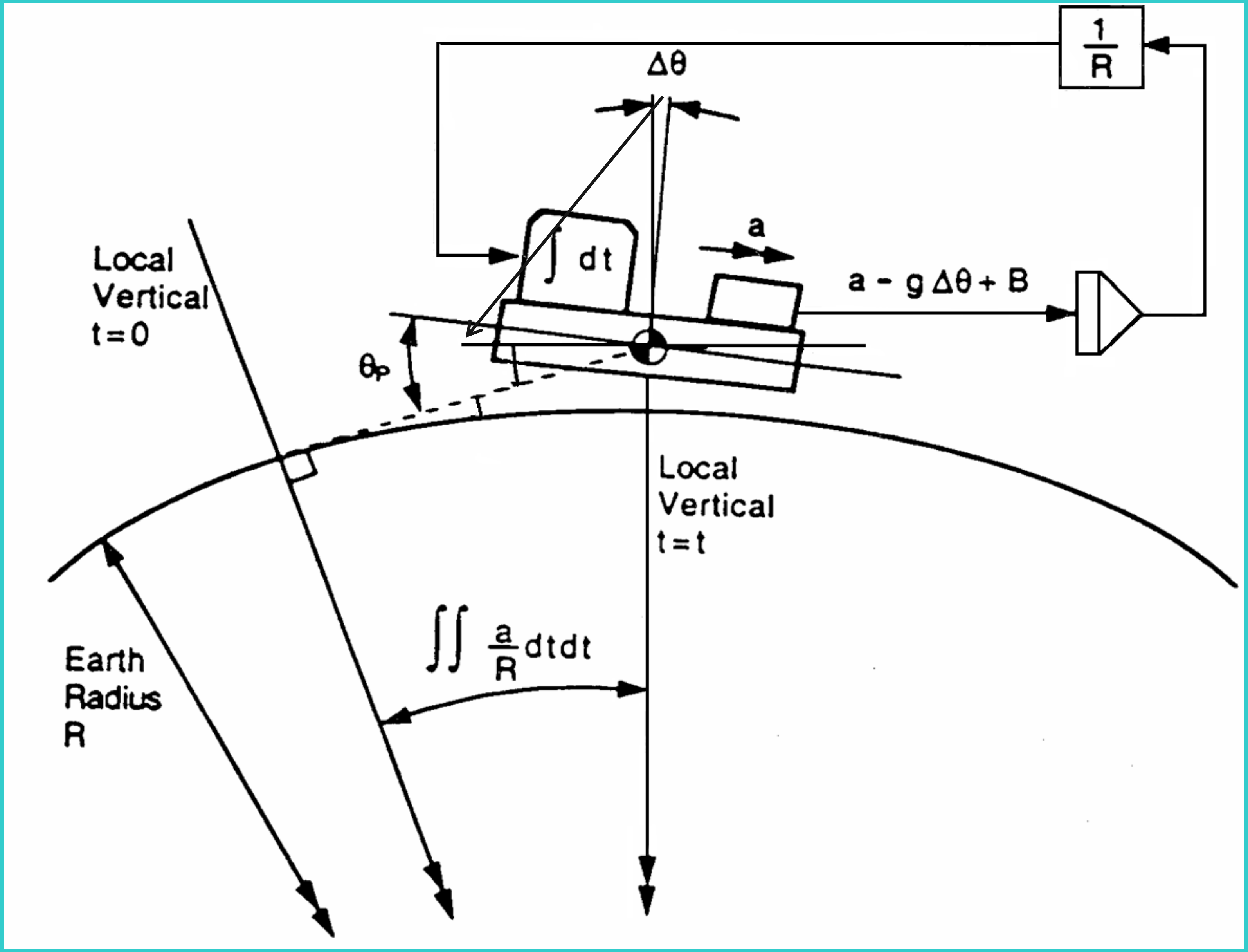


Pendolo di Schuler



$$\text{Period} = 2\pi\sqrt{\frac{\mathbf{R}}{\mathbf{g}}} = 84,4\text{min}$$

Platform tilting



Output dell'accelerometro in generale: $\mathbf{a} - \mathbf{g}\Delta\theta + \mathbf{B}$

dove **B** è l'errore dell'accelerometro

$\theta_{\mathbf{p}}$ = angolo di cui è ruotata la piattaforma nell'intervallo $\Delta\mathbf{t} = \mathbf{t} - \mathbf{t}_0 = \mathbf{t}$

L'angolo di cui è ruotata la verticale locale nello stesso intervallo è:

$\theta_{\mathbf{n}} = \int d\mathbf{t} \int \frac{\mathbf{a}}{\mathbf{R}} d\mathbf{t}$ e quindi: $\Delta\theta = \theta_{\mathbf{p}} - \theta_{\mathbf{n}} \quad \Rightarrow \quad \Delta\theta = \theta_{\mathbf{p}} - \int d\mathbf{t} \int \frac{\mathbf{a}}{\mathbf{R}} d\mathbf{t}$

$$\dot{\theta}_{\mathbf{p}} = \int \frac{\mathbf{a} - \mathbf{g}\Delta\theta + \mathbf{B}}{\mathbf{R}} d\mathbf{t} + \mathbf{W}$$

dove **W** è la deriva del giroscopio. Quindi:

$$\theta_{\mathbf{p}} = \int d\mathbf{t} \int \frac{\mathbf{a} - \mathbf{g}\Delta\theta + \mathbf{B}}{\mathbf{R}} d\mathbf{t} + \int \mathbf{W} d\mathbf{t}$$

sostituendo si ottiene:

$$\Delta\theta = \int d\mathbf{t} \int \frac{\mathbf{a} - \mathbf{g}\Delta\theta + \mathbf{B}}{\mathbf{R}} d\mathbf{t} + \int \mathbf{W} d\mathbf{t} - \int d\mathbf{t} \int \frac{\mathbf{a}}{\mathbf{R}} d\mathbf{t}$$

Differenziando due volte si ha:

$$\ddot{\Delta}\theta + \frac{\mathbf{g}\Delta\theta}{\mathbf{R}} = \frac{\mathbf{B}}{\mathbf{R}} + \dot{\mathbf{W}}$$

Primo caso: $\mathbf{W}=0$

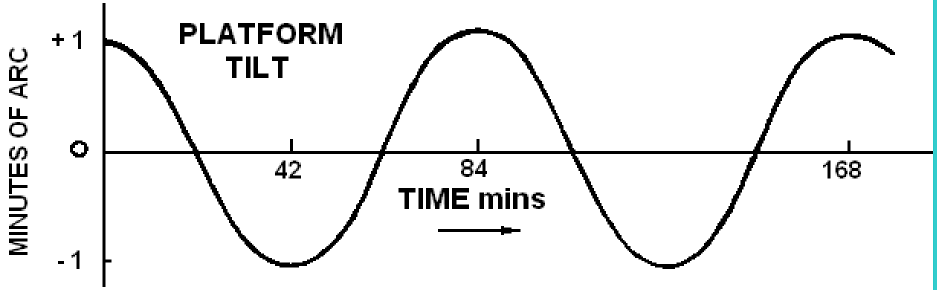
$\dot{\Delta}\theta = 0$ e $\Delta\theta = \dfrac{\mathbf{B}}{\mathbf{g}}$ all'istante $\mathbf{t}=0$ da cui integrando* $\Delta\theta = \dfrac{\mathbf{B}}{\mathbf{g}}\mathbf{cos}\,\omega_0\mathbf{t}$ dove $\omega_0 = \sqrt{\dfrac{\mathbf{g}}{\mathbf{R}}}$.

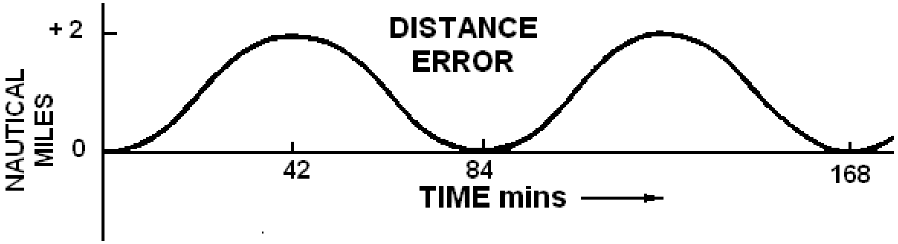
La piattaforma quindi oscilla attorno alla verticale locale con un periodo di: $2\pi\sqrt{\dfrac{\mathbf{R}}{\mathbf{g}}} = 84.4$ min

ed un'ampiezza di: $\mathbf{B}/\mathbf{g}$.

Un errore nell'accelerazione di $\mathbf{g}\Delta\theta$ comporta un errore nella velocità di: $\int \mathbf{B}\,\mathbf{cos}\,\omega_0\mathbf{t}\,\mathrm{dt}$

e nello spostamento di: $\int \mathrm{dt} \int \mathbf{B}\,\mathbf{cos}\,\omega_0\mathbf{t}\,\mathrm{dt} = \dfrac{\mathbf{B}}{\omega_0^{\,2}}\left(1-\mathbf{cos}\,\omega_0\mathbf{t}\right)$





B=2.9x10^{-4}g

*Con le condizioni al contorno stabilite l'integrazione è quella del moto non forzato

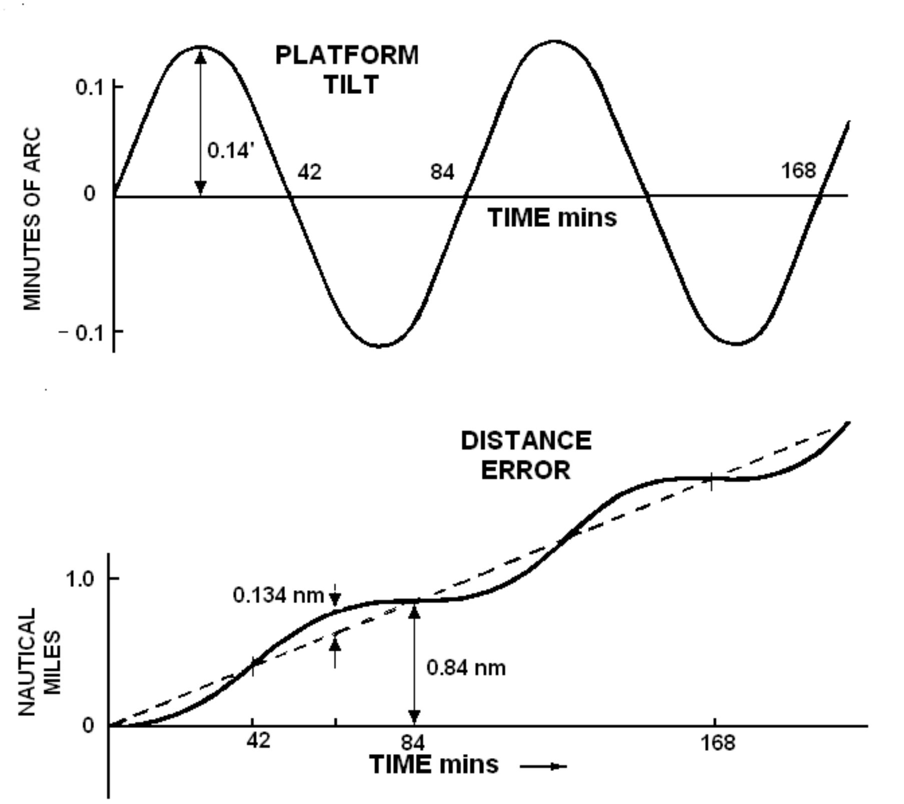
Secondo caso: $\mathbf{B} = 0$ e $\mathbf{W} = \mathbf{cost}$

$\dot{\Delta\theta} = \mathbf{W}$ e $\Delta\theta = 0$ all'istante $\mathbf{t} = 0$ da cui integrando $\Delta\theta = \dfrac{\mathbf{W}}{\omega_0}\mathbf{sen}\,\omega_0\mathbf{t}$.

Un errore nell'accelerazione di $\mathbf{g}\Delta\theta$ comporta un errore

nella velocità di: $\displaystyle\int \frac{\mathbf{gW}}{\omega_0}\mathbf{sen}\,\omega_0\mathbf{t}\,\mathbf{dt} = \mathbf{WR}\left(1-\mathbf{cos}\,\omega_0\mathbf{t}\right)$

nello spostamento di: $\displaystyle\int \mathbf{WR}\left(1-\mathbf{cos}\,\omega_0\mathbf{t}\right)\,\mathbf{dt} = \mathbf{WR}\left(\mathbf{t}-\frac{1}{\omega_0}\mathbf{sen}\,\omega_0\mathbf{t}\right)$



W=0.01°/h