Global Positioning System

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GPS 工作原理

總共24個衛星

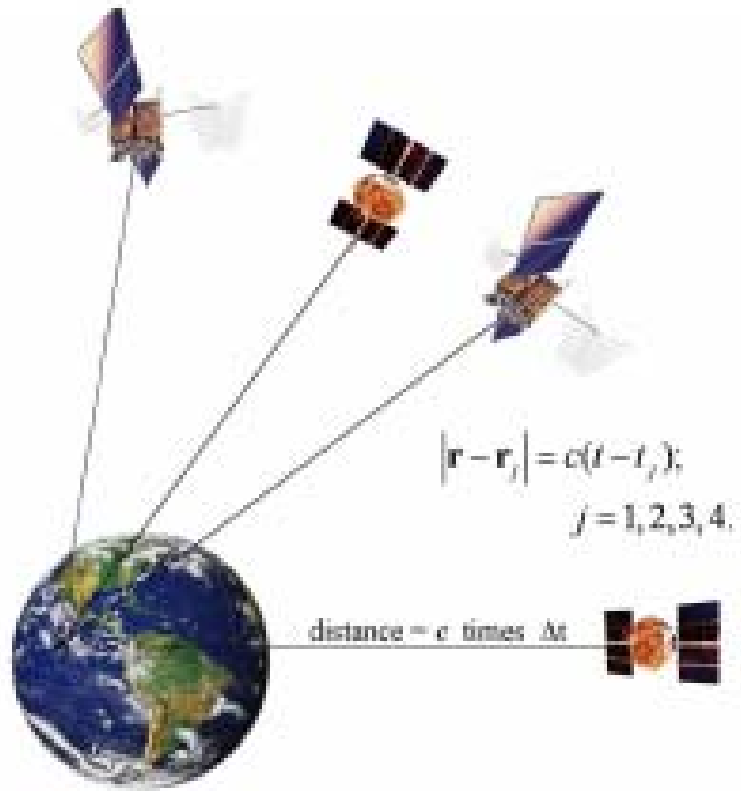
週期爲12小時

平均分爲6軌道面

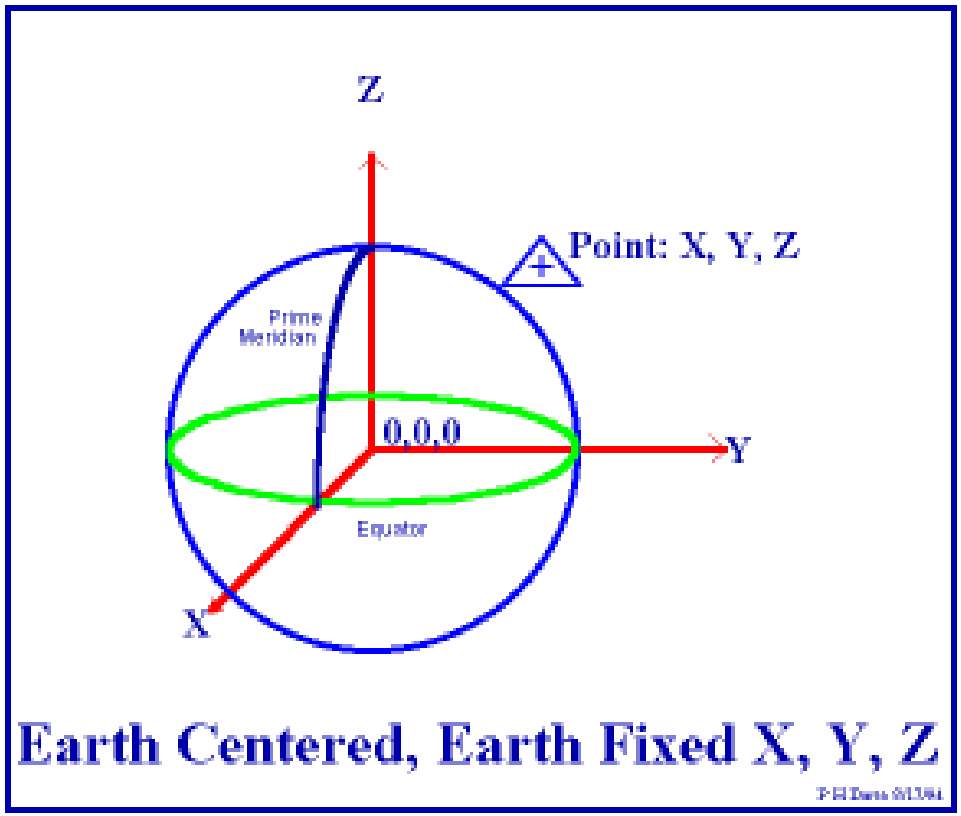
衛星上有atomic clock，記錄的是當時時間，以及當時位置，能發射微波訊號到地表。

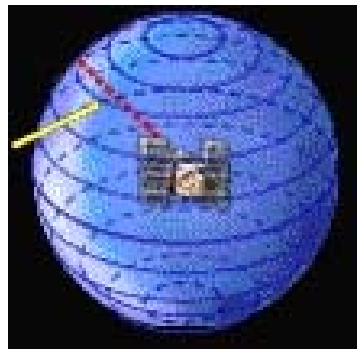
GPS 工作原理

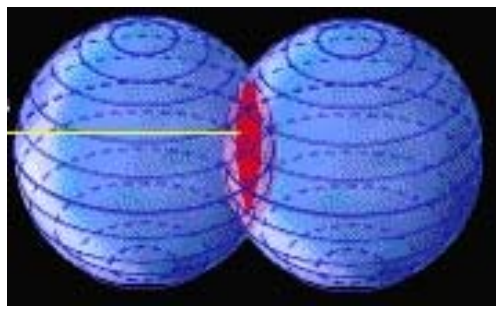
訊號以光速行進，所以只要以光速c乘以訊號傳遞的所需時間，就可以算出”接收器--衛星”的距離

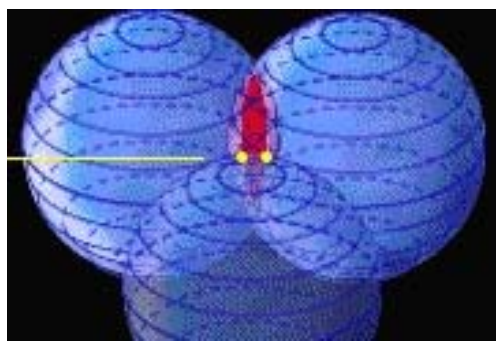


GPS 工作原理









使用ECEF座標作標準

接收器中有micro-processor，當接收到這些訊號後便能算出位置

GPS in General Relativity

Schwarzschild metric： $d\tau^2 = \left(1-\frac{2M}{r}\right)dt^2 - \cancel{\frac{dr^2}{1-\frac{2M}{r}}} - r^2 d\phi^2$

$$\left(\frac{d\tau}{dt}\right)^2 = \left(1-\frac{2M}{r}\right) - r^2\left(\frac{d\phi}{dt}\right)^2$$

$$\left(\frac{d\tau}{dt_{衛星}}\right)^2 = \left(1-\frac{2M}{r_{衛星}}\right) - v_{衛星}^2 \qquad \left(\frac{d\tau}{dt_{地球}}\right)^2 = \left(1-\frac{2M}{r_{地球}}\right) - v_{地球}^2$$

$$\left(\frac{dt_{衛星}}{dt_{地球}}\right)^2 = \frac{\left(1-\frac{2M}{r_{衛星}}\right) - v_{衛星}^2}{\left(1-\frac{2M}{r_{地球}}\right) - v_{地球}^2}$$

GPS in General Relativity

Taking approximation：

$$\left(\frac{dt_{衛星}}{dt_{地球}}\right)^2 = \frac{\left(1-\frac{2M}{r_{衛星}}\right)-v_{衛星}^2}{\left(1-\frac{2M}{r_{地球}}\right)-v_{地球}^2}$$

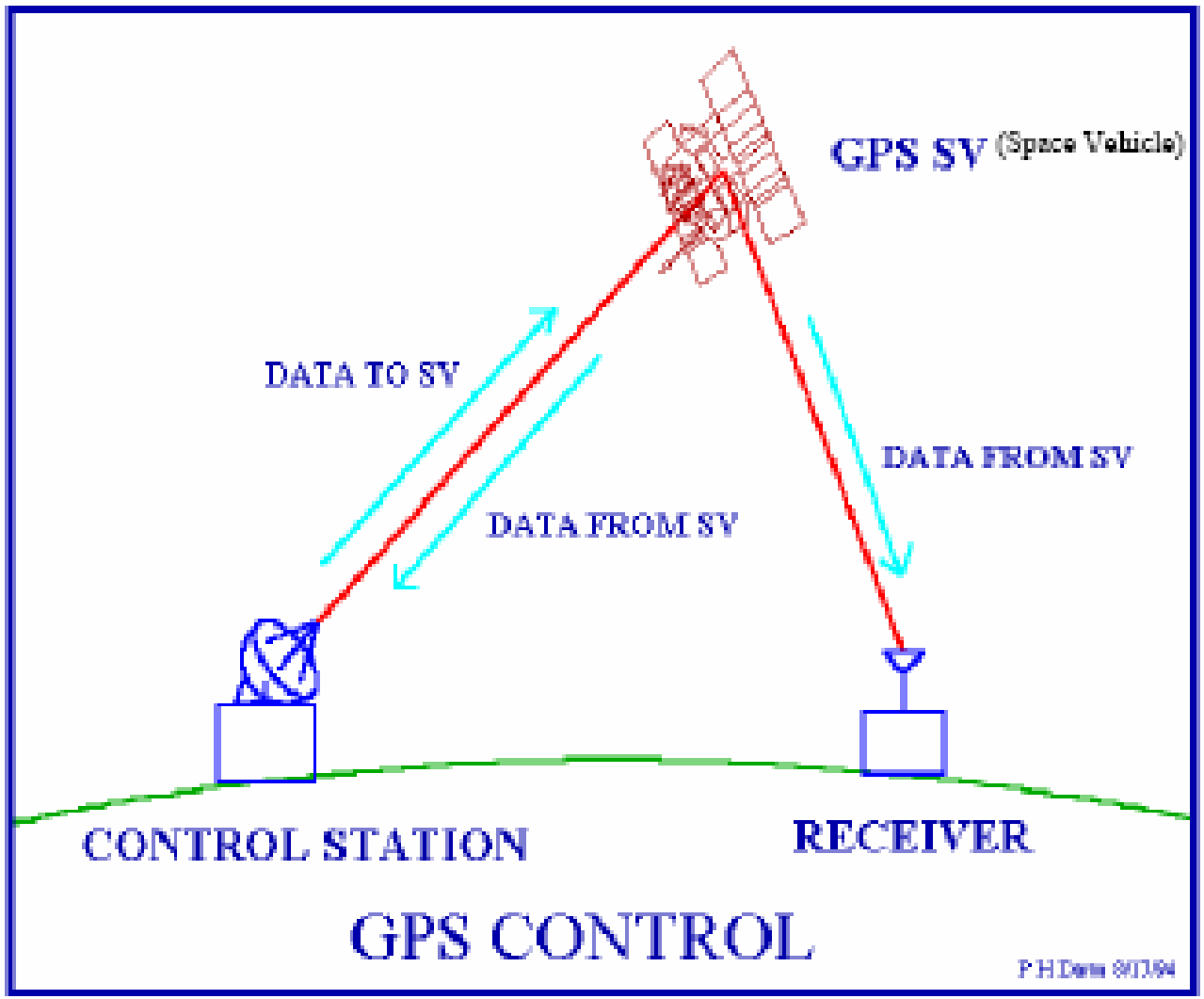
$$(1+d)^n \approx 1+nd$$

$$\frac{dt_{衛星}}{dt_{地球}} = \left[1-\frac{2M}{r_{衛星}}-v_{衛星}^2\right]^{1/2}\left[1-\frac{2M}{r_{地球}}-v_{地球}^2\right]^{-1/2} \approx \left[1-\frac{M}{r_{衛星}}-\frac{v_{衛星}^2}{2}\right]\left[1+\frac{M}{r_{地球}}+\frac{v_{地球}^2}{2}\right]$$

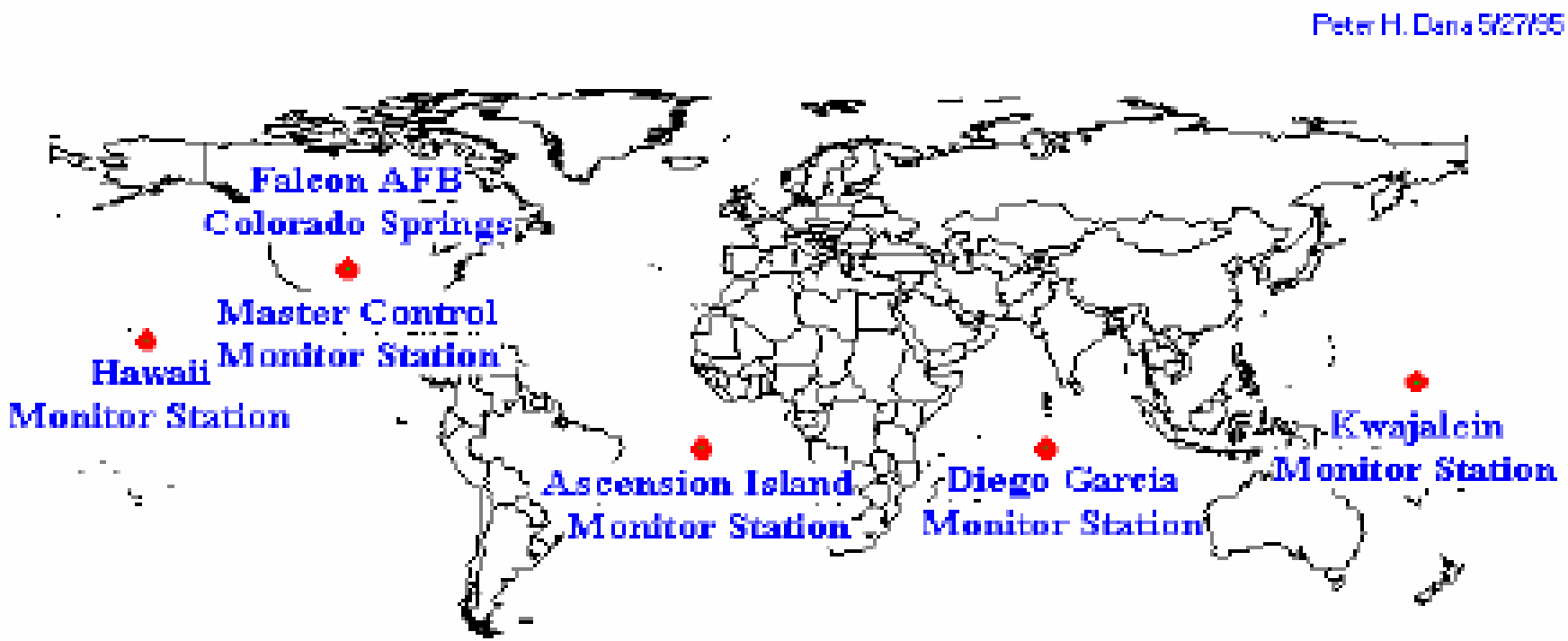
$$\approx 1-\frac{M}{r_{衛星}}-\frac{v_{衛星}^2}{2}+\frac{M}{r_{地球}}+\frac{v_{地球}^2}{2}$$

$$\Rightarrow \quad \frac{dt_{衛星}}{dt_{地球}} \approx 39{,}000 ns/day \quad \Rightarrow \quad 位置的誤差會在\ 10^2$$

How to solve ?

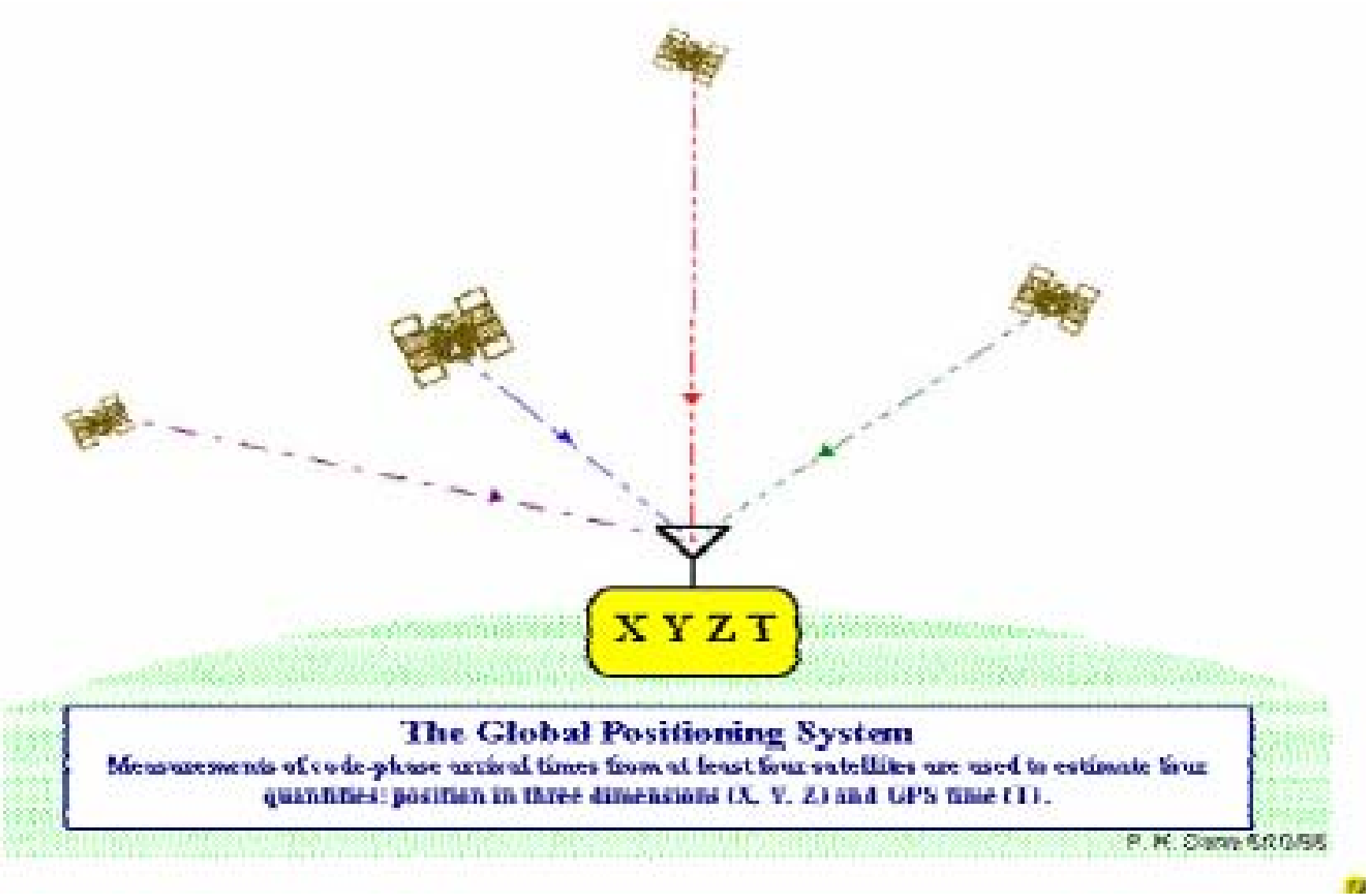

GPS SV (Space Vehicle)
DATA TO SV
DATA FROM SV
DATA FROM SV
CONTROL STATION
RECEIVER
GPS CONTROL

How to solve ?

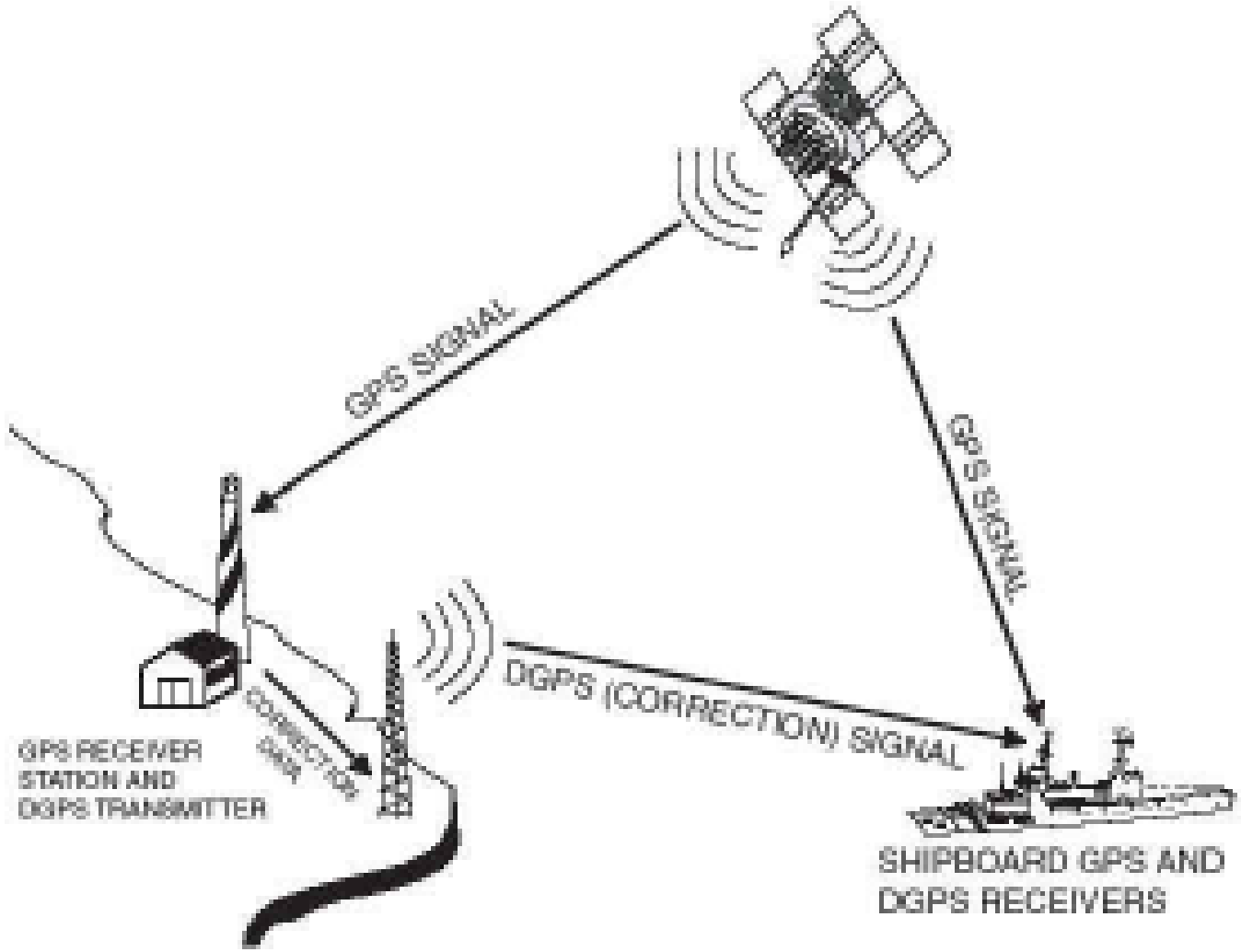


Global Positioning System (GPS) Master Control and Monitor Station Network

How to solve ?

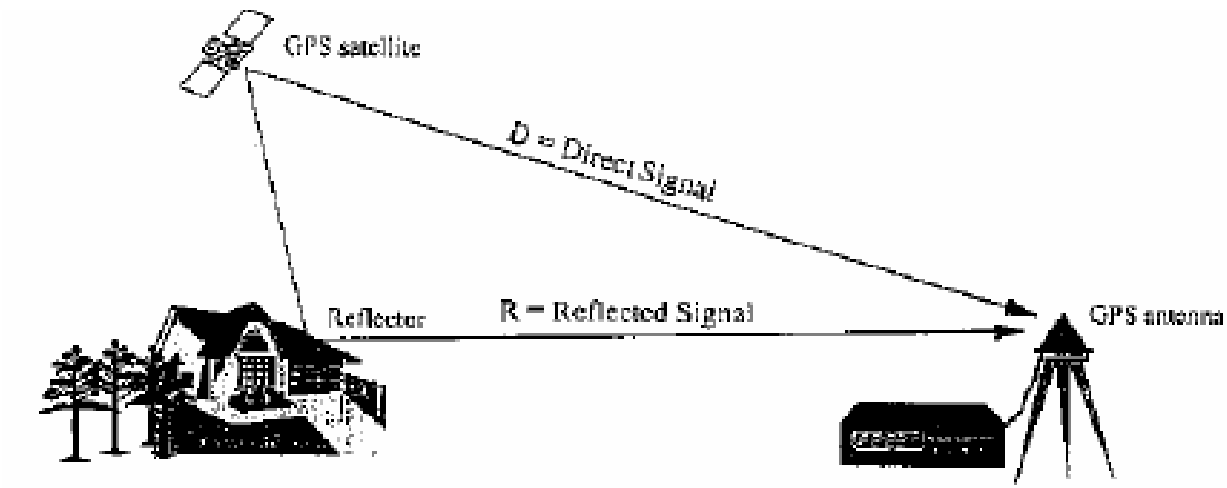


How to solve ?


GPS SIGNAL
GPS SIGNAL
DGPS (CORRECTION) SIGNAL
GPS RECEIVER
STATION AND
DGPS TRANSMITTER
SHIPBOARD GPS AND
DGPS RECEIVERS

影響GPS的其他因素

- Refraction
- Noise
- Doppler effect
- Multi-path



Applications

For Geodesy

For Geodesy

For Geodesy

For GIS

Mobile Navigation

References

Exploring Black holes—introduction to general relativity

Ediwin F. Taylor, John Archibald Wheeler

Atmospheric humidity retrieval with GPS

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Relativistic Effects in the Global Positioning System

Neil Ashby