Attitude Determination System of Small Satellite

Satellite Research Centre

Jiun Wei Chia, M. Sheral Crescent Tissera and Kay-Soon Low
School of EEE, Nanyang Technological University, Singapore

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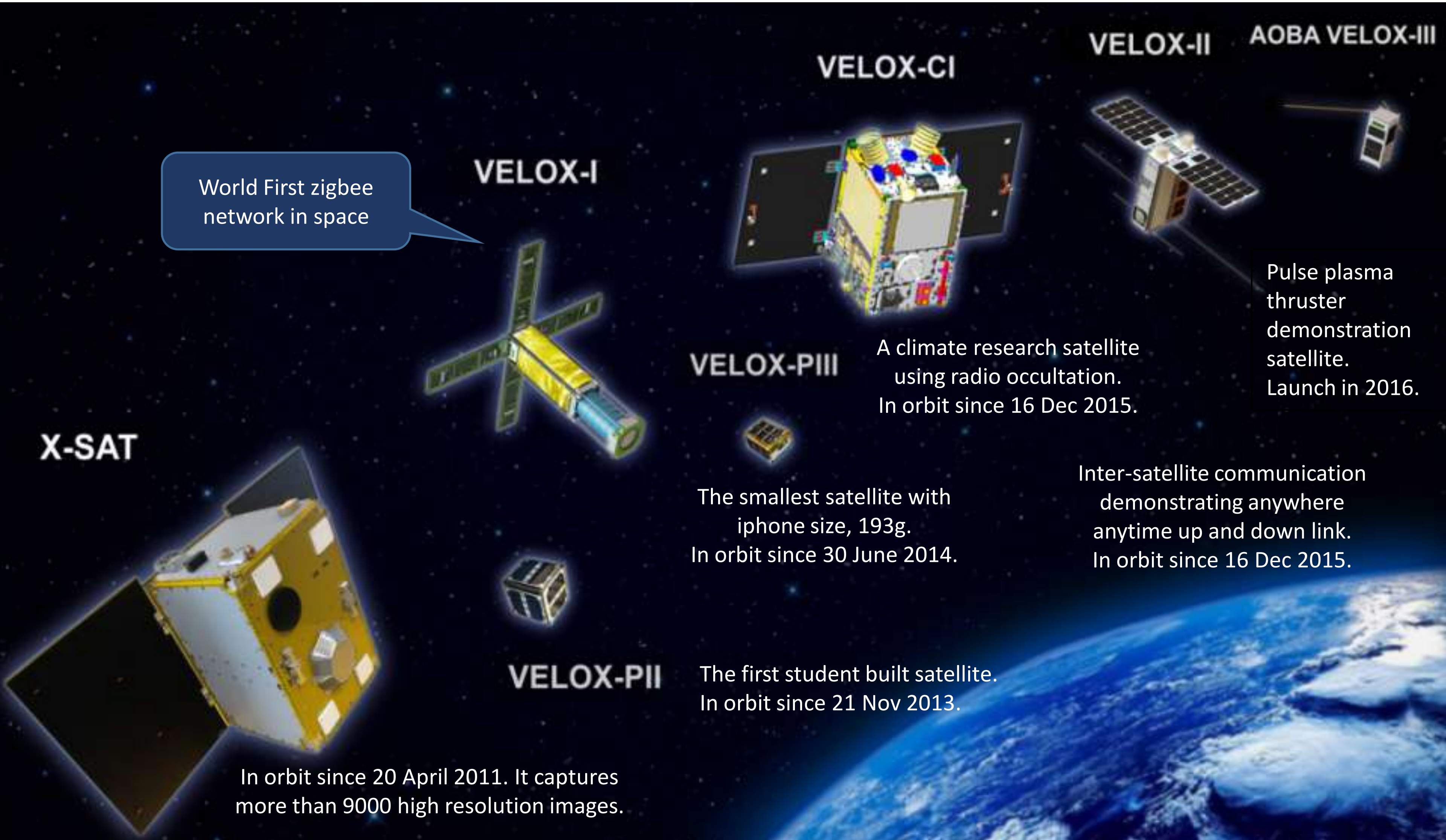
1st Space Science School, Geo-informatics and Space Technology Development Agency (GISTDA), Chonburi, Thailand.

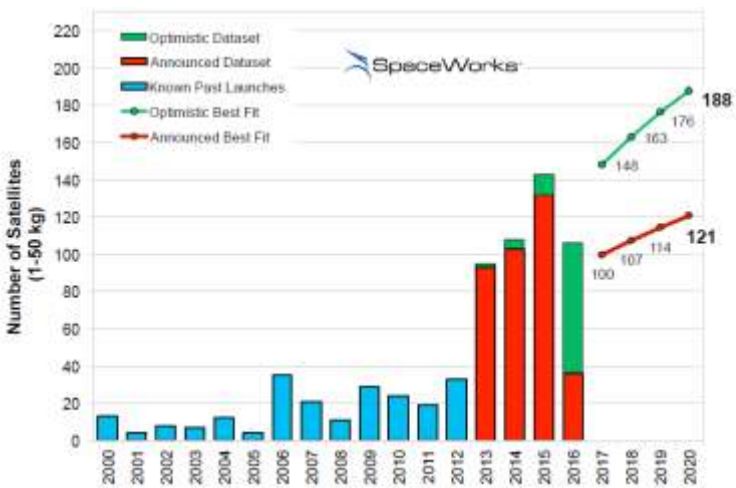
SaRC - Satellite Research Centre

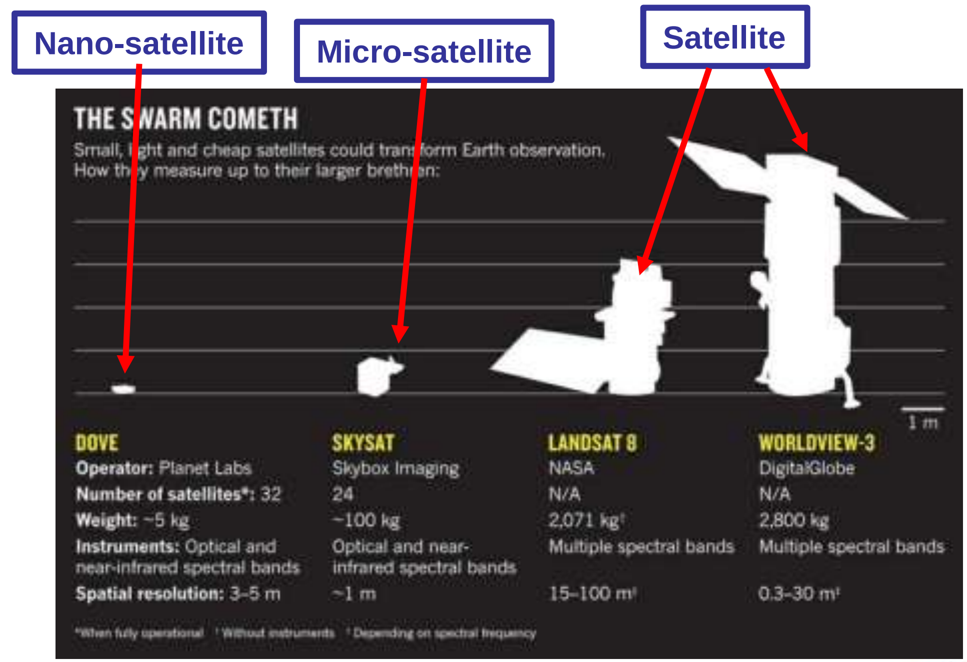
To be a world class centre for advanced research and training in innovative space technologies for small satellite system



Background

- **The industry of miniature satellite has been growing. SpaceWorks' market assessment indicates around 180 nano/microsatellites requiring a launch in year 2020*.**





***D. DePasquale and J. Bradford, "Nano/Microsatellite Market Assessment," SpaceWorks2013.**

Background

- **The nano-satellites industry has changed from research purposes to application focused**
  - **Remote sensing**
  - **Automated Identification System (AIS) for ship tracking**
  - **Automatic dependent surveillance – broadcast (ADS-B) for aircraft position estimation**
  - **Intersatellite Communication**

- **Industry and university that constantly building nano-satellites**
  - **University of Toronto Institute for Aerospace Studies (UTIAS)**
  - **NTU Satellite Research Centre (SaRC)**
  - **Planet Labs**
  - **Spire**
  - **Stensat Group**
  - **Satellogic**

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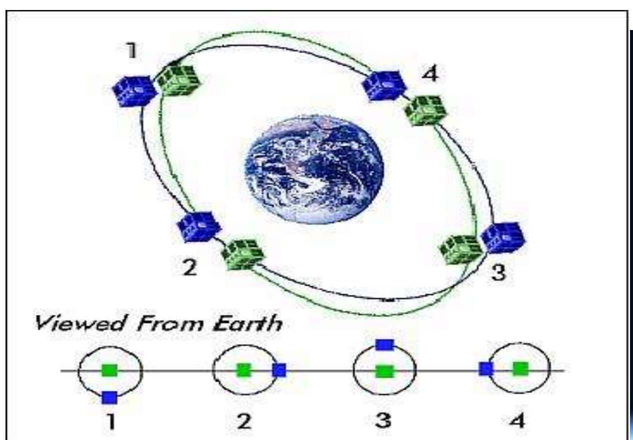
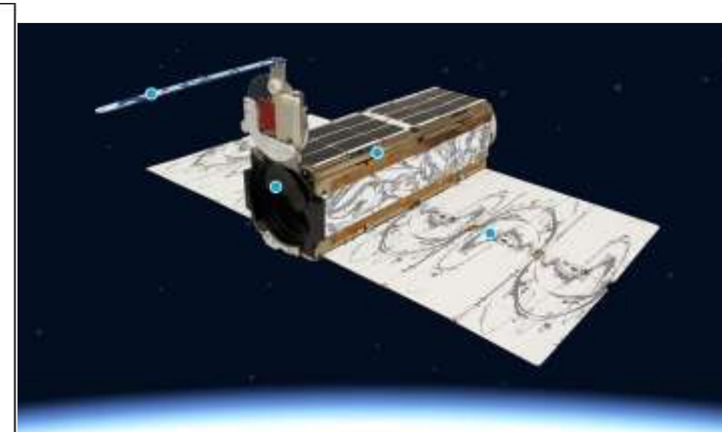


Nano-satellite formation flying



DOVE by Planet Labs

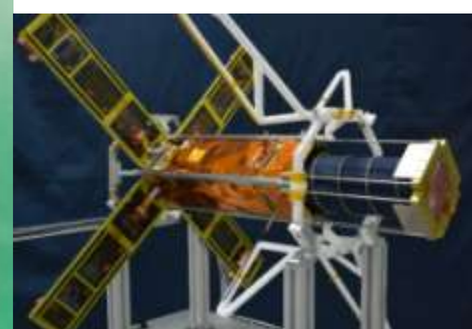
Attitude determination and control system (ADCS)

- Most applications require target tracking, precise attitude determination is important

- Nano-satellite's ADCS
  - MEMS Inertial Measurement Unit with gyroscope and magnetometer
  - Sun Sensors
  - Reaction Wheel
  - Magnetic torquer

ADCS printed circuit board

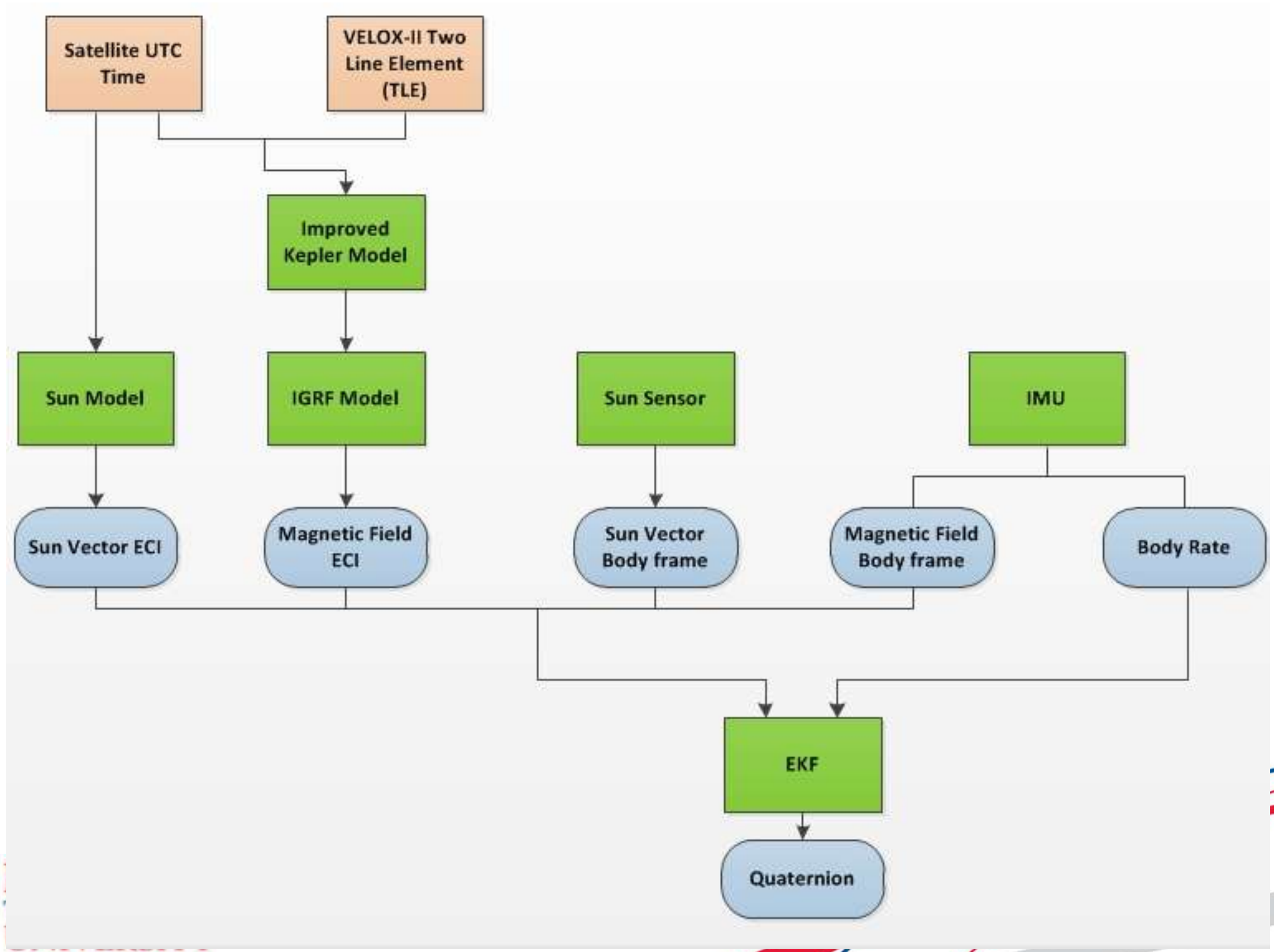
Sun sensor



VELOX- I

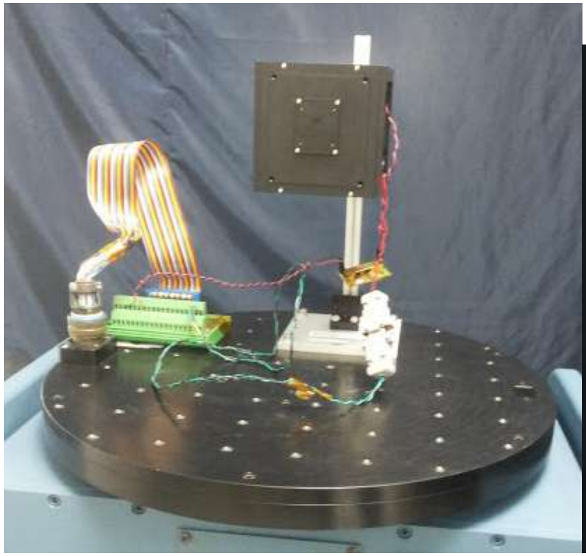
VELOX- II

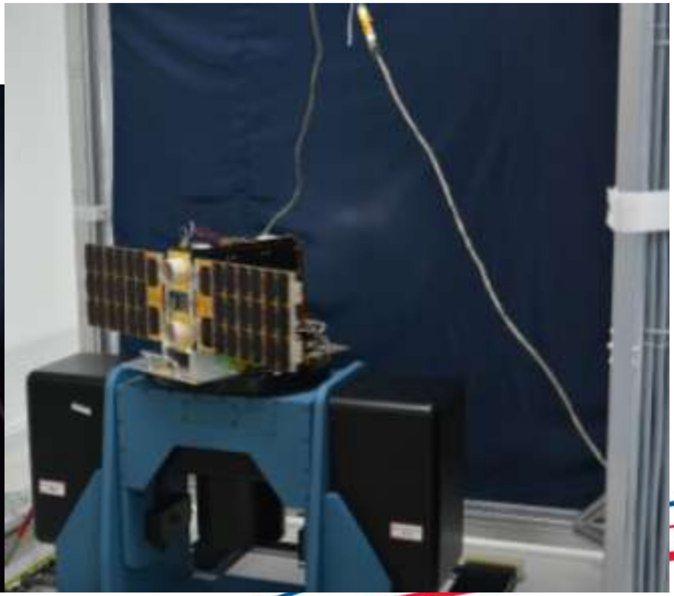
Attitude Determination System (ADS)



ADS: Sun Sensor

- In-house designed Analog Sun Sensor
- Consists of:
  - 2-dimensional position sensitive detector (PSD)
  - Mechanical cover





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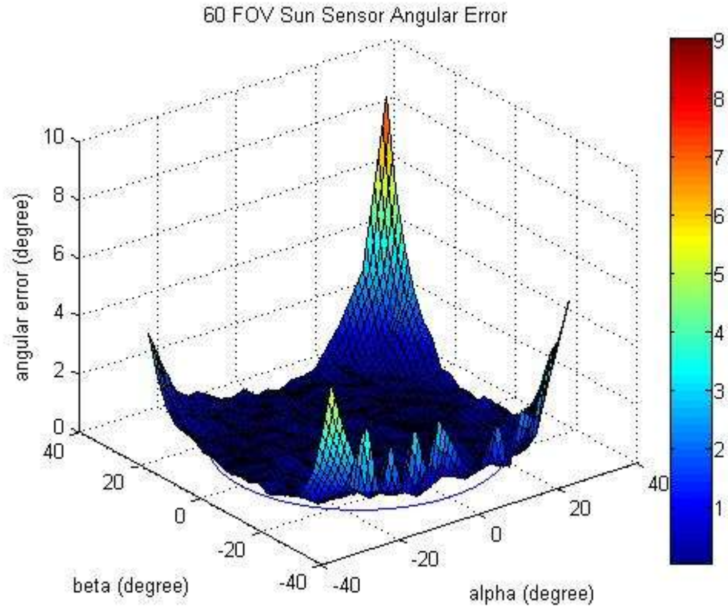
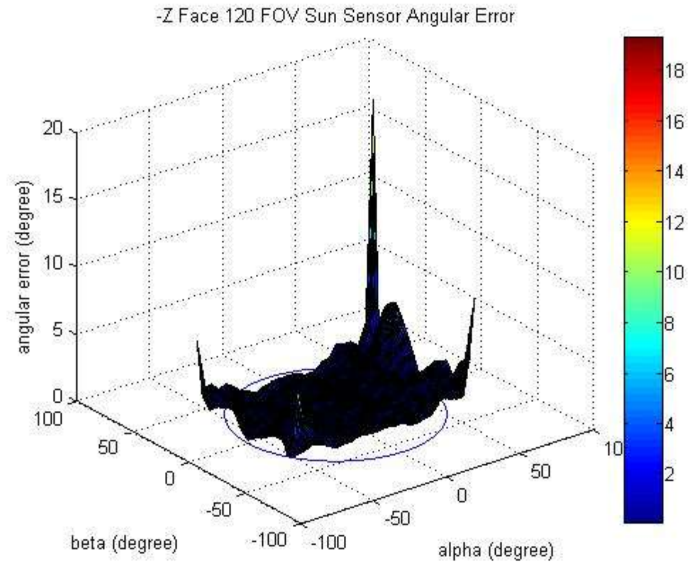
ADS: Sun Sensor

	60FOV	120FOV Z-
RMS (°)	0.36	0.82
Mean (°)	0.29	0.69
Std (°)	0.23	0.45





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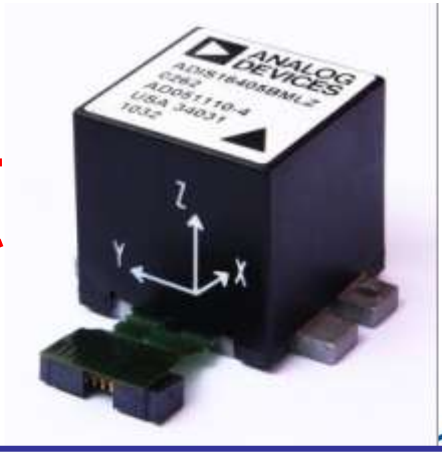
ADS: Inertial Measurement Unit

- Microelectromechanical systems (MEMS) based attitude determination system (ADS) is typically used for nano-satellites due to the limitation of
  - Size
  - Weight
  - Low computational power
- Low accuracy (noisy)

VELOX ADS
printed circuit board



Analog Devices ADIS16405
Inertial Measurement Unit (IMU)

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ADS: Gyroscope

- **Kalman filter to reduce the gyroscope noise**

- **MEMS gyroscope can be modelled as:**

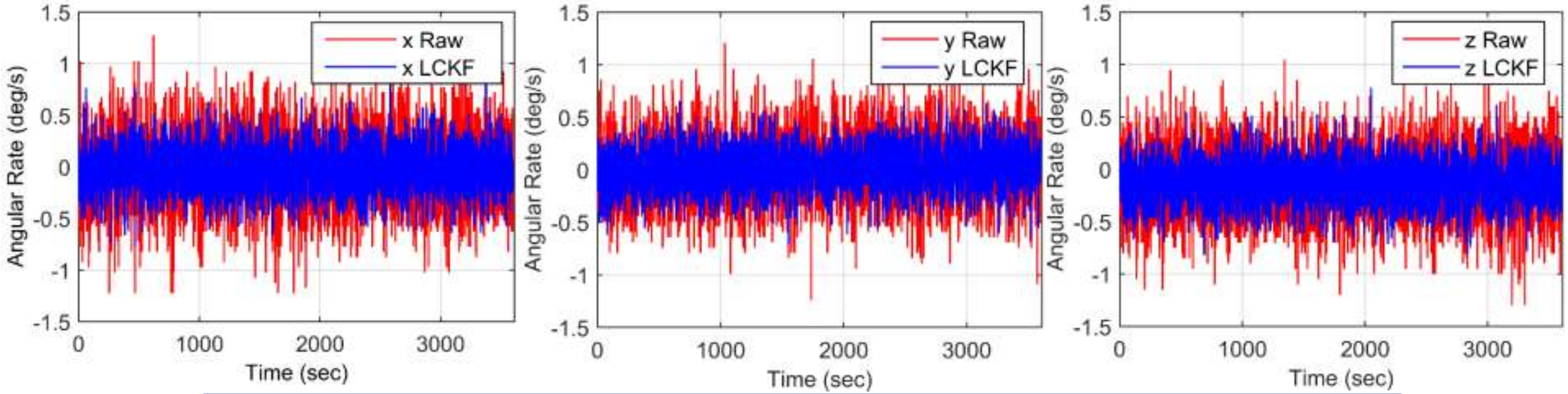
Angular rate · **Sampling time** · **Gyroscope noise**

$$\omega_{k+1} = \omega_k + \dot{\omega}_k \Delta t + \sigma_{noise}$$

Angular acceleration · **First order gyroscope noise**

$$\dot{\omega}_{k+1} = \dot{\omega}_k + \dot{\sigma}_{noise}$$

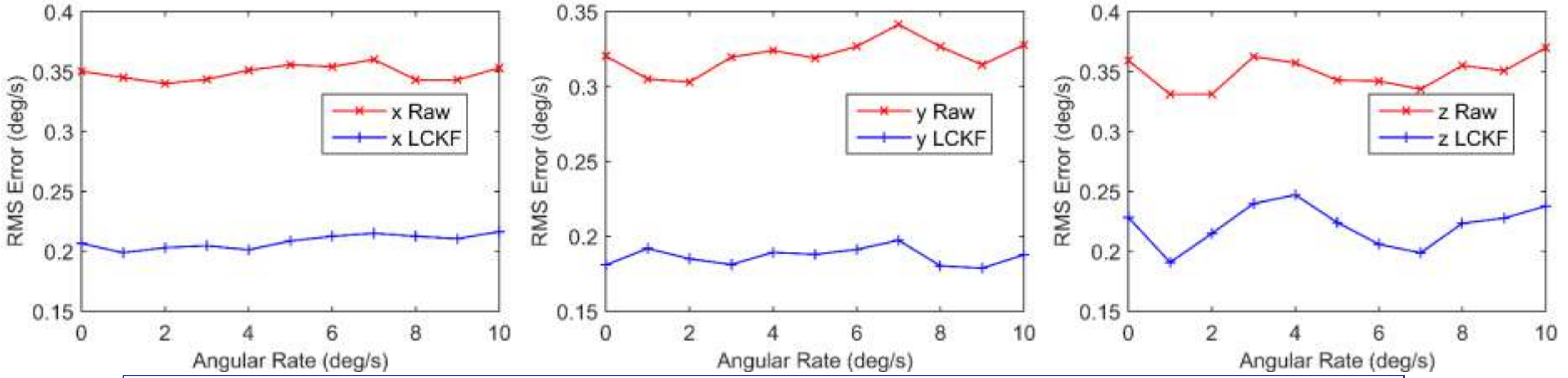
Kalman filter(KF) experimental results



Comparison of raw and KF angular rate at static condition

- **Gyroscope noise reduced by 20.92%**

Kalman filter(KF) experimental results



Comparison of raw and KF angular rate at dynamic condition

- **KF gyroscope angular rate in all axes has lower RMS error at any given rotation rate**

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Observer free sun tracking

- **VELOX sun tracking used an observer free quaternion error correction method together with Model Predictive Control.**

- **The general linearized control law for the observer free sun tracking algorithm is:**

$$T_{RW} = G\begin{bmatrix} \varepsilon_e^T & \omega^T \end{bmatrix}^T$$

Torque applied by reaction wheels → T_{RW}

Control Gain matrix → G

Vector component of error quaternion → ε_e^T

Satellite body rate → ω^T

- **Highly susceptible to gyroscope noise**

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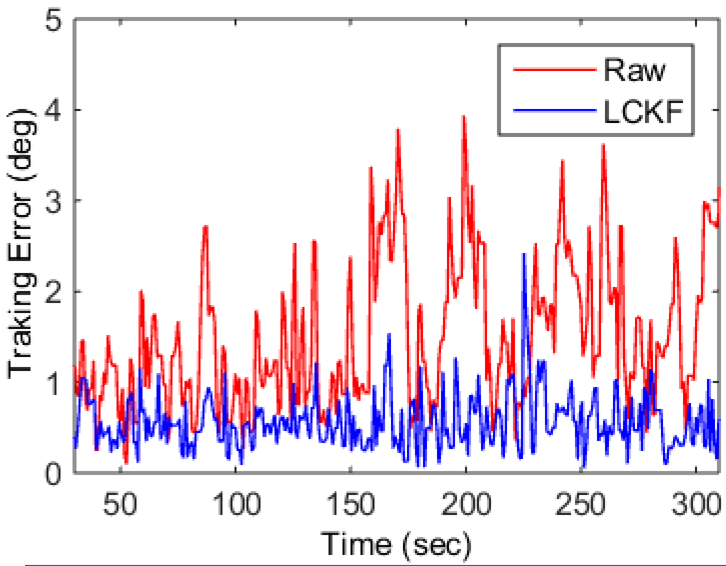
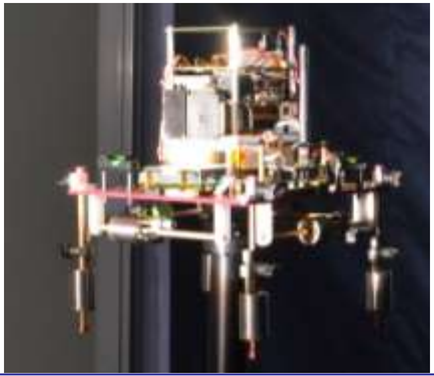
Observer free sun tracking: experiment

- **RMS steady state tracking error without KF is 1.672° whereas with KF is 0.622°**



Sun tracking error at steady state



Spacecraft simulator

Sun tracking experimental setup

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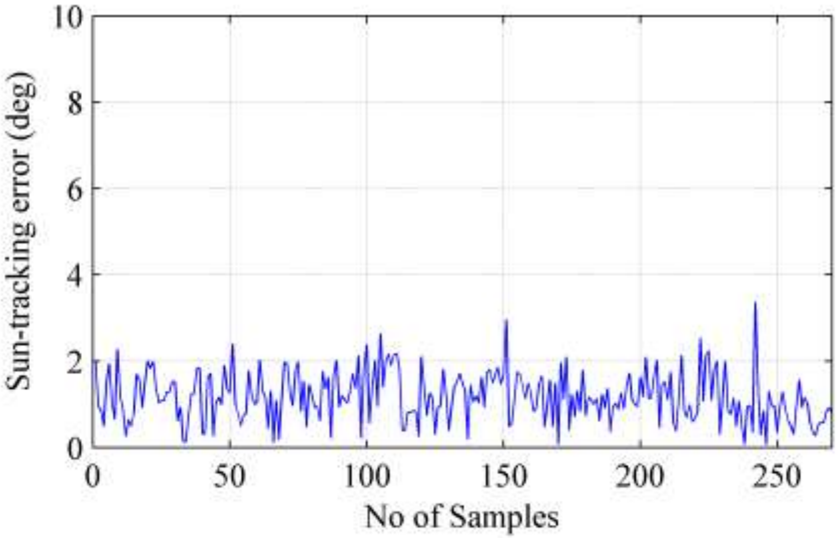
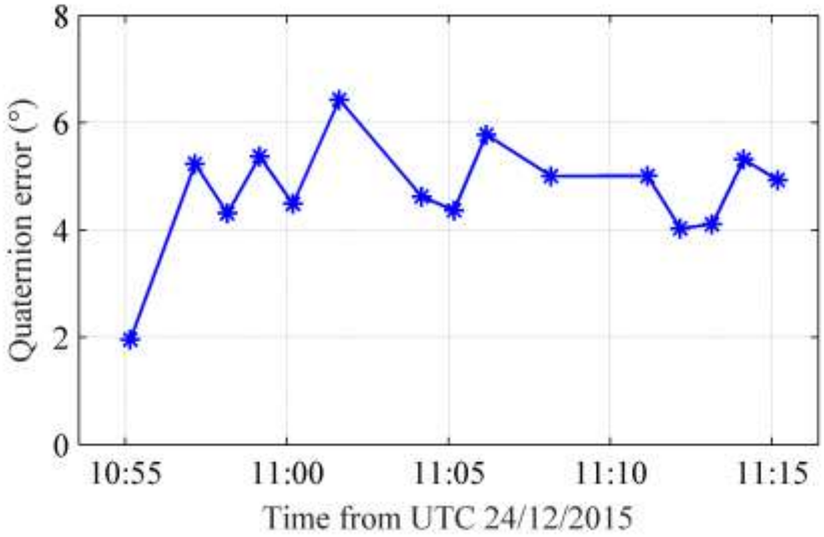
VELOX-II ADCS In-orbit result



Sun tracking performance of VELOX-II on 1st Feb 2016



Performance of nadir pointing conducted on 24th Dec 2015

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Future Work

- **Digital sun sensor development**
  - **Complementary metal-ocide-semiconductor (CMOS)**
- **In-orbit gyroscope and magnetometer calibration**
  - **Thermal variation**
  - **On-board electronics time-varying bias**
  - **Mechanical mis-alignment**
  - **Gyro bias drift (gyroscope)**
  - **Coupling effect of magnetic torquer (magnetometer)**

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