A Snapshot GPS Approach for Precise Positioning and Attitude Determination of MicroSatellites

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Small Satellite Design Trends

- Large satellite >1000kg
- Medium sized satellite 500-1000kg
- Mini satellite 100-500kg
- Micro satellite 10-100kg
- Nano satellite 1-10kg
- Pico satellite 0.1-1kg
- Femto satellite <100g

Small Satellites

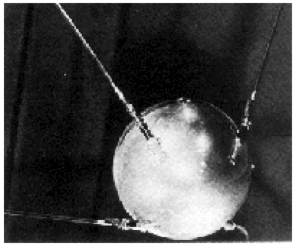
Advantages of Small Satellites

- Low investment and operational costs
- Flexibility in design approach
- Short systems development cycles
- Lower launch costs
- Leveraging COTS technology
- Typical microsat costs <$10M in orbit

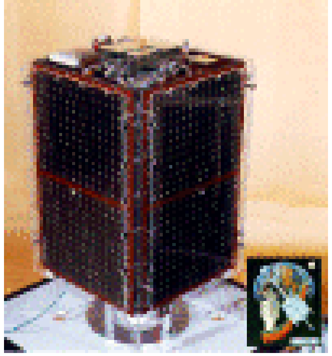
Over 400 microsats have been launched in last 20 years

Examples of Small Satellites

- Sputnik (1957)
  - 84 kg
  - Radio transmission



- PoSAT-1 (1993)
  - 50 kg
  - GPS, Earth Imaging System, Star Sensor, Cosmic Ray Experiment,



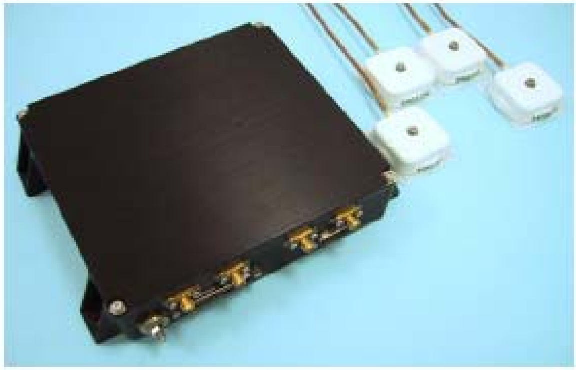
- GeneSat-1 (2006)
  - 10 kg
  - Biological payload, 437 MHz Beacon, 2.4 GHz comms

Small Satellite Design Challenges

- Minimize size, weight, power and cost of onboard avionics and payloads
- Positioning and communication functions are needed to support orbital operations
- COTS commercial GPS solutions do not work well in a space environment
- Custom designed space GPS solutions are large and expensive
- Using a SDR allows sharing of resources for positioning and navigation

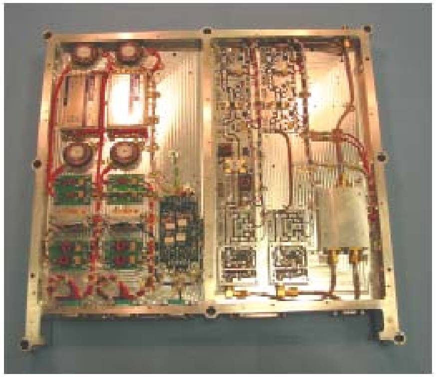
Challenges for Space GPS Receivers

- Hardened electronics and processors
- All-around visibility
- Low cost (typically $50-$350 K currently)



SGR-20 Space GPS receiver and four antennas

SGR-20
(0.95 kg)

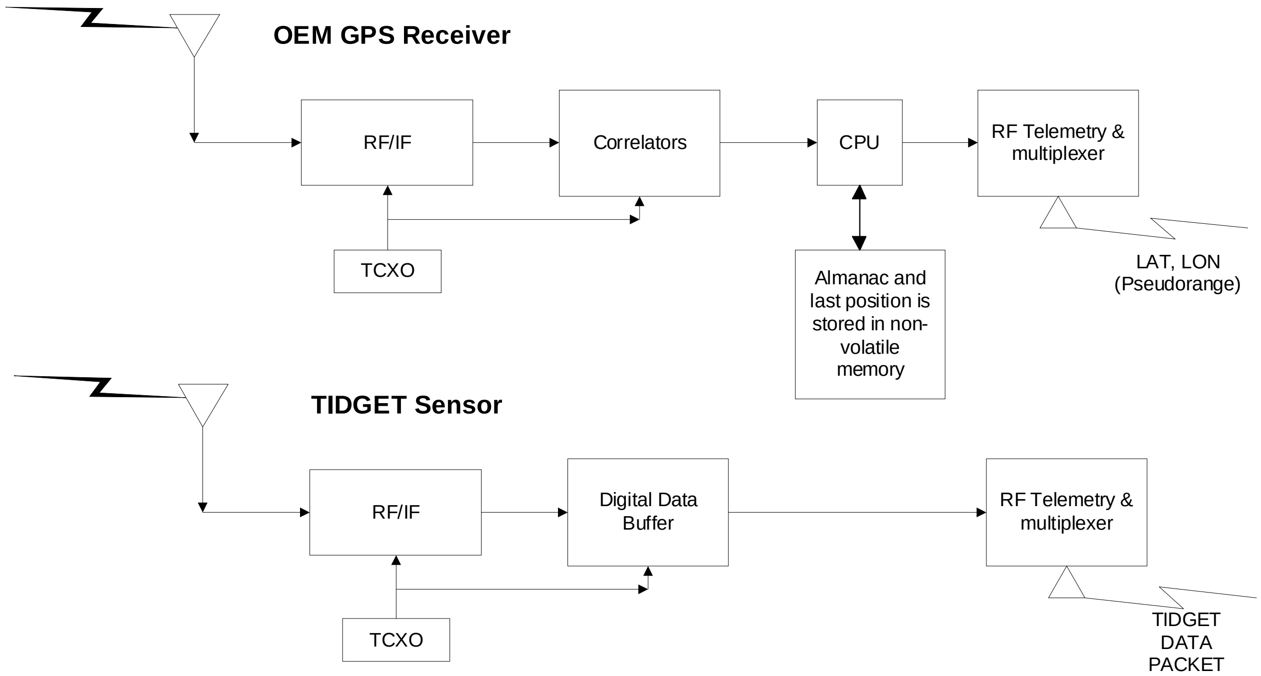


UHF Transmitter
(2.5 kg)

Computer
(1.7 kg)

Prior Software Defined Radios with GPS Processing

Networked GPS Positioning Solution

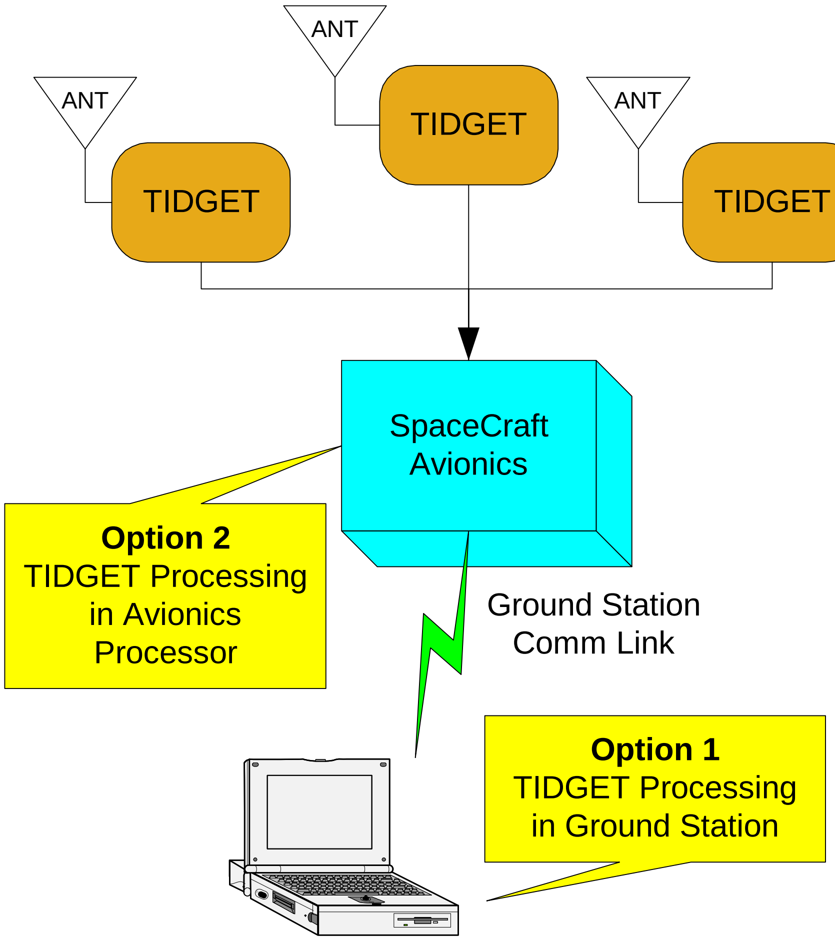


TIDGET "Tracking Widget" collects GPS data to be processed by Software Defined Radio

Space TIDGET Architecture

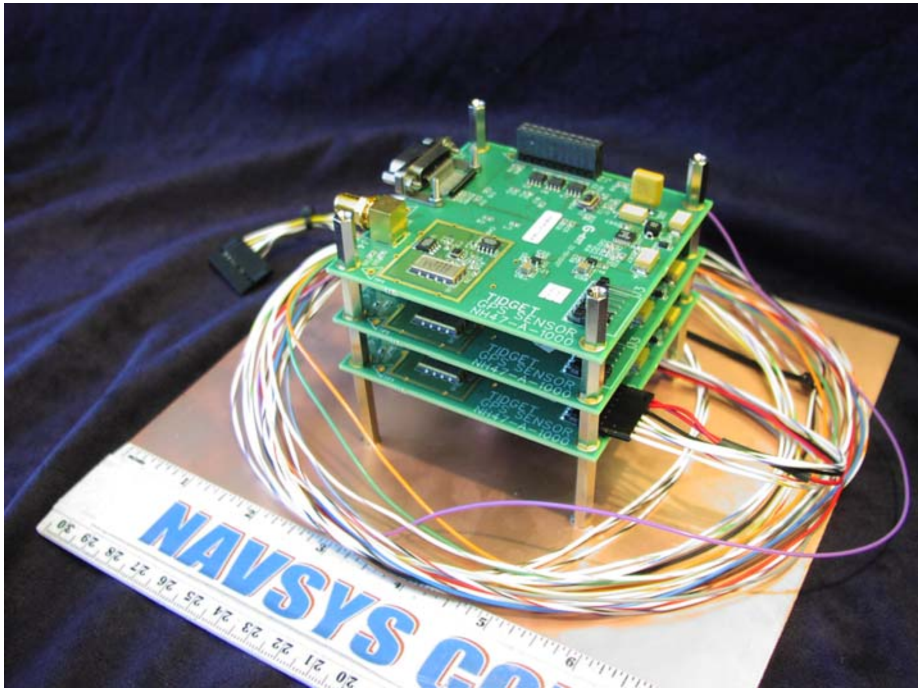
Advantages

- TIDGET sensor includes only hardened GPS RF electronics
- Multiple TIDGET sensors provide all-around visibility and attitude determination
- Processing performed using SDR in Ground Station or onboard Processor



Space TIDGET Hardware

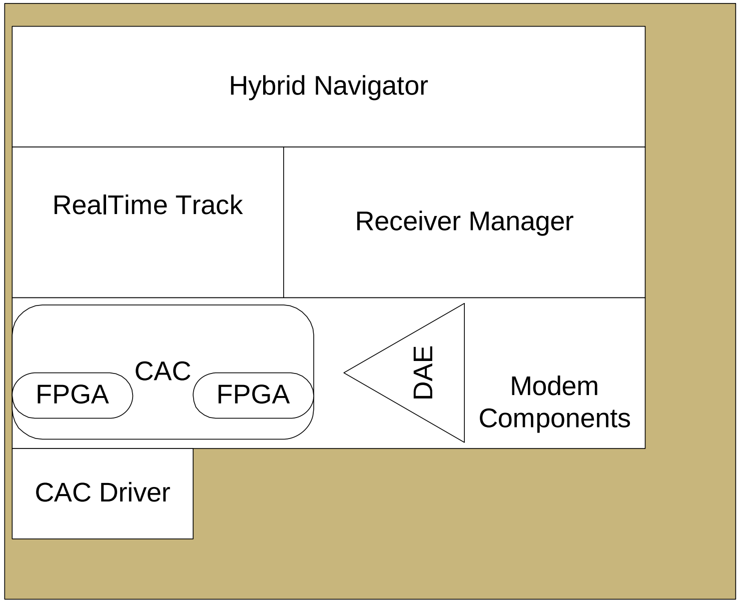
- Sensor stack
  - 3 TIDGET circuit boards (1 Master, 2 Slaves)
- Connectors
  - Avionics host (power, control, data)
  - GPS antenna
  - Stack-thru connector



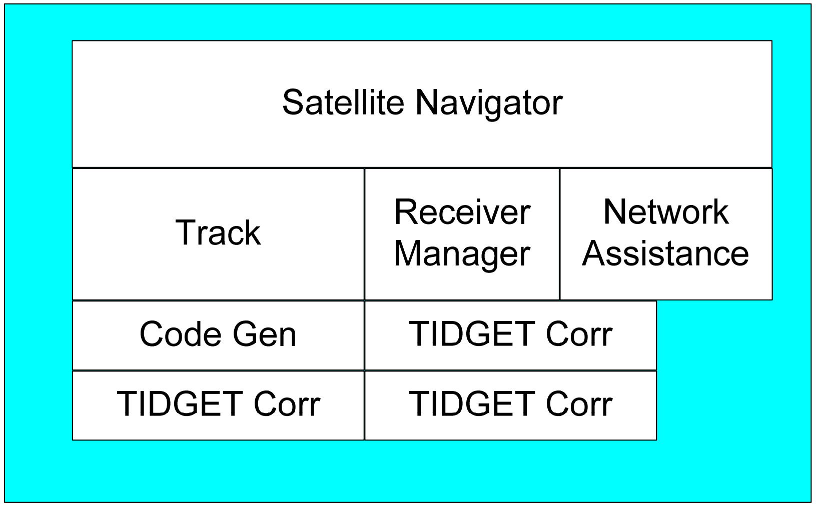
TIDGET Sensor Stack Features

- Low power Design
  - Circuitry powered on and off by CPLD logic
- Common Timing
  - Precise sync between units allows for both position and attitude determination
- Hardened electronics
  - Extended temperature range commercial parts
  - TCXO specified for high vibration/shock
- Built in redundancy through SDR processing

Conventional Software GPS vs TIDGET Processor



Software GPS Receiver
SW Components



TIDGET Processor
SW Components

GPS Signal Sampling & Correlation

<u>Conventional SGR</u>

- FPGA used to generate code and carrier
- Real-time search, acquisition and tracking
- Multiple channels used to handle different GPS satellite signals and Receiver RF inputs

<u>TIDGET Processor</u>

- Code generation performed in SW
- Uses SV orbit to preposition code/freq
- Only single set of code/carrier reference needed for all 3 TIDGET sensors

GPS Satellite Tracking

Conventional SGR

- Each individual channel independently tracks one GPS satellite and one RF input
- Generates Pseudo-Range (PR), Doppler and Carrier Phase (CPH) for each GPS SV/antenna pair

TIDGET Processor

- All 3 TIDGET sensors processed in parallel
- Tracking loops estimate composite SV Pseudo-range and Doppler and estimate delta-PR and delta-CPH for each sensor
- Improves reliability of lock detection and tracking through signal fades

GPS NAV Data Collection

Conventional SGR

- SGR demodulates NAV data to unpack GPS ephemeris
- Used to calculate GPS position and velocity

TIDGET Processor

- GPS ephemeris data obtained from ground network
- Can be uploaded daily or more frequently
- Also can improve accuracy using Precise GPS Ephemeris (PGE)

GPS Navigation

Conventional SGR

- Uses Kalman Filter or Least Squares to estimate position and velocity (stand-alone)
- Hybrid GPS/inertial solution calibrates error on inertial sensors

TIDGET Processor

- Navigation filter estimates position, velocity and attitude of spacecraft orbit
- State propagation performed using orbital dynamics rather than inertial navigation unit

Advantages of Space TIDGET SDR Approach

- TIDGET sensors are lighter, smaller and lower power than full GPS receiver
- TIDGET solution offers “on-demand” location and queued processing for resource sharing
- TIDGET/SDR architecture offers an inexpensive, modular positioning system
- Flexibility of SDR TIDGET processing optimizes GPS performance for challenged space environment

Backup

Functions performed by SGR SW Components

Component	Functions Performed
Modem - DAE	RF/Digital Conversion
Modem - FPGA	Code Generation, Correlation & Carrier Mixing
CAC Driver	FPGA interfaces (e.g. NCO settings and Correlator Outputs)
Real-Time Track	Real-Time Code & Carrier Tracking loops and NAV data demodulation
Receiver Manager	GPS SV position calculation and SV selection
Hybrid Navigator	Position/Velocity Calculation (Least Squares or Kalman Filter)

Functions performed by TIDGET Processor Components

Component	Functions Performed
Code Gen	Code & Carrier Generation using Code phase/Doppler Prepositioning
TIDGET Corr	Code & Carrier correlation of TIDGET data
Track	Assisted Code & Carrier Tracking loops for all TIDGET sensors
Receiver Manager	GPS SV position calculation and SV selection Code phase/Doppler Prepositioning with GPS/Satellite position/velocity
Network Assistance	Receives GPS NAV data through Network
Satellite Navigator	Position/Velocity Calculation (Orbital Kalman Filter)