Tracking non-cooperative low earth orbit objects via multi-static radar using GNSS satellites

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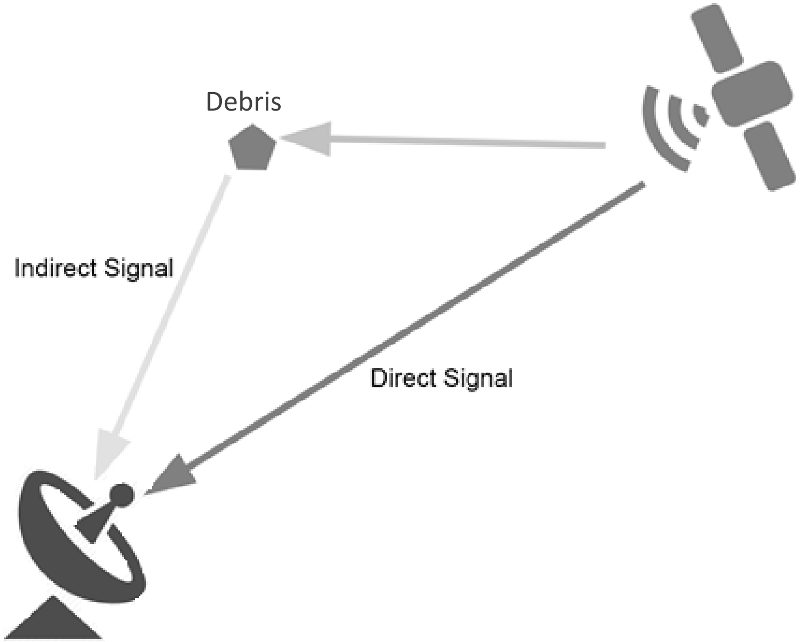
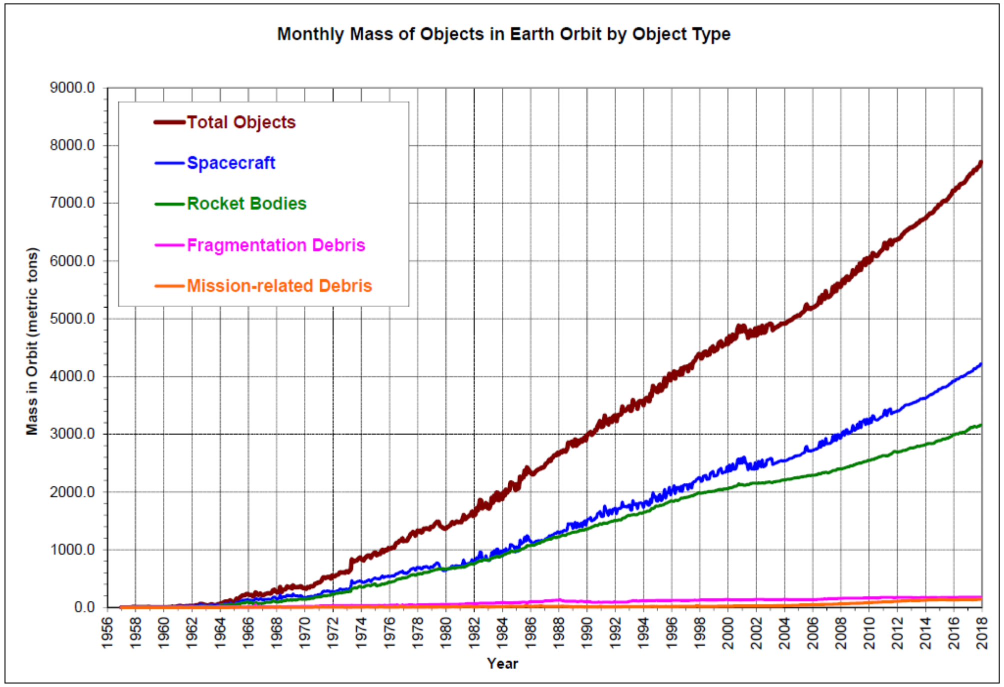


Photo credit: European Space Agency (ESA)

Space Situational Awareness

- Detecting hazards
- Space based services become essential
- Any shutdown or loss to space assets will seriously effect our commercial and civilian activities



[1] Anz-Meador, P. (2018). Orbital debris quarterly news.

Space Debris

- Size and amount [1]
  - 29,000 (larger than 10cm)
  - 750,000 (1 to 10cm)
  - More than 166 million (smaller than 1cm)
- Moving at a speed of 7.6 km/s approximately in LEO

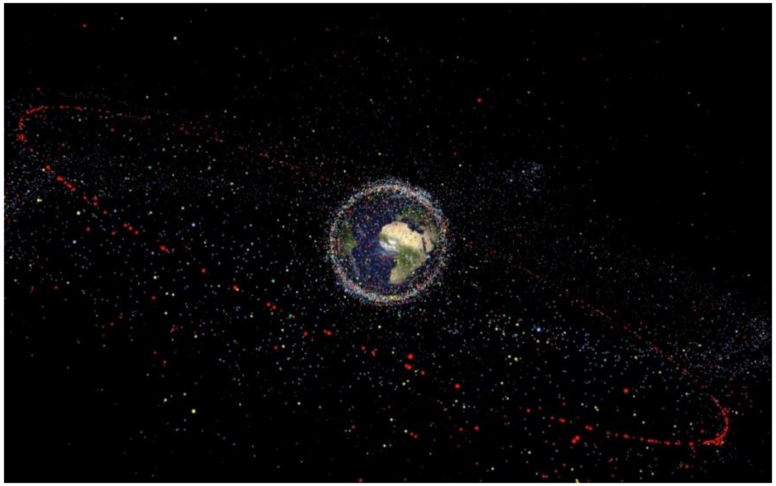


Image source: http://www.esa.int/spaceinimages/Images/2013/04/Distribution_of_debris

[2] http://www.esa.int/Our_Activities/Operations/Space_Debris/Space_debris_by_the_numbers

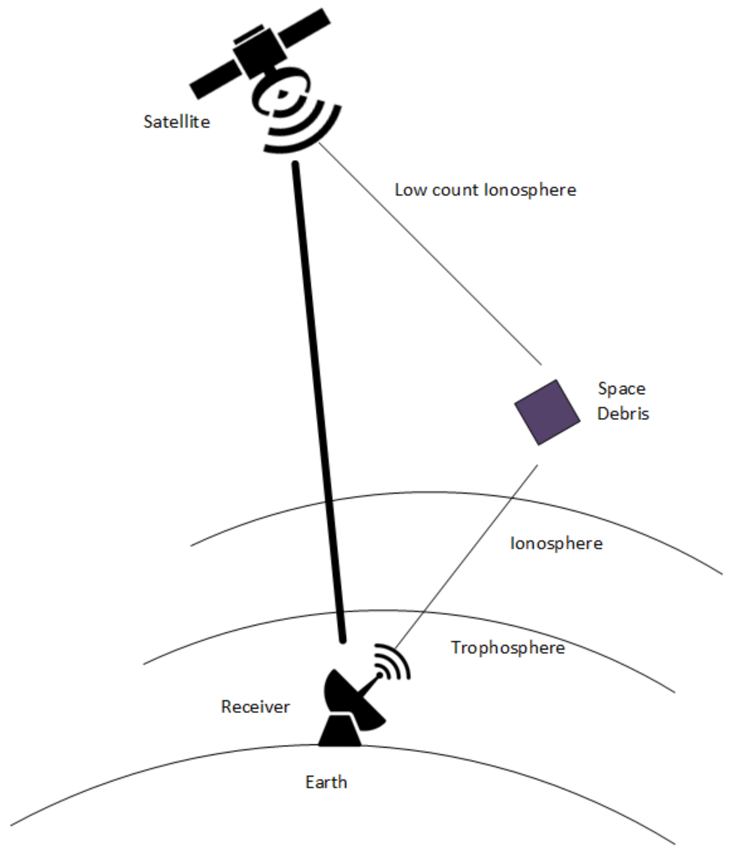
Space Debris is a Problem

- Risk of collision
  - Threat to active satellites
  - Future space missions in danger
- Shortens satellite life due to fuel burn to avoid collisions
- Collisions resulting more debris which in turn increase chance of collision

Bistatic Radar Tracking

- GPS Satellites as possible transmitters
  - Transmits from MEO (~20,000)
  - Well monitored signal and stable
  - L-band, which minimises atmospheric interaction

- Direct vs Indirect
  - GPS signal as direct
  - Debris-scattered as indirect



[3] Benson CR, (2014) Enhancing space situational awareness using passive radar from space based emitters of opportunity, Military Communications and Information Systems Conference (MilCIS), vol., no., pp.1,5, 11-13 Nov. 2014 doi: 10.1109/MilCIS.2014.7002727

Challenges?

- Weak-Strong problem
  - Strong direct signals are possible interferers

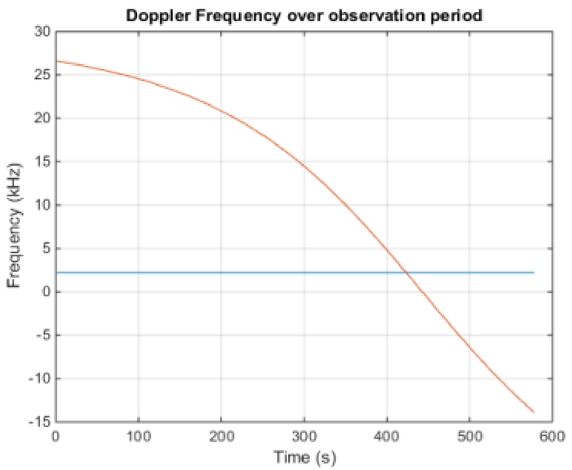
- Very low power debris scattered signal
  - Very long coherent integration needed to get sufficient gain

- Signal processing
  - Long integration costs additional processing burden

[4] Mahmud, M. S., Lambert, A., & Benson, C. (2015, July). Predictability of GNSS signal observations in support of Space Situational Awareness using passive radar. In Proceedings of the International Global Navigation Satellite Systems Society IGNSS Symposium 2015, held 14-16 July, 2015, Outrigger Gold Coast, Australia. Paper no. 24, 13 pages.

Detecting Debris-Scattered Weak Signal

- Weak-Strong problem
  - Strong counter signals
  - Detection of weak signal requires high correlation gain of desired signal
  - Correlation rejection for non-desired signals is also required

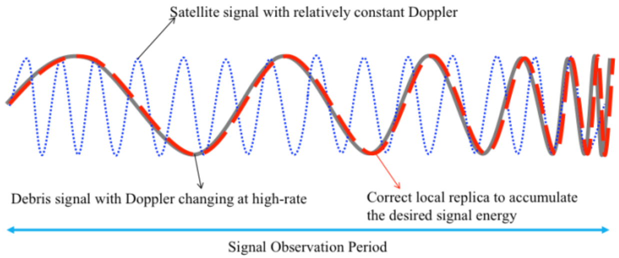


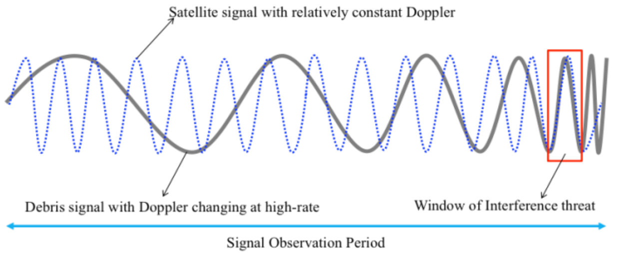
- Debris scattered signal has a much higher Doppler and rate of change over the observation period fairly quickly in compare to direct signal
  - Maximum Doppler Shift for direct signal ±5kHz
  - For Debris-scattered Maximum Doppler Shift is **±37kHz**

[5] Mahmud, M. S., Qaisar, S. U., & Benson, C. (2016, April). Weak GPS signal detection in the presence of strong signals with varying relative Doppler and long integration gain. In Position, Location and Navigation Symposium (PLANS), 2016 IEEE/ION (pp. 1015-1020). IEEE.

Detecting Debris-Scattered Weak Signal

- The local replica is generated following the predicted trajectory
- Local replica matches the desired signal
- Strong counter signals experience change of Doppler offset during correlation

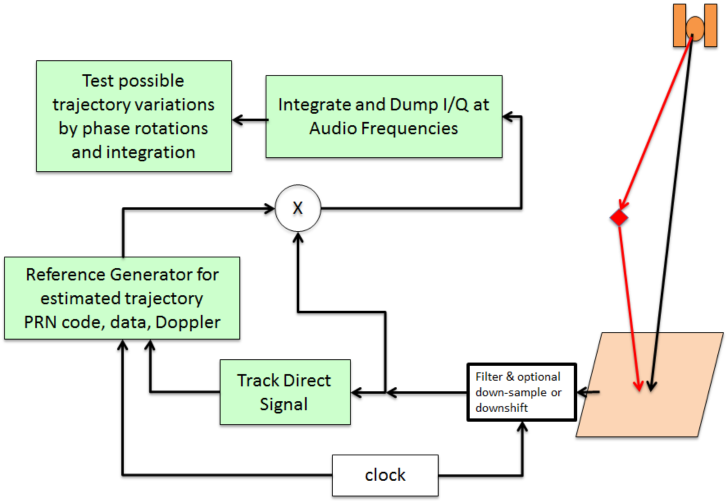




[6] Mahmud, M. S., Qaisar, S. U., & Benson, C. (2016, December). Efficient Processing of Long Duration GNSS Signal Observations for Space Debris Tracking. In Proceedings of the International Global Navigation Satellite Systems Association, IGNSS Conference 2016, held 6-8 December, 2016, Colombo Theatres, Kensington Campus, UNSW Australia . Paper no. 12, 12 pages.

Signal Processing

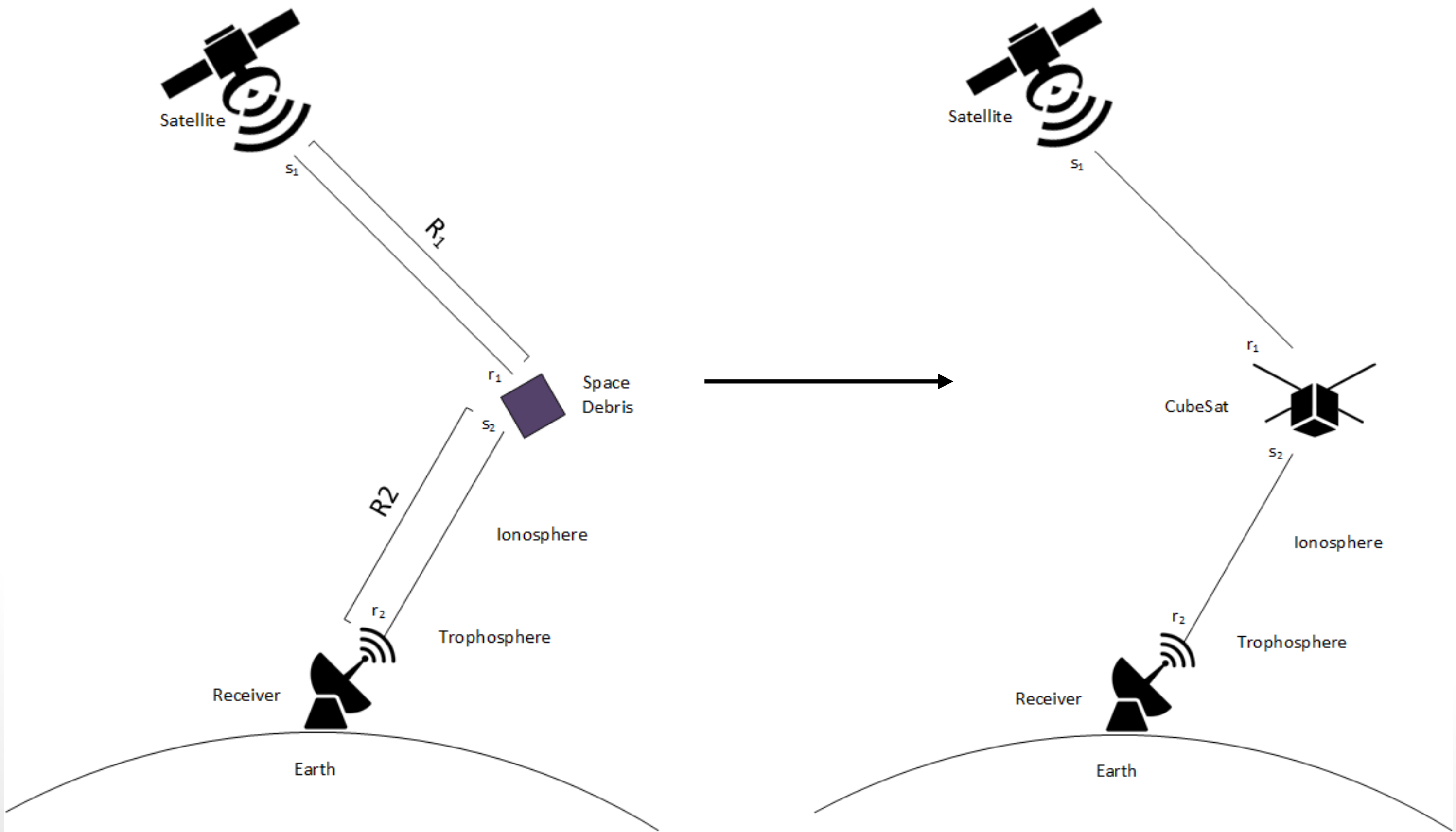
- Processing should be done in stages to minimise the processing cost of multiple possible track deviations
- Receiver generates replica for expected signal
  - With PRN, data and Doppler shifted in complex domain
- Integrate and Dump (I&D)
  - Down shifted to audio-rate signal
  - To minimize phase error
- Test possible trajectories at low cost



[7] Mahmud, M. S., Qaisar, S. U., & Benson, C. (2016, April). Affordable processing for long coherent integration of weak debris-scattered GNSS signals with inconsistent Doppler. In Systems Conference (SysCon), 2016 Annual IEEE (pp. 1-6). IEEE.

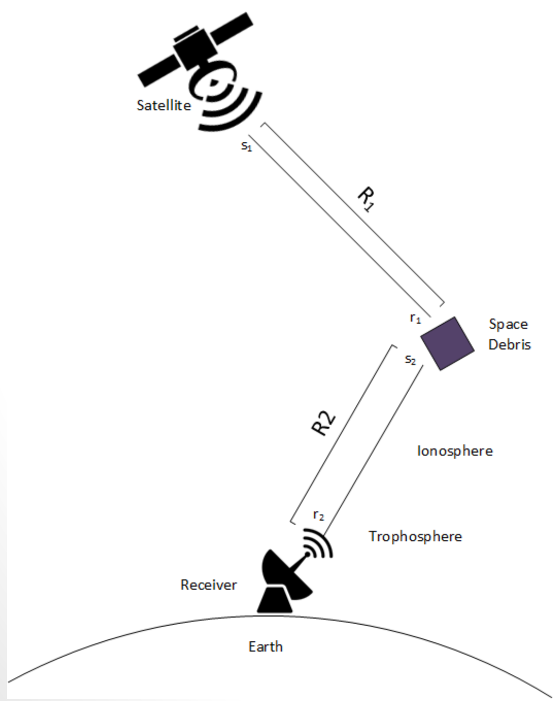
In-orbit Demonstration

- LEO CubeSats carrying a GPS repeater
- In-orbit Demonstration
  - Verify proposed technique
  - Helps modelling LEO debris orbit determination

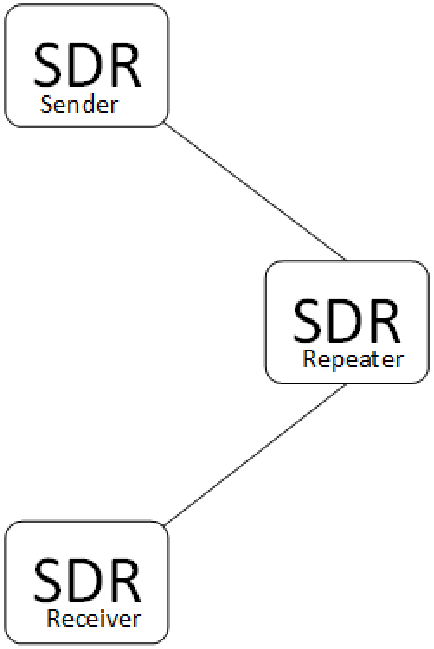


Concept Demonstration

- Software Defined Radio (SDR)
  - Flexible
  - Cost efficient



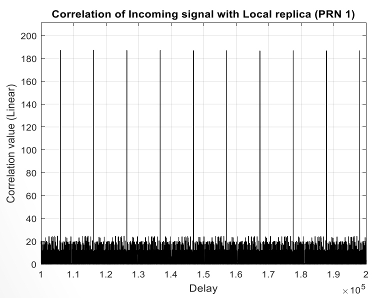
Lab demonstrations



Experimental results

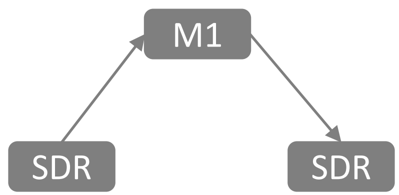
SDR – SDR

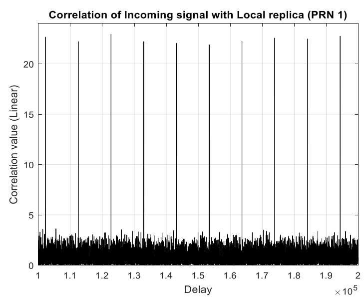
- ❑ PRNs (Detected)
- ❑ Modulated Signal (Detected)
- ❑ GPS Signal (Detected)



SDR-M1-SDR

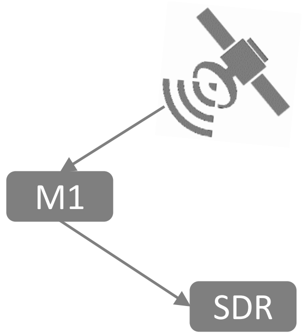
- ❑ PRNs (Detected)
- ❑ Modulated Signal (Detected)
- ❑ GPS Signal (Detected)

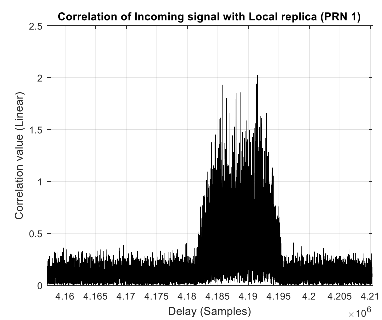




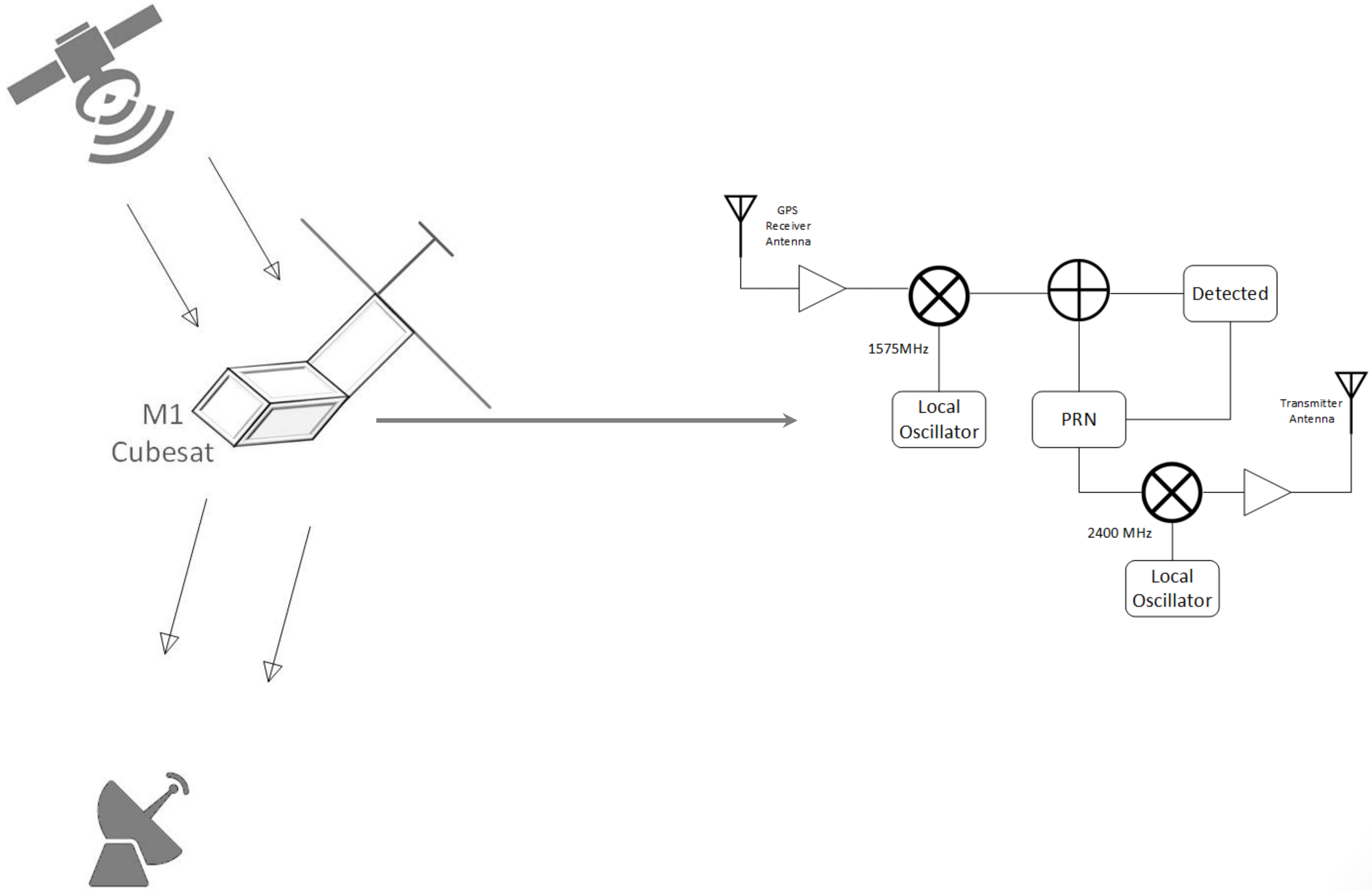
GPS - M1 - SDR

- ❑ Not detected





Improved SNR through Regeneration



Plan for Technique Validation

- M1 CubeSat has SDR that received GPS
- SDR can also transmit in 2.4GHz band
- SDR can retransmit GPS L1 signal onto 2.4GHz
  - Includes Doppler shift from both reception and (scaled for frequency) transmission
- Much stronger
- 2W radiated power, 0-5dB antenna gain depending on pointing
- Regeneration is via digital baseband
  - Could also insert pilot tone to make spacecraft tracking easy
- Ideal engineering development model
- M1 has a retroreflector (laser ranging is possible too)

Conclusions

- Substantial processing gain is required to detect the extremely low power debris-scattered GNSS signals.
- Long duration integration is achievable
- Affordable processing technique
- Realistic experiments to verify proposed technique