Pseudolite System in 2414.28 MHz or in 2483.5-2500 MHz Band

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SFCG Recommended Spectrum for Lunar Pseudolite & Satellite Systems in S Band

- SFCG proposes two recommendations:
  - Frequencies for lunar region (SFCG 32-2R6)
  - Protection of Lunar S Band for PNT (SFCG 43-1)
- Compliance of both the recommendations is mandatory to ensure protection of lunar in-situ PNT.
- LunaNet Augmented Forward Service (AFS) is in the 2.4835-2.5 GHz band.
- Systems need to be compatible with the LunaNet AFS and other systems under development.
- Feasibility is being explored with SFCG for interoperable & compatible systems for lunar PNT.

SFCG Recommendations for Lunar S Band Spectrum Transmissions

	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
Wireless (surface to surface)	2400-2480 MHz	EVAs	Voice/Data (Comm. & PNT)/ video	3 Mbps (Max., rate will drop as distance increases)	2480-2483.5 is considered as Guard Band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT Band is necessary
		Rover-LCT	Voice/Data (Comm. & PNT)/ video	30 Mbps (Max.)	
		EVAs-Landers, Rover	Voice/Data (Comm. & PNT)/ video	3 Mbps (Max.)	OOB Filtering of the harmonics falling in 2.8 to 4.99 GHz band (secondary RAS) is necessary in the SZM
In-situ PNT (Orbit to surface)	**2483.5-2500 MHz (LO to LS)**	**Rover-Orbiter, EVAs-Orbiter, surface Hubs (Hab, Lander, etc.)-Orbiter**	**PNT-SAR Forward messages**	**500 bps**	**Limited one-way PNT transmissions from LO to LS and LO to LLO (Low Lunar Orbit)**
	2483.5 to 2500 MHz (LO to LS)				
Wireless (surface to surface)	**2503.50 – 2655 MHz**	**EVAS**	**Voice/Data (Comm. & PNT)/ video**	**100 Mbps (Max.)**	**2500-2503.50 MHz is considered as Guard Band. 2480-2483.5 is considered as Guard Band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT Band is necessary**
		Rover-LCT			
		EVAs-Landers, Rover			

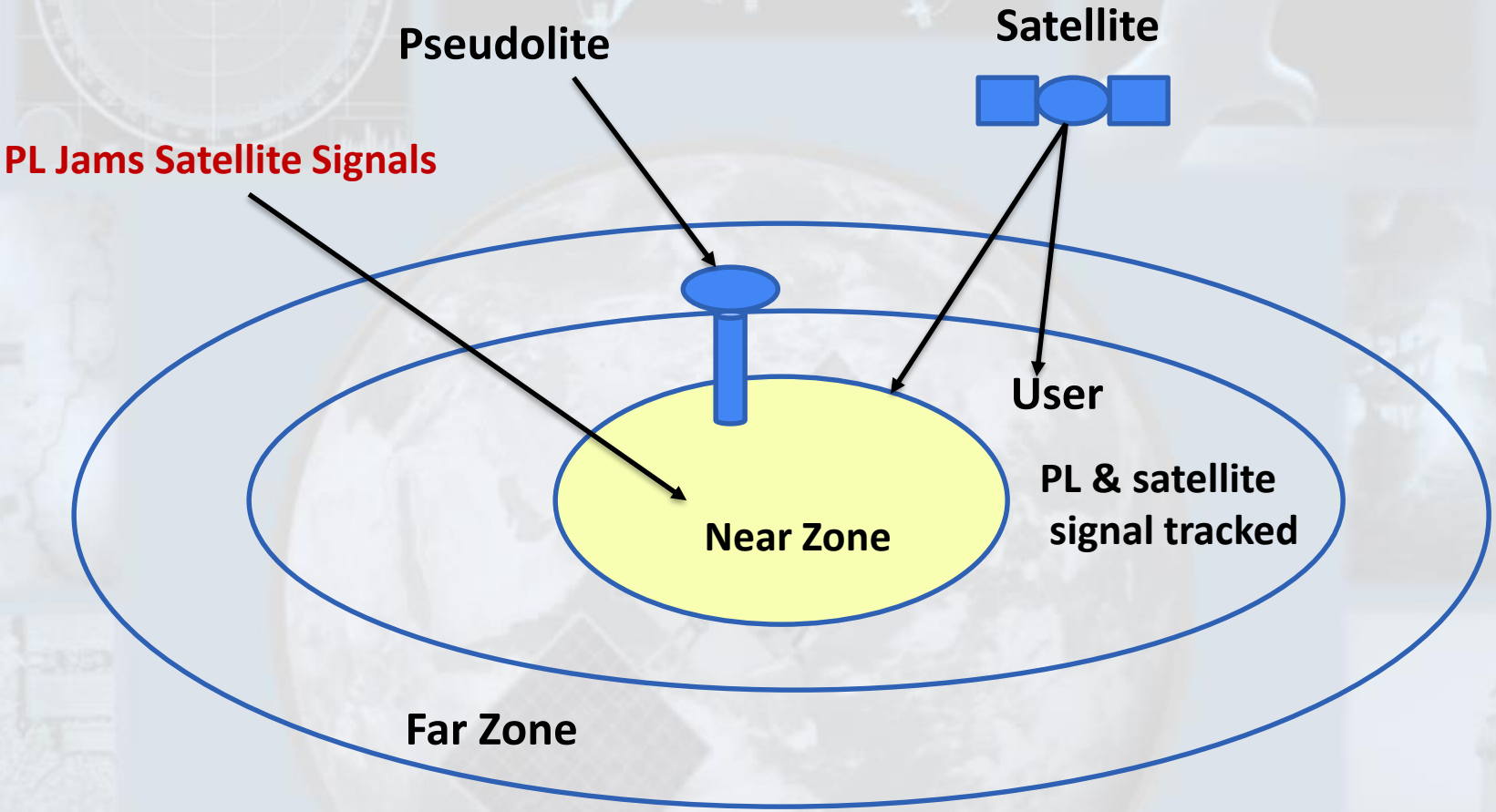
- EVA-Extra Vehicular Activity
- LO-Lunar Orbit
- LS- Lunar Surface
- LCT- Lunar Communication Terminals
- OOB- Out Of Band

Ref: Luc Issler et al. , ION 2025

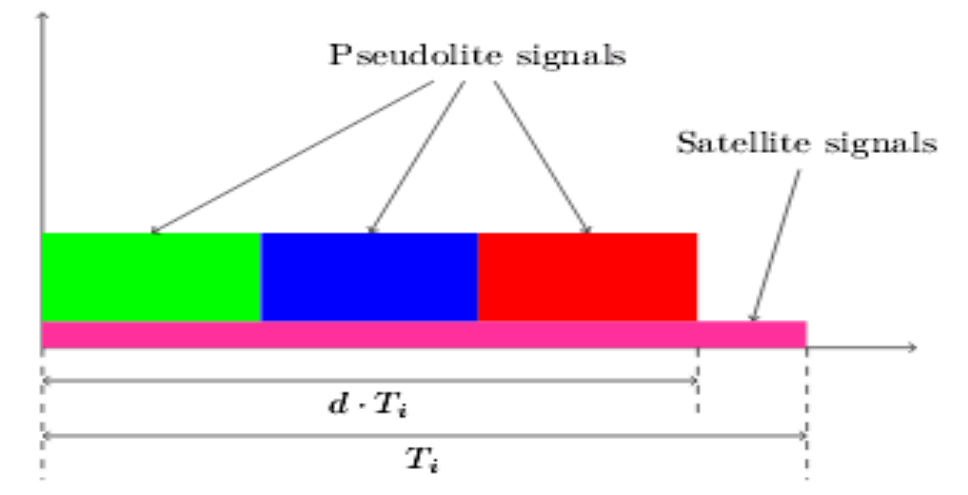
Choice of Frequency for Lunar Pseudolite & Satellite Systems

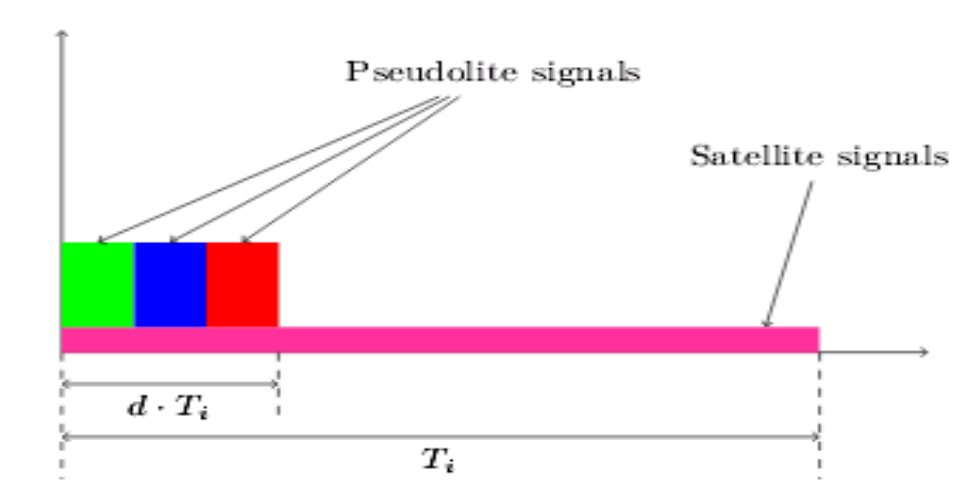
Frequency	
2414.28 MHz	Frequency used in Pseudolite System for Re-usable Launch Vehicle (RLV).
2491.005 MHz	Frequency used for Lunar PNT system developers & is the most likely candidate for Pseudolite & Satellite based Lunar PNT
2492.028 MHz	NavIC S-Band frequency

Near-Far Problem with Pseudolites



Pulsing Scheme to Avoid Near-Far Problem





Pulse Characteristics

Pulse duty cycle	Under study and to be complaint with SFCG recommendations

System Architecture

- Space Segment in Lunar orbits
  - Signal Structure similar to Luna-Net AFS
- Pseudolites on Lunar surface
  - Pulsed CDMA
  - Band: 2483.5 – 2500 MHz (SFCG)
- Hybrid PNT solution
  - Best accuracy mainly impacting VDOP
- Important PL parameters impacting co-existence as per SFCG recommendations
  - Pulse width
  - Repetition Rate
- As per Issler et al, “Ensuring Lunar and Martian In situ PNT Coexistence with Surface Wireless by Respecting SFCG Recommendations” paper:
  - Tolerable duty cycle
    - <= 10.9% (with blanking)
    - <= 5.6% (with AGC)
  - => For 2ms integration time (500 sps, LunaNet AFS), tolerable aggregate pulse duration = 100us (5% duty cycle)
- Pseudolite Network configuration respecting SFCG recommendations being worked out as constraints on duty cycle impact the number of pseudolites, thus service region.

Conclusions

- After careful consideration of SFCG Recommendations & LunaNet & other lunar system deigns, it is preferred to have Pseudolite & Satellite Systems to be in lunar in-situ band of 2483.5-2500 MHz, identified as lunar PNT band.
- Pseudolite network configuration along with Near-far effect, inter and intra system analysis with suitable code designs & pulse blanking methods are under study to comply the system as per SFCG recommendations.

Thank You