A simulator to compute interference from lunar surface wireless to lunar PNT: Architecture and Results.

Jean-Luc ISSLER*, Jacques SOMBRIN**, Philippe PAINBLANC**
Antoinette LABEYRIE*, Robin QUINTART*, Jean PLA*, ROMAIN DESPLATS*

* CNES ** TÉSA LABORATORY

2ND JOINT ICG-IOAG MULTILATERAL CISLUNAR PNT WORKSHOP

VIENNA – 12TH FEBRUARY 2026

APPROPRIATE BAND FOR LUNAR PNT: 2483.5-2500 MHZ

The 2483.5-2500 MHz band:

- **Has been chosen for Lunar in-situ PNT**: only band recommended by **SFCG** (Space Frequency Coordination Group) for Lunar In-Situ PNT (following initial proposal by CNES).
- Is the **only GNSS band** recommended by SFCG for radiocommunications from Martian orbit to Martian surface, (initial CNES proposal).
- Is adapted to **protect Radio Astronomy** in the SZM contrary to any part of the other GNSS bands used on Earth. Both RNSS L and C bands are a threat for R.A. in the SZM.

SFCG issued two recommendations concerning the protection of lunar in-situ PNT in the 2483.5-2500 MHz band:

- **Recommendation SFCG 32-2R6:** "Communication and Positioning, Navigation, and Timing Frequency Allocations and Sharing in the Lunar Region", also called "Freqs for Lunar Region".
- **Recommendation SFCG 43-1:** "Protection of In-Situ Lunar Region Positioning Navigation, and Timing (PNT) Services in the 2483.5-2500 MHz Frequency Band from Unwanted Emissions From Lunar Surface Communication Systems", also called "Protection of Lunar S-band PNT".

SFCG: Space Frequency Coordination Group

EXTRACT OF SFCG REC 32-2R6, RELATED TO LUNAR PNT BANDS, SERVICES AND LIMITATIONS

Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
8.0 Earth based GNSS to Lunar Orbit and Lunar Surface	1164-1215 MHz 1215-1300 MHz 1559-1610 MHz	Lunar Orbiters, Surface hubs (Hab, Landers, Rovers, etc.), LCT	PNT	50 bps	Limited to transmission of signals from GNSS Constellations in the Earth region

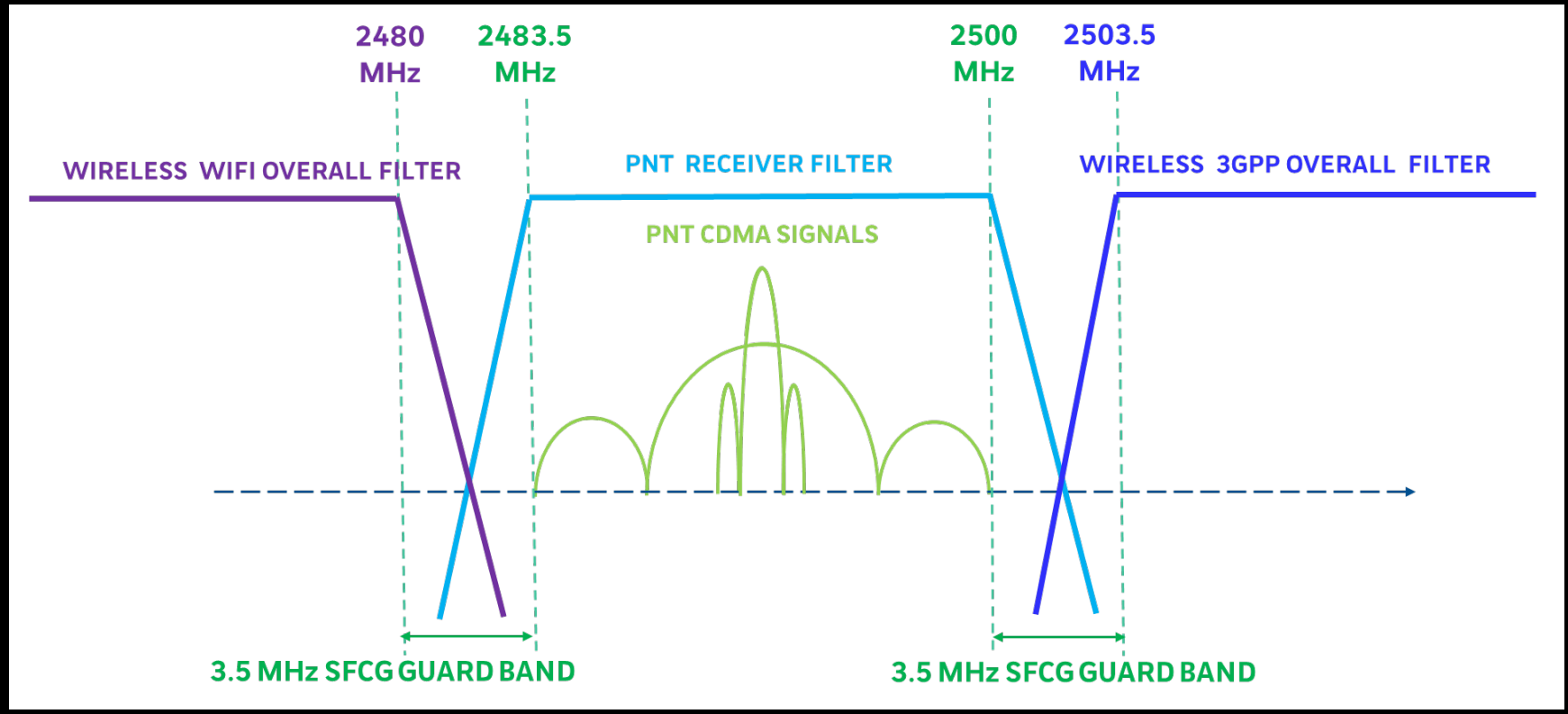
Link Type	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
9.0 In-situ Lunar based PNT to Lunar Orbit and Lunar Surface	2483.5-2500 MHz (LO-LS) 2483.5-2500 MHz (LO-LO)	Rover-Orbiter, EVAs- Orbiter, Surface hubs (Hab, Landers, etc) – Orbiter	PNT, SAR Forward Messages	500 bps	Limited to one way PNT transmissions from LO to LS and LO to LO, with the in-situ lunar based PNT service provider at a higher altitude than the lunar orbiting user spacecraft receiving the PNT signal

LCT: Lunar Communications Terminals
LO / LS: Lunar Orbit / Lunar Surface
SAR: Search And Rescue

EXTRACT OF SFCG REC 32-2R6 RELATED TO LUNAR PNT
GUARD BANDS AND FILTER REQUIREMENT

	Frequency Band	Users	Service Type	Typical Data Rate per User	Limitations
Wireless (Surface to Surface)	2.400 – 2.480 GHz	EVAs	Voice/data (comm & PNT)/ video	3 Mbps (max, rate will drop as distance increases)	2480-2483.5 MHz is considered as the 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 harmonic falling in 4.8-4.99 GHz band (secondary RAS) is necessary in the SZM
In-situ PNT (Orbit to Surface)	2483.5-2500 MHz (LO-LS)	Rover-Orbiter, EVAs-Orbiter, Surface hubs (Hab, Landers, etc) – Orbiter	PNT, SAR Forward Messages	500 bps	Limited to one way PNT transmissions from LO to LS and LO to Low Lunar Orbit (LO to LLO)
	2483.5-2500 MHz (LO-LS)				
Wireless (Surface to Surface)	2.5035 – 2.655 GHz	EVAs	Voice/data (comm & PNT)/video	100 Mbps (max)	2.500-2.5035 MHz is considered as the guard band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary.
		Rover - LCT			
		EVAs – Landers, Rover			See Note 9 of Table 1

SFCG REC 43-1 PFD LIMIT IN PNT BAND



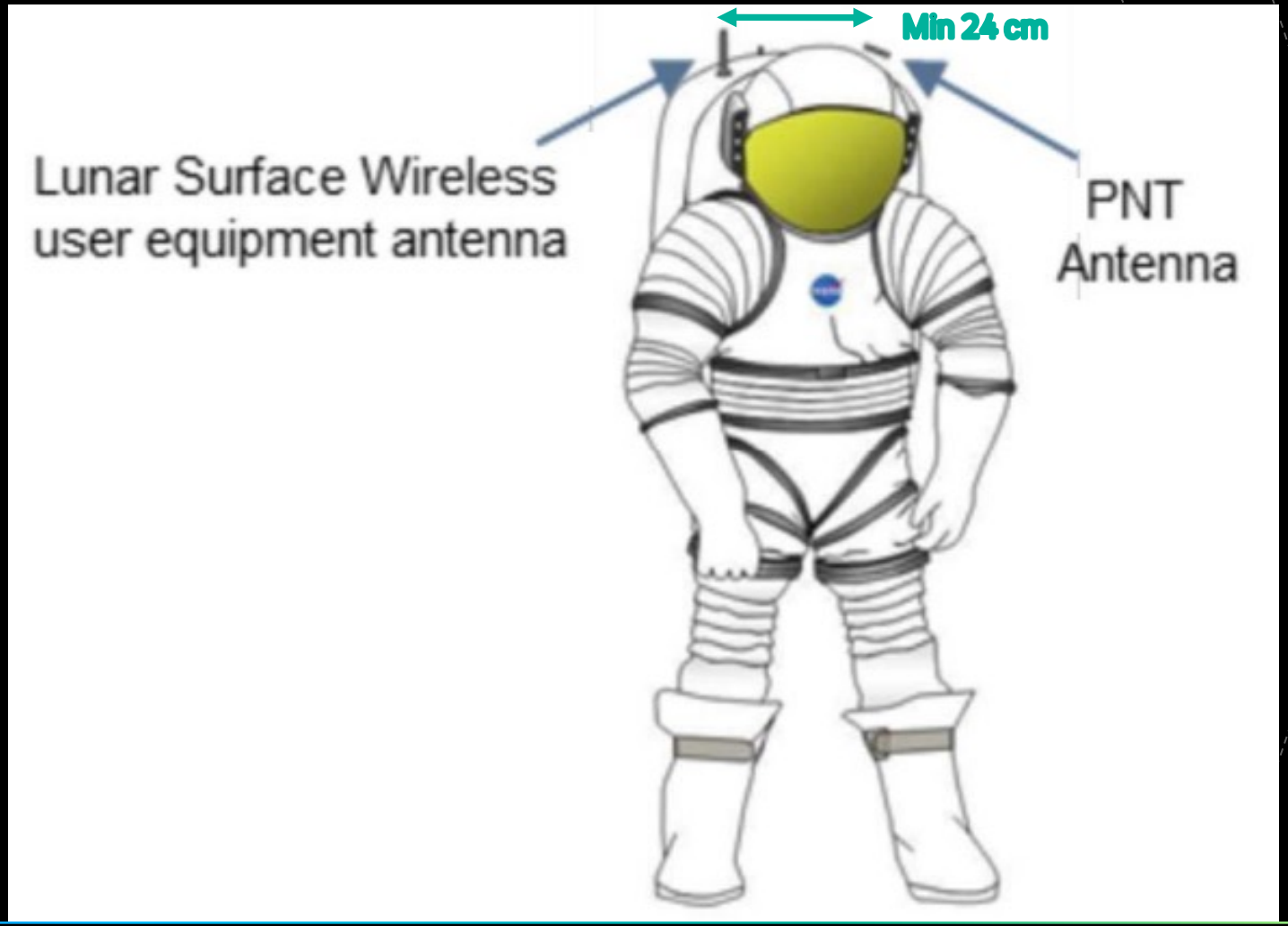
SFCG REC 43-1 recommends that the maximum PFD of a lunar wireless system in the 2483.5-2500 MHz band is limited to **-121 dBW/m²/MHz** at the input of the receiver PNT antenna.

PFD: Power Flux Density

LUNAR ASTRONAUT SUIT WITH BOTH WIRELESS AND PNT ANTENNAE

SFCG REC 43-1 considers that the PNT antenna is typically located at least **0.24 meters** from the lunar surface wireless user equipment antenna in order to be in the antenna radiation far field.

The PFD limit of **-121 dBW/m²/MHz** recommended by SFCG REC 43-1 at the input of the receiver PNT antenna shall be respected for this distance of 24 cm.



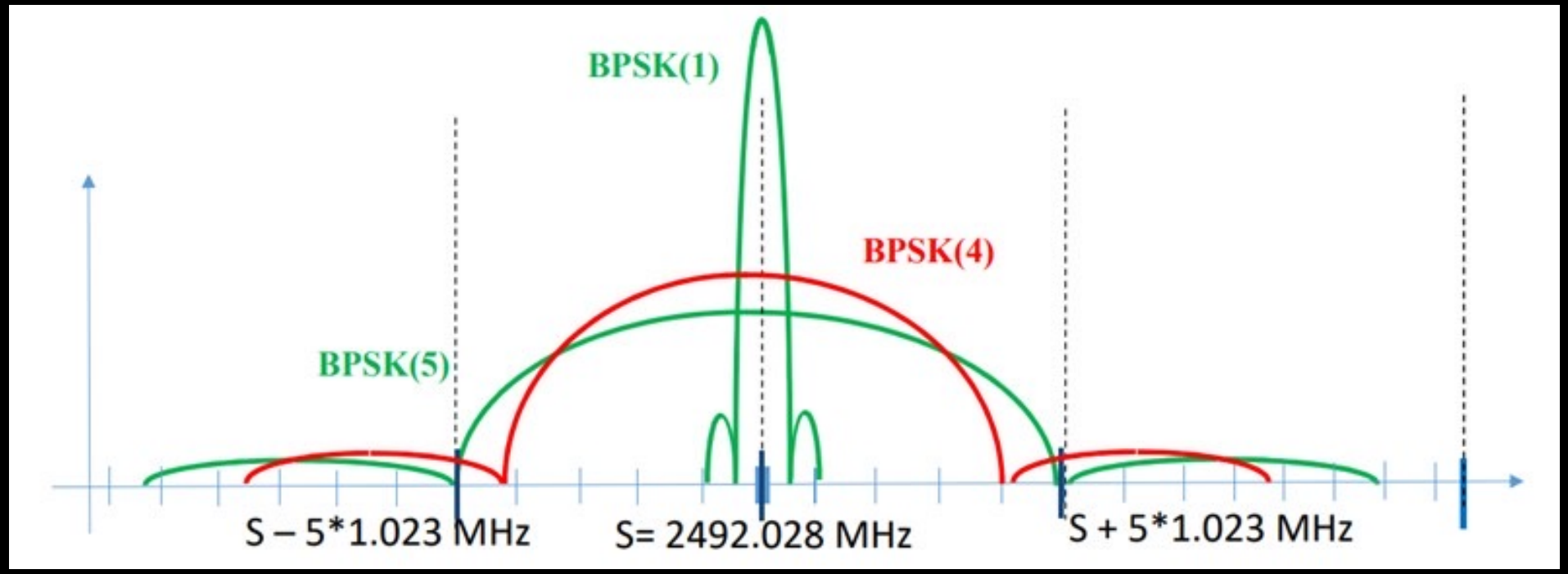
PFD: Power Flux Density

SFCG TEXTS TO PROTECT LUNAR PNT FROM WIRELESS LINKS

Type of lunar Link, related band	SFCG REC	Text of the REC related to protection of PNT, applied to the type of lunar link
Wireless, 2400-2480 MHz	32-2R6, Recommend **1**	2.480-2.4835 MHz is considered as the guard band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary.
Wireless, 2503.5-2655 MHz	32-2R6, Recommend **1**	2503.5-2655 MHz is considered as the guard band. Sufficient OOB filtering to protect the 2483.5-2500 MHz LO-to-LS PNT band is necessary.
Wireless, 2400-2480 MHz and 2503.5-2655 MHz	43-1, Considering **f**	lunar surface communications system deployments may require additional RF filtering to reduce the unwanted emission levels in the 2 483.5 – 2 500 MHz band;
2400-2480 MHz and 2503.5-2655 MHz, and PNT	43-1, Considering **g**	the PNT antenna is typically located at least **0.24 m** from the surface wireless user equipment antenna to be in the antenna radiation far field, and at least **17 m** from the surface wireless base station antenna;
Wireless, 2400-2480 MHz and 2503.5-2655 MHz	43-1, Considering **h**	unwanted emissions from the surface wireless system typically have bandwidths greater than 1 MHz, and will result in wideband continuous interference rather than pulsed interference to the lunar PNT receiver;
Wireless, 2400-2480 MHz and 2503.5-2655 MHz	43-1, Considering **i**	analysis of interference from unwanted emissions from a lunar surface wireless system to the lunar PNT receiver may need to consider the aggregate effect of four or more wireless transmitters;
2400-2480 MHz, 2503.5-2655 MHz, and PNT	43-1, Recommend **1**	the maximum aggregate unwanted emissions into the frequency range 2 483.5 – 2 500 MHz from each lunar surface wireless system is limited to **-121 dB(W/m^2/MHz)** at the input of the PNT receive antenna
PNT, 2483.5-2500 MHz	43-1, Recommend **2**	lunar surface PNT receiver RF front end operating in the 2 483.5 – 2 500 MHz band have sufficient filtering of signals in the adjacent bands to avoid saturation.

The minimum guard bands of 3.5 MHz between wireless and PNT bands are a **minimum** to respect. If there is no other way but to increase this guard band to ensure RF compatibility with viable filters, the guard band shall be increased as much as needed.

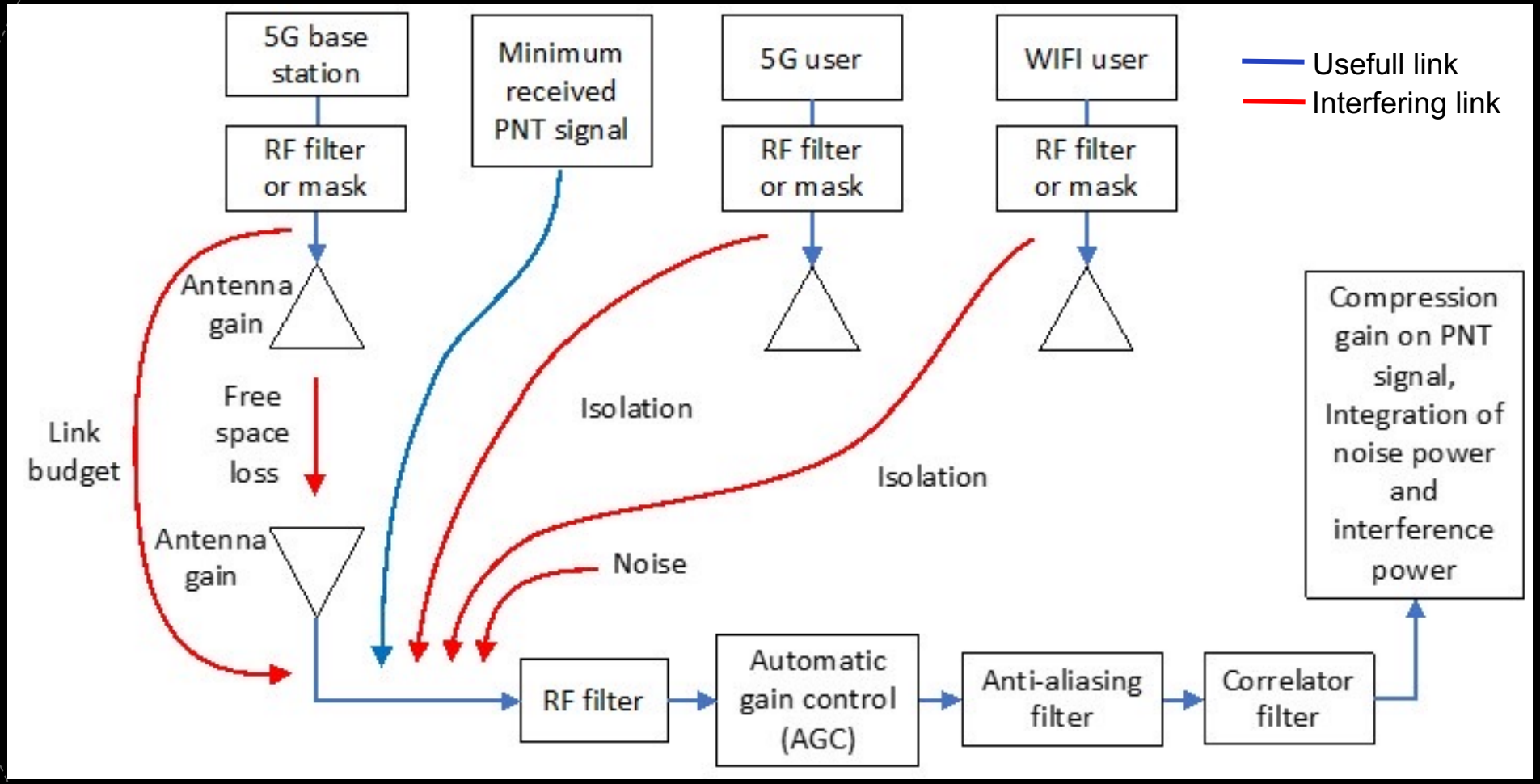
LUNAR IN-SITU PNT SPECTRA WITH LUNANET AFS IN GREEN AND ASSUMED BASELINE CHINESE LUNAR PNT IN RED



AFS lunar PNT data:

- Minimum received power levels are -166 dBW for I and Q each, (5° elevation, at PNT receiver antenna input on lunar surface).
- Transmitted power is evenly split between I and Q components.
- Data symbol rate is 500 sps.

TÉSA WIRELESS TRANSMITTERS TO LUNAR PNT RECEIVER INTERFERENCE MODEL



This model has been used by CNES to contribute to the SFCG REC 32-2R6 and REC 43-1

C/NO DEGRADATION OF A LUNAR IN-SITU PNT BPSK(5) SIGNAL RECEIVED BY AN ASTRONAUT

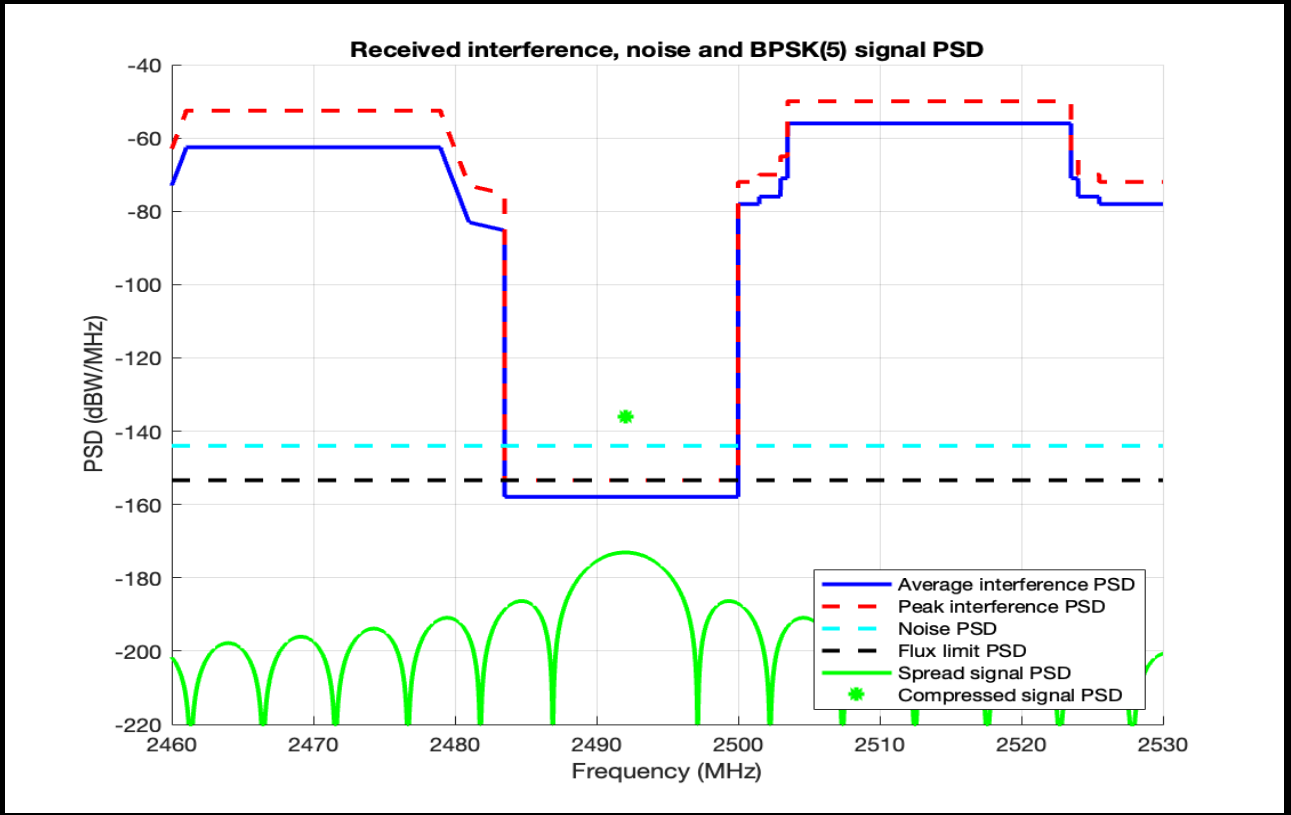
wireless transmitters configuration	BPSK(5) Peak C/No degradation	BPSK(5) Average C/No degradation
Transmitter masks for WIFI and 5G transmitters, no filter at the wireless transmitter output, no PFD limit in the PNT band	67.3 dB	60.6 dB
Measured PSD values for 5G user equipment Tx and mask for WIFI Tx, no filter at the wireless transmitter output, not any PFD limit in the PNT	61.2 dB	51.3 dB
WIFI and 5G user equipement interference masks and PFD limit. Average sum of interferences is lower due to the considered activity of both transmitters, 25% for the 5G user equipment and 10% for the WIFI.	36.8 dB	30.7 dB
WIFI and 5G user equipement interference masks and PNT Rx RF filters	13.1 dB	7.4 dB
Measured interference mask for the 5G Tx, WIFI mask, 3.5 MHz guard band, oversamplig of 2 samples per chip (no narrow correlation) and PFD limit.	0.48 dB	0.17 dB

This table shows that all of the following measures are needed to protect the BPSK(5) PNT signal from both 5G and WIFI :

- § Interference masks for the wireless transmitters
- § 3.5 MHz minimum guard bands
- § -121 dBW/m²/MHz PFD limit in the 2483.5-2500MHz band

This is only sufficient if an oversampling of 2 samples/chip is used on the PNT receiver

WIFI AND 5G USER EQUIPEMENT INTERFERENCE MASKS AND PFD LIMIT



In this configuration, the peak PNT C/No degradation is as high as 36.8 dB (see previous page).
The PFD limit in every 0.5 MHz portion of the PNT band is respected, but this is not sufficient.
Respecting additional PNT protection criteria is necessary.

CONCLUSIONS

- Both SFCG RECs 32-2R6 and 43-1 shall be followed to avoid wireless interference to lunar in-situ PNT.
  CNES contributed within SFCG to elaborate these RECs thanks to the TéSA simulator.

- A system study involving wireless to PNT interference computations is necessary to keep PNT protected.
  This system study shall consider the worst case in the design of the global PNT-wireless system, it shall involve Wireless and PNT teams. Specific tools such as the TéSA simulator are necessary.

- The aggregate PFD has to be calculated for all elevation angles of the wireless transmitter(s) from the PNT antenna, and all distances between each wireless Tx and the PNT antenna (24 cm in particular).

- The aggregate PFD shall be computed in all the different portions of the 2483.5-2500 MHz lunar PNT spectrum, typically for each of the 33 bands of 0.5 MHz in that 16.5 MHz wide spectrum.

- In all cases, the maximum aggregate PFD at the input if the PNT antenna shall always be below -121 dBW/m^2/MHz.

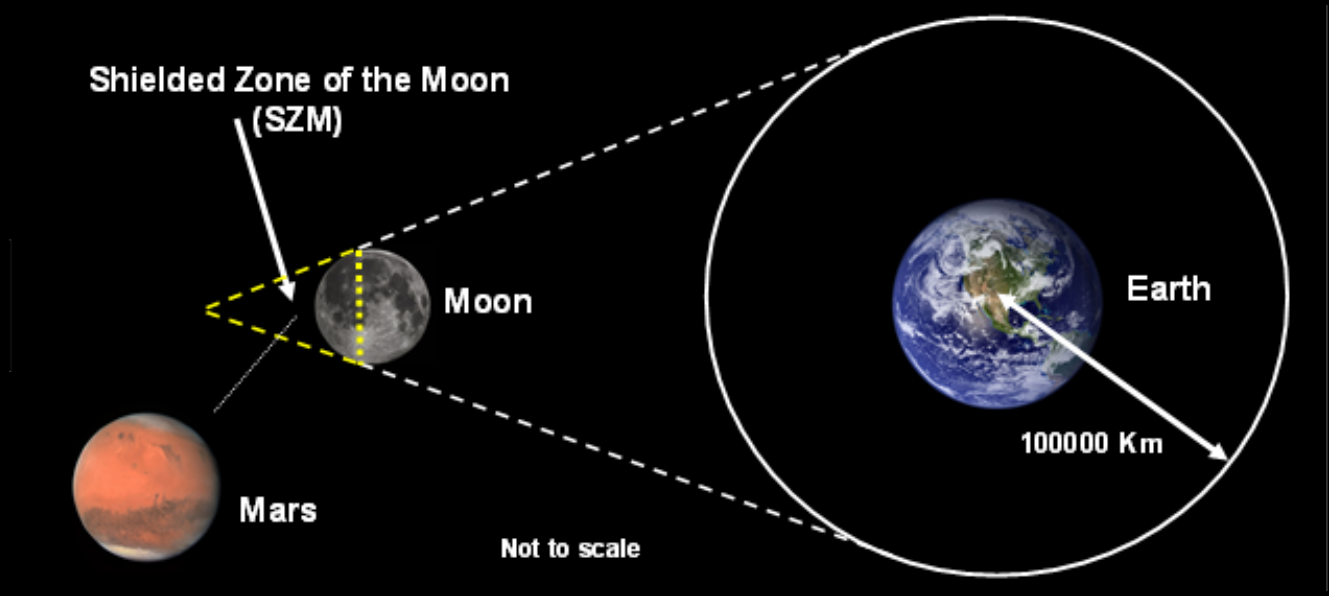
- Guard bands of at least 3.5 MHz shall be considered around the 2483.5-2500 MHz band of interest. If the size of the PNT receiver's front end filter would be still not viable, effective guard band sould be larger than 3.5 MHz

- PNT receiver performance tests for different effective guard bands are needed in the presence of real wireless signals.

Back-up Slides

CNES INVOLVEMENT AND ITU REC FOR THE SHIELDED ZONE OF THE MOON (SZM)

CNES is involved in the protection of Radio Astronomy in the SZM → implication in Lunar in-situ PNT frequency band choice and its RF compatibility with Lunar Surface Wireless links.



ITU REC RA.479-5: "Protection of frequencies for radioastronomical measurements in the SZM":

- "The 300 MHz to 2 GHz range should be reserved for radio astronomy observations"
  → No L-band emissions in the SZM.
- Protection of the R.A. Continuum Bands like the one in the neighborhood of the 5 GHz "terrestrial" Radio Astronomy band → No GNSS C-band emissions in the SZM.

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ITU: International Telecommunication Union
PNT: Positioning, Navigation & Timing

EXTRACT OF SFCG REC 32-2R6:
LUNAR SURFACE WIRELESS NETWORK BANDS

Recommended Frequency Bands for Communications in the Lunar Region:

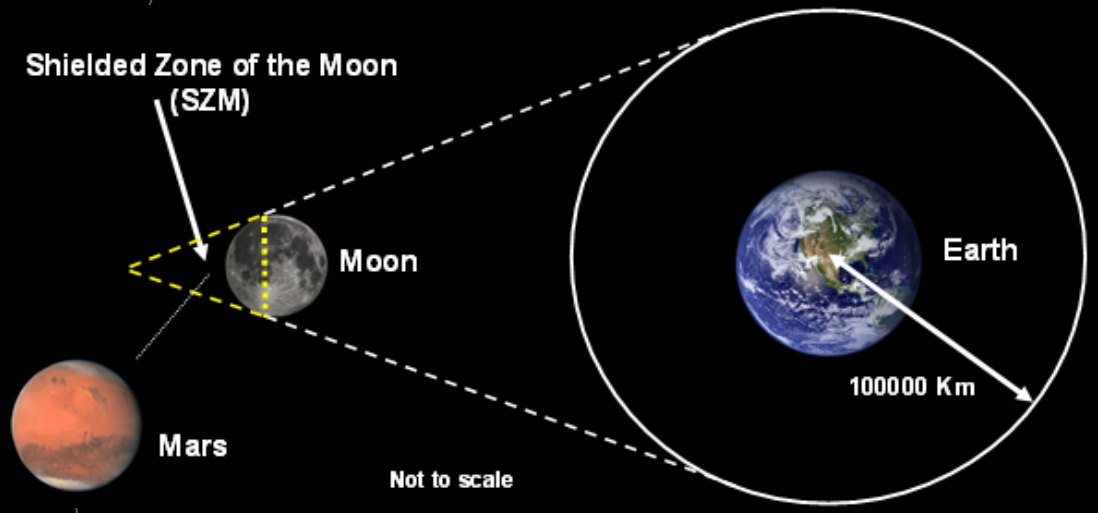
Lunar Surface Wireless Network	390-405	MHz (Note 4)	0.0150 GHz (outside SZM)
	410-420	MHz (Note 8) (Note 10)	0.0100 GHz
	435-450	MHz (Note 4)	0.0150 GHz (outside SZM)
	2.400-2.480	GHz (Note 7)	0.0800 GHz
	2.5035 – 2.655	GHz (Note 9)	0.1515 GHz
	2.655-2.690	GHz (Note 4)	0.0350 GHz (outside SZM)
	3.5-3.8	GHz	0.3000 GHz
	5.15-5.835	GHz (Note 6)	0.6850 GHz
	5.855-5.925	GHz	0.0700 GHz
	25.25-25.5	GHz	0.2500 GHz
	27.225-27.5	GHz	0.2750 GHz
	27.5-28.35	GHz	0.8500 GHz

12 lunar surface wireless bands.

Total cumulated bandwidth for lunar surface wireless = 2.7365 GHz ≈ 165 times more than lunar in-situ PNT bandwidth (16.5 MHz).

→ having 2 guard bands of 3.5 MHz as a minimum to protect the 2483.5-2500 MHz PNT band should not be a problem to design a suitable lunar wireless network.

Summary of Orbit to Surface and Surface to Surface Martian bands recommended by SFCG REC 22-2R4.



Orbit-to-surface:	435-450 MHz [3]
	2025-2110 MHz
	2483.5-2500 MHz
	7190-7235 MHz
	14.5-15.35 GHz
	22.55-23.55 GHz

CNES has shown Radio Astronomy issues with the use of GNSS L and C bands in the vicinity of Mars, which is regularly visible from the Shielded Zone of the Moon.

Like in the Moon region, the 2483.5-2500 MHz band is the only GNSS band allocated in the Mars region. This band is therefore the natural candidate for Martian PNT. The protection measures for a Martian in-situ PNT in 2483.5-2500 MHz would be similar to the ones described for lunar in-situ PNT systems.

POINTS OF CONTACT REGARDING THE SIMULATOR

TéSA laboratory https://www.tesa.prd.fr/en/home/

Corinne MAILHES *corinne.mailhes@tesa.prd.fr*

Jacques Sombrin *jacques.sombrin@tesa.prd.fr*