National Aeronautics and Space Administration

SLS-RFM_22-02 - Action AI_21-01: Update to Worst-case Doppler scenario for GMSK 0.25

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Status on Action AI_21-01

- AI_21-01: W. Fong should define the worst-case scenario to analyze and repeat his comparison at the same loop SNR. M. Lanucara would perform hardware tests for the same configuration using available ESA GMSK modulator and demodulator.
- We presented a scenario in Fall 2021 which was agreed by ESA. Afterwards there were some further problems with ESA's hardware which changed the scenario settings slightly.
- November 22, 2021: ESA provided test data confirming the gamma=0.02 limit on the agreed upon scenario.
- January 3, 2022: ESA provides additional test data of additional scenarios that exceed the 0.02 gamma limit by decreasing the normalized loop bandwidth to lower values validated with 3 minutes of test time.

ESA Report January 3 (1)

- ESA report performed a more comprehensive testing of various scenarios summarized in the following table:

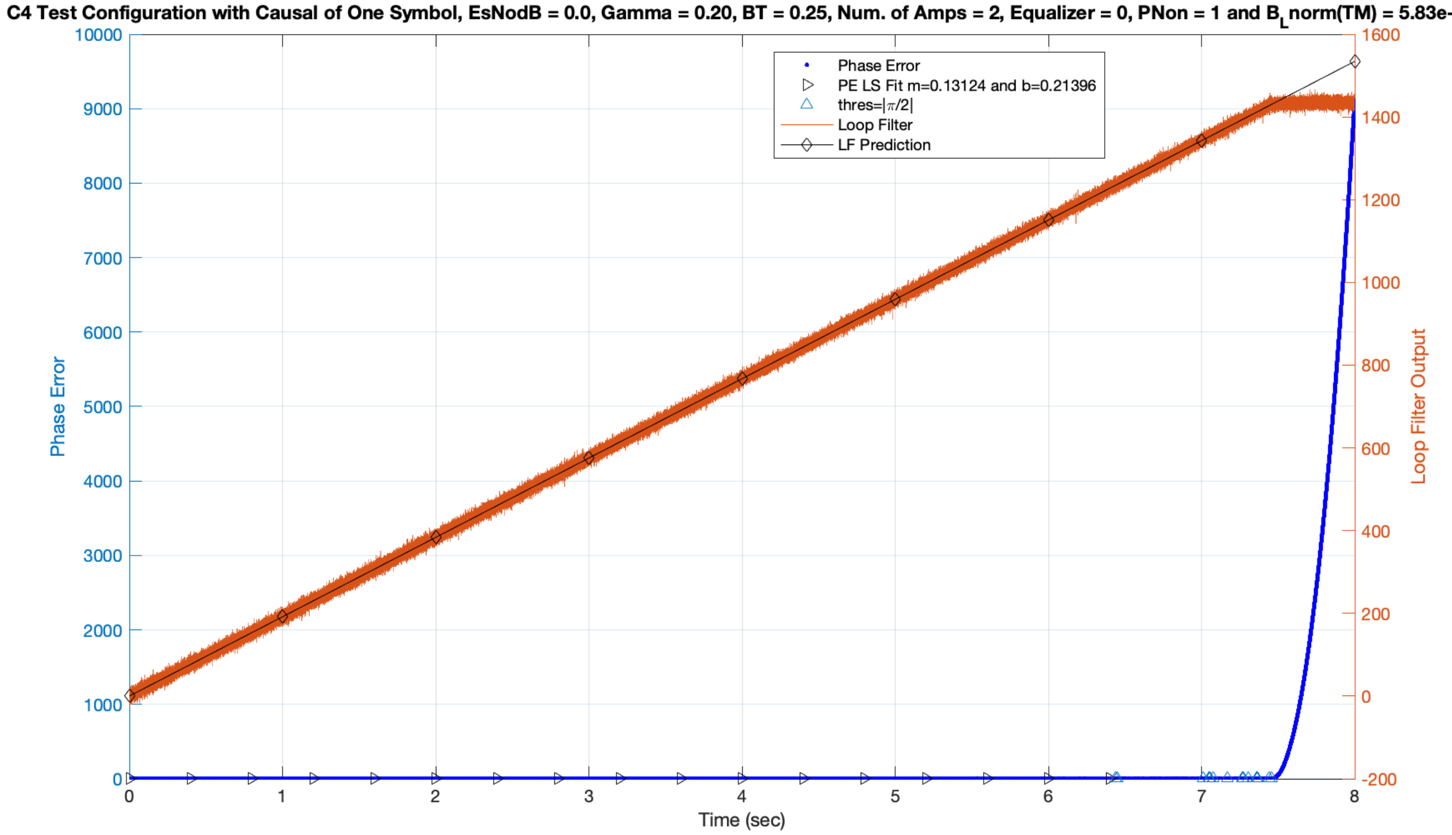
Case id	TM Modulation	PN RNG modulation	coding	Es/N0 [dB]	Rs [binary symbols per second]	PN RNG Chip rate [cps]	Configured PLL bandwidth (2BL) [Hz]	Internally configured damping factor	Actual PLL bandwidth (2BL) [Hz]	Norm. loop bandwidth BL^{TM}	Actual damping factor	Actual wn [1/sec]	sweep rate [Hz/sec]	gamma	measured phase jitter [degrees]	measured mean phase error [degrees]	measured RNG delay [nsecs]	measured RNG delay jitter wiith no sweep [nsec]	measured RNG delay variation during sweep [nsec]	duration [seconds]	Lost frames	Observed half cycle slips
A4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	-3.0	1.0E+06	1032700	1050	1	482	2.41E-04	0.57	478	10535	0.290	3.0	16.5	308.4	1.3	1.5	287	0	None
B4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	-3.0	5.0E+06	5032700	1000	1	459	4.59E-05	0.57	455	10535	0.319	1.2	18.7	308.1	0.1	0.2	287	0	None
C4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	-3.0	5.0E+05	502700	1270	1	583	5.83E-04	0.57	578	10535	0.198	5.1	12.1	309.6	3.9	3.8	191	0	None
D4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	-3.0	2.4E+07	23997300	984	1	452	9.41E-06	0.57	448	10535	0.330	0.6	20.1	307.9	0.02	0.1	192	0	None
E4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	9.0	1.0E+06	1002700	530	1	530	2.65E-04	1.00	424	10535	0.368	0.3	21.1	308.3	0.3	0.5	192	0	None
F4	GMSK BT = 0.25	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	-3.0	1.0E+06	1002700	5000	1	2295	1.15E-03	0.57	2276	10535	0.013	6.7	not measured	308.3	0.8	1.4	190	0	None
G4	GMSK BT = 0.5	T4B, sin, 0.444rad	turbo (k=8920, r=1/4)	9.5	1.0E+06	1002700	475	1	475	2.38E-04	1.00	380	10535	0.458	0.2	26.2	308.0	0.3	0.6	192	0	None
H4	GMSK BT = 0.5	T4B, sin, 0.444rad	turbo (k=8920, r=1/6)	-5.0	1.0E+06	1002700	1050	1	483	2.41E-04	0.57	479	10535	0.289	3.7	18.0	308.9	2.0	2.2	192	0	None
I4	GMSK BT = 0.5	T4B, sin, 0.444rad	turbo (k=8920, r=1/6)	-5.0	1.0E+06	1002700	5000	1	2298	1.15E-03	0.57	2279	10535	0.013	8.2	not measured	307.9	2.5	2.2	192	0	None

ESA Report January 3 (2)

- Since memory prevents us from performing an MTLL analysis of any of the additional scenarios, the only avenue of analysis to us is to focus on scenario C4 with B_Lnorm(TM) = 5.83e-04 and gamma=0.198 using a single run.
- The initial evaluation had a simulation time memory limited to 8 seconds.
- Results indicate there the static phase error caused by the frequency ramp (and directly related to gamma) will linearly drift upward until it reaches $\frac{\pi}{2}$ and slips.
- The assumption is that the system is essentially noiseless due to the small B_Lnorm(TM) and if you apply too high of frequency ramp (possibly due to exceeding gamma 0.02 or pull-in time is too great), the loop cannot reacquire and no longer track the frequency ramp until a reset occurs.
- This catastrophic failure is predictable; however, in real operations, it would depend on the spacecraft path and the accumulated phase error.

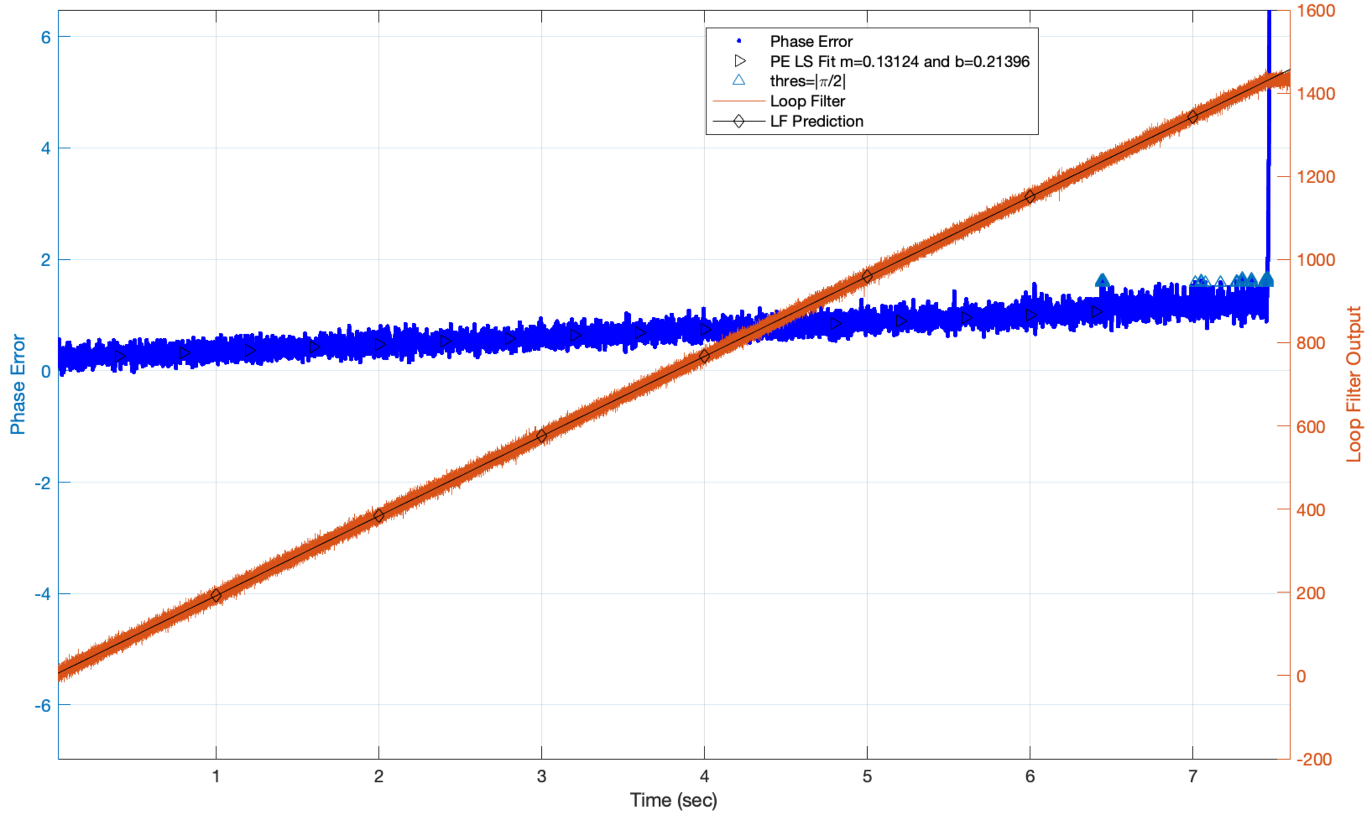
ESA Report January 3 (3)

C4 Scenario with MAP sync and one symbol causal delay



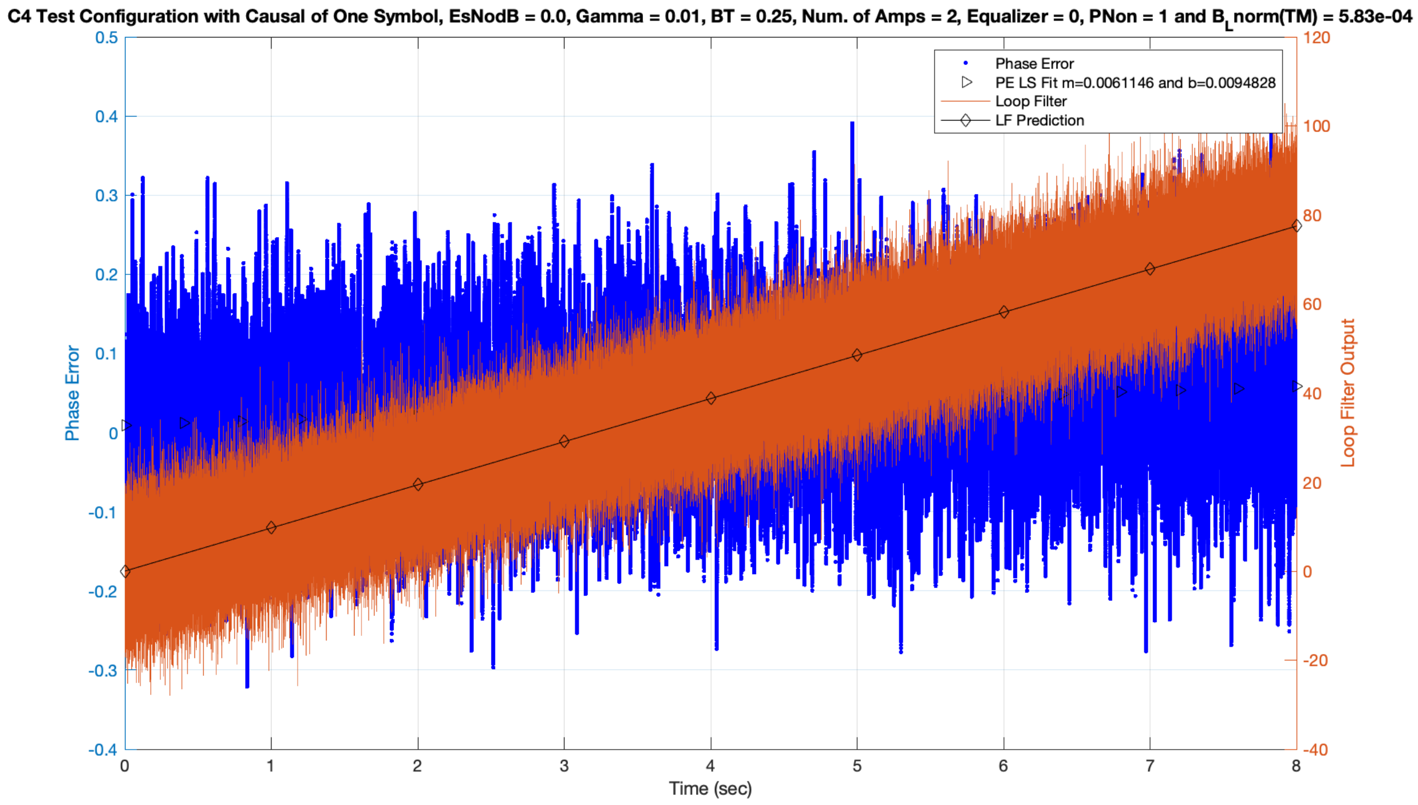
ESA Report January 3 (4)

Previous plot zoomed in



ESA Report January 3 (5)

Gamma reduced to 0.01

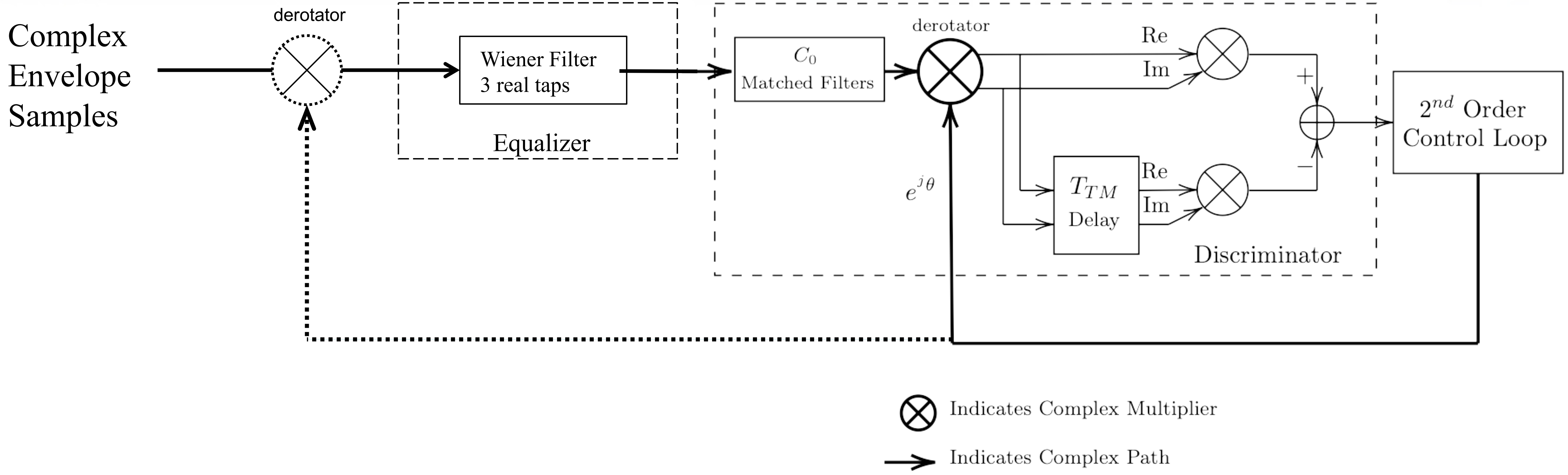


Conclusions from Initial Evaluation

- Delays from the loop will create a non-static phase error which will increase linearly with predictable time that will create a catastrophic slip.
- In the Fall report, we looked at moving the derotator to mitigate gamma limitations, which we found to be ineffective.
- We therefore try to focus on minimizing the delays.
  - The delay was outlined in the Fall report, and they were two-fold: 1) delay from matched filter and 2) delay from causality in loop
  - Matched filter delay can not be changed, therefore we looked to minimize causality delay

Conceptual Architecture from Fall Report

Relocating the Derotator in the Modified Low SNR MAP Algorithm

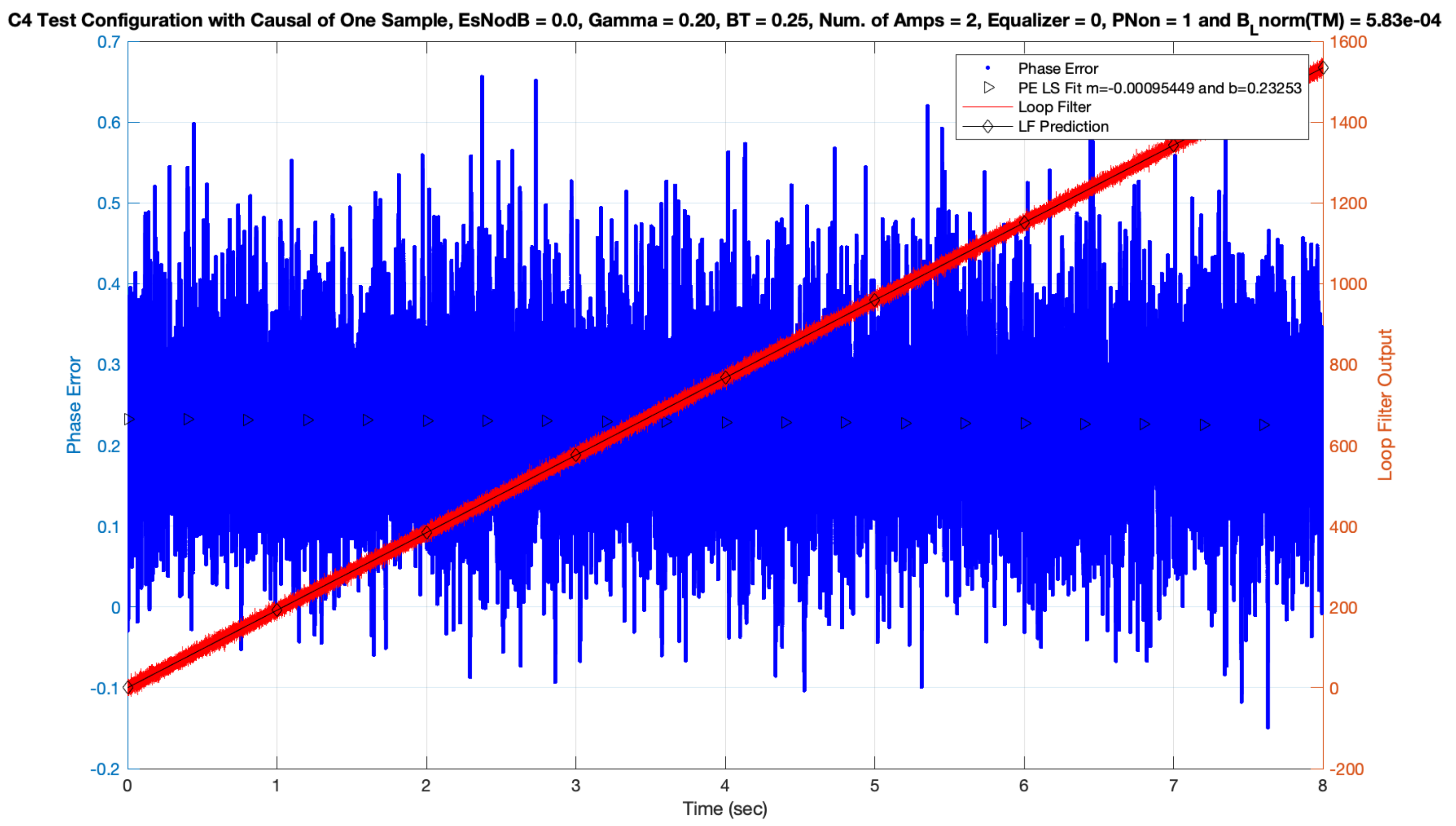


Causality Delay

- All feedback loops must be causal and therefore an insertion of typically a single delay is necessary for the loop to operate
- Our MAP architecture currently implements a single symbol delay to be in line with decimation to one sample per symbol.
- As a possible reduction in the delay, we can instead implement a single sample delay which would reduce the causality by a fraction of a symbol, the actual value depends on the number of samples per symbol.

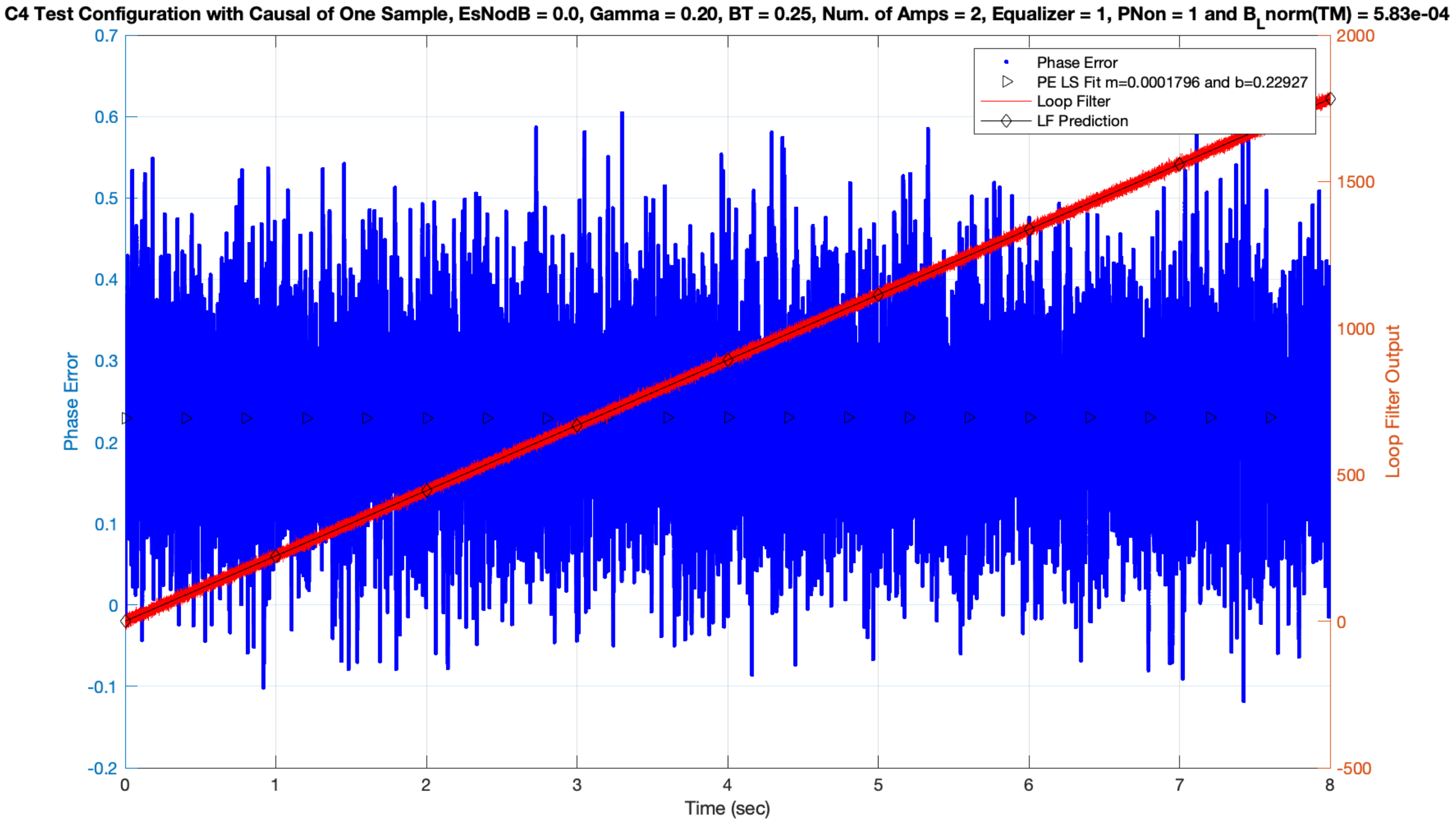
Results

One sample causal delay MAP sync for 8 seconds



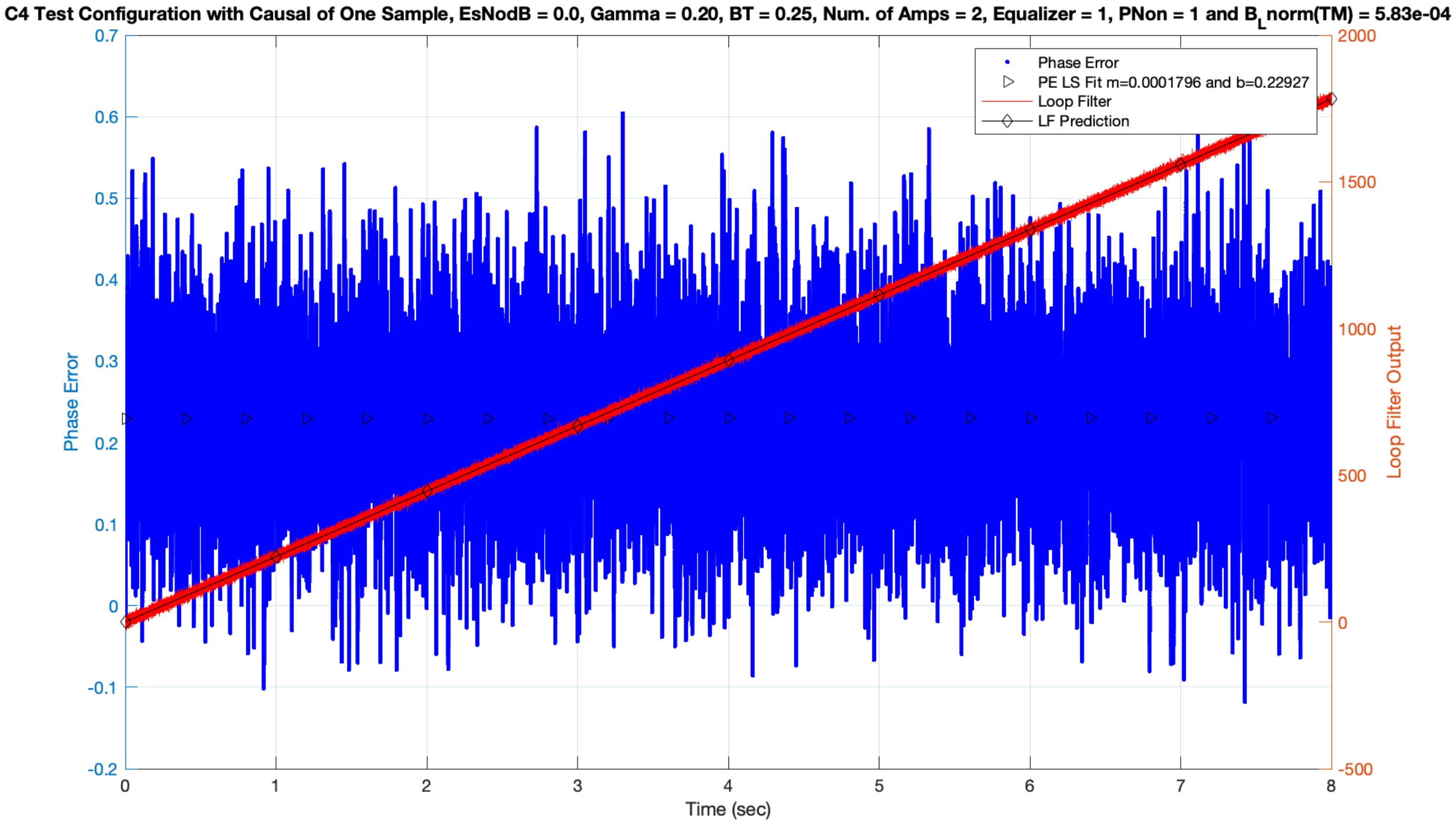
Results (2)

One sample causal delay MAP sync with Equalizer On



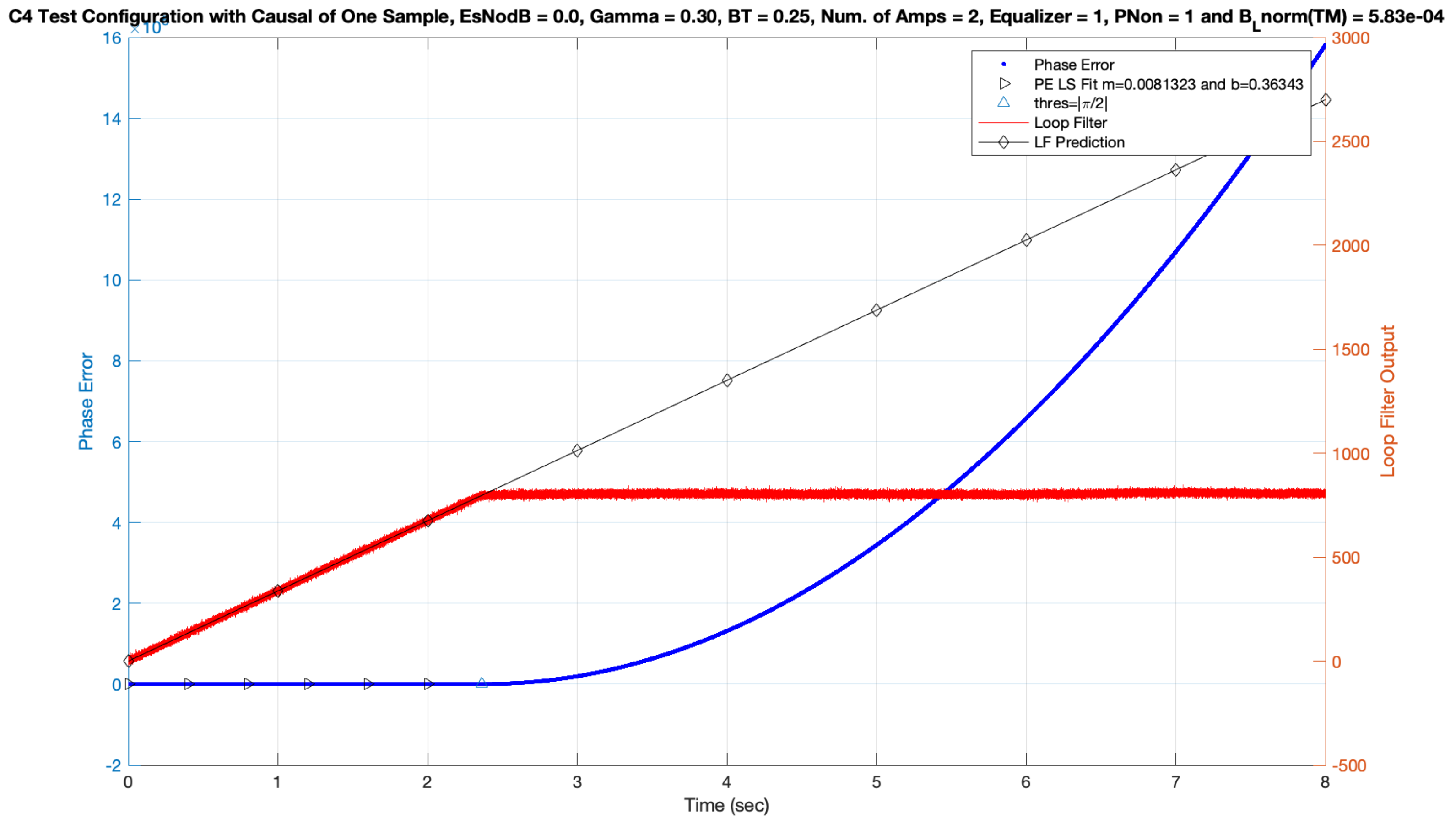
Results (3)

Gamma now set to 0.3, first run



Results (4)

Gamma now set to 0.3, second run
Observed random failure with previous setting



General Observations

- Compared to the single symbol delay circuit, it's likely that the single sample delay circuit is an improvement because you removed the deterministic catastrophic failure, however, result indicate that a probabilistic failure will create the same catastrophic failure as a symbol delay circuit.
- Other observations: we tried different settings of 1 Amp or 2 Amps, PN on and off, PN square pulse, equalizer on and off, and BT=0.5.
- Using 1 Amp degrades the gamma performance, PN off improves the gamma performance, a square PN pulse has no ability to track any of the gamma settings we used, equalizer on improves the gamma performance slightly and BT=0.5 shows similar behavior.

Conclusion (1)

- We have shown that delays can cause catastrophic deterministic sync failures in MAP synchronization circuits.
- We have considered a new single sample delay sync design over the previous single symbol sync design.
- We have shown that it maybe possible that deterministic sync failures that was shown in C4 scenario with symbol delay loops mitigated with sample delay loop however we cannot conclusively say this is an improvement since we can't do an MTLL analysis.
- We have also shown that if we further take gamma=0.3 in C4 with sample delay loop, it will randomly catastrophically fail.
- We have shown that the static error worsens as an increasing function of gamma.
- We have shown that if you keep gamma < 0.02, the tilt in the phase error goes away in symbol delay loop.
- Since we are constrained by computer memory, we cannot assess the MTLL for C4.
- Given that we cannot fully validate C4 we would not recommend using the 0.198 gamma setting.
- We are still recommending that users set gamma < 0.02.

Conclusion (2)

- We have shown that GMSK 0.25 with very low B_Lnorm(TM) = 5.83e-04 and a MAP synchronizer has poor performance at gamma =0.198 under the C4 scenario with the symbol causal delay and we have also shown that a sample causal delay may or may not be better.
- We would still advise to stick with gamma < 0.2 for Lunar missions.
- As for GMSK 0.5, we would recommend using a higher B_Lnorm(TM)=2.5e-3 as that setting has shown to be robust to reach nearly theoretical gamma limits. Lower settings could result in catastrophic failures and comm outages.

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