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# SLS-RNG_06-08
# AI_05-07: Influence of transparent ranging channel on the acquisition time

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# Applicable Documents

**AD.1** "Pseudo-Noise (PN) Ranging Systems", CCSDS 4XX.1-W-1 WHITE BOOK, CCSDS Fall 2005

**AD.2** **SLS-RNG_05-04** -- AI_04-10: Propose figures for XPND linearity, gain flatness, 3 dB bandwidth and group delay variation for the selected PN Ranging scheme(s), CCSDS Fall 2005

**AD.3** **SLS-RNG_05-05 – "**BepiColombo Chip Rate Requirement Vs the Current White Book Specification"

**AD.4** **SLS-RNG_04-09** -- AI-04-11: "Report on acquisition test results on BepiColombo breadboard from 10 dBHz (TBC) to 27 dBHz for the 3 Tausworthe schemes identified", CCSDS Fall 2004.

**AD.5** **SLS-RNG_04-07** -- PN ranging-code schemes--past & future, James L. Massey, CCSDS Fall 2004.

**AD.6** **SLS-RNG_ 04-03** – "Study on PN ranging codes for future missions", James L. Massey, CCSDS Spring 2004

**AD.7** **SLS-RNG_ 05-06** – "Reciprocal influence between ranging codes and TC/TM (AI_04-08)", G. Boscagli, M. Visintin, E. Vassallo

**AD.8** **SLS-RNG_ 05-03** – "Analyse the RFI of all proposed PN Ranging schemes with TC/TM (AI_04-08)", G. Boscagli, P. Holsters

# 1 INTRODUCTION

This note describes the activities performed and the results obtained in the frame of the AI_05-07: “Start working on the transparent ranging cahnnel” from the CCSDS 2005 Fall Meeting.

# 2 TRANSPARENT RANGING CHANNEL SPECIFICATION

In the current draft version of the CCSDS recommendation titled Pseudo-Noise ranging systems from November 2005, chapter 4 provides the recommendations for the transparent ranging channel. Among others, the transparent channel is currently specified as follows:

- **In-band group delay variation** (TBC) - For minimization of spectral distortion, the end-to-end in band group delay variation of the ranging channel shall be constant to within +/- 1/(30* $F_{chip}$) in the range from ($F_{clock}$/4) to (7* $F_{clock}$/4).
- **Gain flatness** (TBC) - The end-to-end in band gain deviation from an ideally flat gain shall be constant to within +/- 0.5 dB (TBC) in the range from ($F_{clock}$/2) to (3* $F_{clock}$/2).
- **The –3 dB frequencies** shall be below ($F_{clock}$/4) and above (7* $F_{clock}$/4) from the carrier.
- **The one-sided noise bandwidth** shall be ≤ 2.5* $F_{clock}$ (TBC).

In a first step, we have modelled the transparent ranging channel by a signal filter which adheres to some of the specifications above. In particular, the single bandpass filter was designed to have cut-off frequencies at ($F_{clock}$/4) and (7* $F_{clock}$/4) and an in-band ripple of +/- 0.5 dB. Goal was to see how the correlation properties and eventually the acquisition times of the various ranging sequences under investigation are affected by this channel.

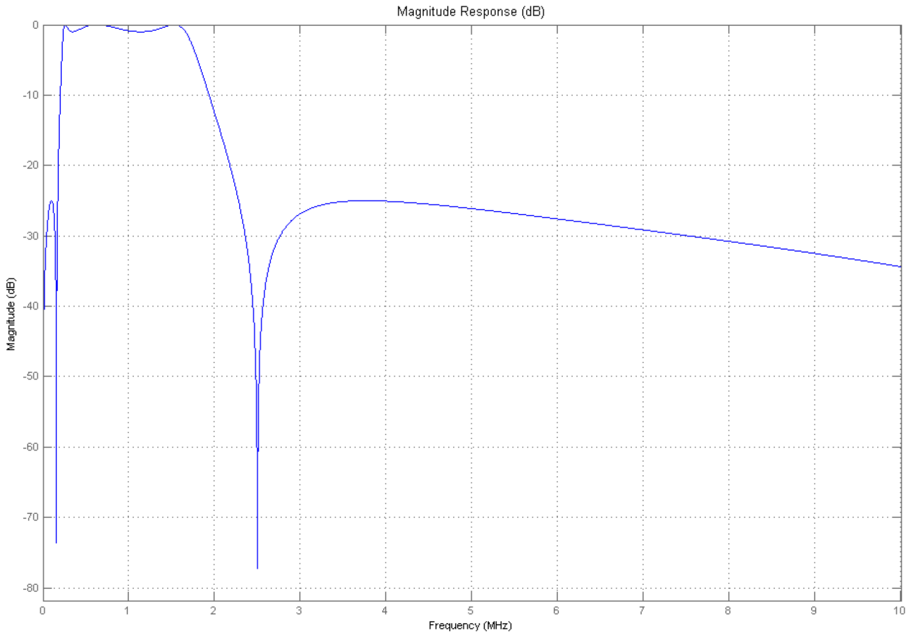
Assuming a chip-rate of 1.9 Mcps, the ranging clock frequency is 950 kHz which leads to -3dB cut-off frequencies:

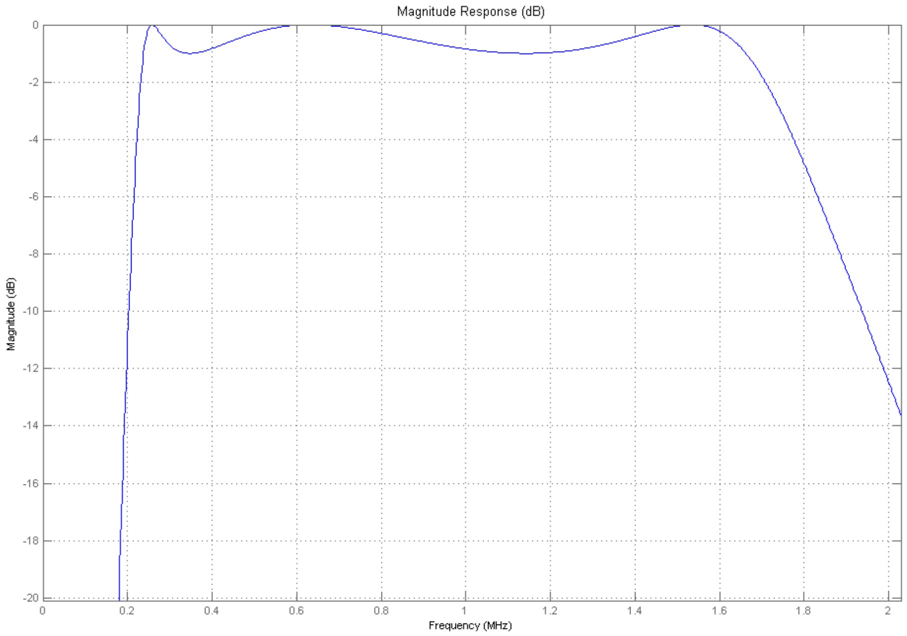
- $F_{clock}/4 = 237.5$ kHz
- $7*F_{clock}/4 = 1662.5$ kHz

Other specifications for the filter were:

- Stopband frequency: 100 kHz band 3 MHz
- Stopband rejection: > 25 dB
- In band ripple: +/- 0.5 dB

In the end, the selected filter was a 6th order elliptic filter with the following magnitude response:


Magnitude Response (dB)
Magnitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
0
1
2
3
4
5
6
7
8
9
10
Frequency (MHz)


Magnitude Response (dB)
Magnitude (dB)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Frequency (MHz)

# 3 RESULTS OF SIMULATION

## *3.1 Correlation with probing sequences*

The table below gives the correlation values of the received ranging signal with the different probing sequences C1, C2, C3, C4, C5 and C6. Only the JPL99 and the different Tausworthe sequences have been considered, as well as only square chip waveforms.

First, the correctness of the simulation has been verified by comparing the correlation with the values reported in [AD.6]. In this case, the column is labelled 'no filter' (basically this is just correlation the sequence with its probing sequences). After verification, the transparent ranging channel as modelled by the bandpass filter specified above is inserted in the simulation.

As expected, the correlation of the received signal with its probing sequences is affected by the transparent channel. Both in-phase and out-of-phase correlations have been computed and are shown below. To compute the out-of-phase correlation value, an off-set of one chip is applied.

| In-phase correlation | | | |
|---|---|---|---|
| JPL99-SQ | | | |
| | No filter | Massey results | Transparent channel |
| C1 | 0.954 | 0.9544 | 0.798 |
| C2 | 0.046 | 0.0456 | 0.016 |
| C3 | 0.046 | 0.0456 | 0.022 |
| C4 | 0.046 | 0.0456 | 0.018 |
| C5 | 0.046 | 0.0456 | 0.020 |
| C6 | 0.046 | 0.0456 | 0.019 |
| T2-SQ | | | |
| | No filter | Massey results | Transparent channel |
| C1 | 0.617 | 0.6176 | 0.516 |
| C2 | 0.258 | 0.2591 | 0.102 |
| C3 | 0.257 | 0.2569 | 0.123 |
| C4 | 0.255 | 0.2525 | 0.105 |
| C5 | 0.254 | 0.2545 | 0.117 |
| C6 | 0.254 | 0.2538 | 0.108 |
| BT2-SQ | | | |
| | No filter | Massey results | Transparent channel |
| C1 | 0.627 | 0.6274 | 0.523 |
| C2 | 0.245 | 0.2447 | 0.104 |
| C3 | 0.248 | 0.2481 | 0.131 |
| C4 | 0.249 | 0.249 | 0.104 |
| C5 | 0.249 | 0.2492 | 0.118 |
| C6 | 0.250 | 0.2496 | 0.107 |
| T4-SQ | | | |
| | No filter | Massey results | Transparent channel |
| C1 | 0.933 | 0.9334 | 0.781 |
| C2 | 0.066 | 0.0662 | 0.027 |
| C3 | 0.066 | 0.0662 | 0.033 |
| C4 | 0.066 | 0.0662 | 0.027 |
| C5 | 0.066 | 0.0662 | 0.031 |
| C6 | 0.066 | 0.0662 | 0.028 |
| BT4-SQ | | | |
| | No filter | Massey results | Transparent channel |
| C1 | 0.939 | 0.9387 | 0.780 |
| C2 | 0.061 | 0.0613 | 0.025 |
| C3 | 0.061 | 0.0613 | 0.032 |
| C4 | 0.061 | 0.0613 | 0.026 |
| C5 | 0.061 | 0.0613 | 0.029 |
| C6 | 0.061 | 0.0613 | 0.027 |

| Out-of-phase-phase correlation | | |
|---|---|---|
| **JPL99-SQ** | | |
| | Massey results | Transparent channel |
| C1 | -0.9544 | -0.798 |
| C2 | 0 | 0.003 |
| C3 | 0 | 0.002 |
| C4 | 0 | 0.002 |
| C5 | 0 | 0.002 |
| C6 | 0 | 0.001 |
| **T2-SQ** | | |
| | Massey results | Transparent channel |
| C1 | -0.6176 | -0.516 |
| C2 | -0.0267 | 0.002 |
| C3 | -0.0158 | 0.014 |
| C4 | -0.0112 | 0.001 |
| C5 | -0.0086 | 0.009 |
| C6 | -0.0070 | 0.008 |
| **BT2-SQ** | | |
| | Massey results | Transparent channel |
| C1 | -0.6274 | -0.524 |
| C2 | -0.0410 | 0.021 |
| C3 | -0.0247 | 0.014 |
| C4 | -0.0177 | 0.009 |
| C5 | -0.0139 | 0.009 |
| C6 | -0.0113 | 0.008 |
| **T4-SQ** | | |
| | Massey results | Transparent channel |
| C1 | -0.9334 | -0.780 |
| C2 | -0.0267 | 0.005 |
| C3 | -0.0158 | 0.004 |
| C4 | -0.0117 | 0.002 |
| C5 | -0.0086 | 0.002 |
| C6 | -0.0070 | 0.002 |
| **BT4-SQ** | | |
| | Massey results | Transparent channel |
| C1 | -0.9387 | -0.785 |
| C2 | -0.0103 | 0.005 |
| C3 | -0.0061 | 0.003 |
| C4 | -0.0044 | 0.002 |
| C5 | -0.0034 | 0.002 |
| C6 | -0.0028 | 0.002 |

## 3.2 Normalised correlation time

We now want to translate the change in correlation values to a more practical metric to assess the influence of the transparent ranging channel. For this, we use the *normalised correlation time* $\tau_{cor}$ as defined in [AD.6].

The normalised correlation time $\tau_{cor}$ of a probing sequence is defined as:

$$\tau_{cor} = \frac{1}{\xi^2 \cdot \lambda}$$

where we have that

- parameter $\xi$ = in-phase percentage correlation
- parameter $\lambda$ = correlation scale factor of the probing sequence

The correlation scale factor itself is defined as:

$$\lambda = \frac{\xi - \psi}{2\xi}$$

where

- parameter $\psi$ = out-of-phase percentage correlation

As an example, for the probing sequences of the JPL99 code, we have the following values for parameters $\xi$, $\psi$ and $\lambda$:

| **Probing sequence** | **In-phase percentage correlation, $\xi$** | **Out-of-phase percentage correlation, $\psi$** | **Correlation scale factor** |
|---|---|---|---|
| **C1 (range clock)** | 0.9544 | - 0.9544 | 1 |
| **C2** | 0.0456 | 0 | 1/2 |
| **C3** | 0.0456 | 0 | 1/2 |
| **C4** | 0.0456 | 0 | 1/2 |
| **C5** | 0.0456 | 0 | 1/2 |
| **C6** | 0.0456 | 0 | 1/2 |

which results is a normalised correlation time $\tau_{cor}$ for C1 equal to 1.098 and about 961.8 for the five other probing sequences

## 3.3 Acquisition process

To acquire a particular probing sequence, one needs to correlate the received sequence in turn against each cyclic shift of that sequence and choose the cyclic shift with the greatest correlation. The probing sequences in the JPL99 PN ranging-scheme are the range clock sequence together with the five component PN sequences. The total number of correlations required for the probing sequences is thus 2 + 7 + 11 + 15 + 19 + 23 = 77. Note that the cyclic shift of the range clock is simply the negative of itself, which means that the correlation of the received sequence with the range clock is just the negative of its correlation with the cyclic shift of the range clock–hence only one correlation is required for the range-clock probing sequence. Thus, in all, to acquire the signal, 76 correlations must be carried out for the probing sequences in the JPL99 PN ranging-sequence scheme.

When only one correlator is used to perform the correlations against all cyclic shifts of a particular probing sequence, the *normalised acquisition time* becomes:

$$\tau_{acq} = l * \tau_{cor}$$

where l is the period of the probing sequence and hence the number of cyclic shifts that need to be performed.

However, in case of transparent PN ranging, the only correlations are performed on-ground. Instead of using just six correlators (one for each probing sequences), we can speed the acquisition process by using a bank of 76 correlators (as processing power on-ground is less an issue than on-board) to perform all the correlations in parallel. **In this case, the normalised acquisition time equals the normalised correlation time.** In the following, we will assume this is the case for transparent PN ranging.

As the probing sequences for the Tausworthe sequences are in principle the same (apart from a sign change in the balanced sequences), the same applies to the Tausworthe sequences.

## 3.4 Normalised acquisition time

We are now ready to derive the normalised acquisition times in case of the transparent ranging channel (i.e. using full parallel acquisition). The table below summarises the normalised acquisition times calculated using the formulas and the simulation results (in-phase and out-of-phase correlation values) from above. Also the increases (x times) in normalised acquisition times due to the introduction of the transparent ranging channel model are given in the last column.

| Normalised acquisition time | | | |
|---|---|---|---|
| **JPL99-SQ** | | | |
| | Massey results | Transparent channel | Increase |
| C1 | 1.10 | 1.57 | 1.4 |
| C2 | 961.83 | 9,337.83 | 9.7 |
| C3 | 961.83 | 4,745.75 | 4.9 |
| C4 | 961.83 | 6,839.93 | 7.1 |
| C5 | 961.83 | 5,233.11 | 5.4 |
| C6 | 961.83 | 6,134.06 | 6.4 |
| **T2-SQ** | | | |
| | Massey results | Transparent channel | Increase |
| C1 | 2.62 | 3.76 | 1.4 |
| C2 | 27.01 | 196.30 | 7.3 |
| C3 | 28.55 | 149.30 | 5.2 |
| C4 | 30.04 | 183.04 | 6.1 |
| C5 | 29.87 | 158.68 | 5.3 |
| C6 | 30.21 | 185.82 | 6.2 |
| **BT2-SQ** | | | |
| | Massey results | Transparent channel | Increase |
| C1 | 2.54 | 3.65 | 1.4 |
| C2 | 28.61 | 232.09 | 8.1 |
| C3 | 29.55 | 130.59 | 4.4 |
| C4 | 30.12 | 203.16 | 6.7 |
| C5 | 30.50 | 155.88 | 5.1 |
| C6 | 30.71 | 189.53 | 6.2 |
| **T4-SQ** | | | |
| | Massey results | Transparent channel | Increase |
| C1 | 1.15 | 1.64 | 1.4 |
| C2 | 325.38 | 3,430.47 | 10.5 |
| C3 | 368.52 | 2,063.68 | 5.6 |
| C4 | 387.82 | 3,014.57 | 7.8 |
| C5 | 403.73 | 2,256.91 | 5.6 |
| C6 | 412.56 | 2,765.87 | 6.7 |
| **BT4-SQ** | | | |
| | Massey results | Transparent channel | Increase |
| C1 | 1.13 | 1.64 | 1.4 |
| C2 | 455.68 | 4,060.30 | 8.9 |
| C3 | 484.07 | 2,191.98 | 4.5 |
| C4 | 496.60 | 3,245.84 | 6.5 |
| C5 | 504.27 | 2,581.14 | 5.1 |
| C6 | 508.99 | 2,969.14 | 5.8 |

# 4 CONCLUSIONS

Comparing the results in terms of "increase in acquisition time due to the transparent ranging channel", they seem to be very consistent.
We can conclude the following:

- For all sequences, the normalised acquisition time of the clock is increased by 40 %.
- Most affected seems to be the C2 probing sequence, accounting for an increase in normalised acquisition time of up to a factor of 10 in case of T4!
- There is no real sequence which is more favourable; all sequences are affected in more or less the same way.