Pulse Shape Selection for Navigation Systems in a Multipath environment

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BIOGRAPHY

Alexander Steingass graduated in 1996 from the University of Ulm/Germany with a degree in electrical engeneering. He began working with the German Aerospace Center (DLR) in 1997 and is a Ph.D. candidate at the University of Essen/Germany. He took part in major navigation studies such as the Signal Design and Transmission Performance Study for GNSS-2 performed by the European Space Agency.

ABSTRACT

This publication deals with the pulse shape selection for satellite navigation systems in terms of inventing the new european naviagtion system ”‘Galileo”’ or the GPS modernisation. Based on a given bandwidth of 20 MHz two competitive candidates have been identified: A rectangular pulse shape chip rate 10 MChip/s (P-code like) and a root raised cosine pulse shape chip rate 16.7 MChip/s. These two competitors have been transmitted over the AWGN channel and multipath channels as well. The receiver has been selected as an standard narrow correlation receiver with a Costas PLL included.

The results from these simulations are showing

- that in terms of pseudorange accuracy the root raised cosine pulse gains about 1dB in comparison to the rectangular pulse transmitted over an AWGN channel.
- Transmitting over a multipath channel the gain for the pseudorange accuracy reaches dimensions up to several dBs.
- In terms of the Phase estimation accuracy there is no influence of the selection of the pulse shape. All simulations result in the same characteristics of performance.

Since the only disadvantage of the root raised cosine pulse is the higher complexity the question arises wether the gain in accuracy should be waised to keep the complexity low. This question can only be answered by the system designers of the new navigation systems.

INTRODUCTION

When we talk about the modernisation of GPS or inventing the european navigation system ”Galileo”, we encounter many possible viewpoints on the pulse shape that should be selected.

CRAMER RAO BOUND

To allow for a fair comparison between the two existing choices we assume a limited bandwidth of 20 MHz. Both signal options must fit completely into this bandwidth. No sidelobes outside of this band are allowed (sidelobe suppression >50 dB). For both selections the best Chiprate-Bandwidth ratio has to be selected. To secure the optimal selection we consider the Cramer Rao Bound for navigation Systems [1]. The Cramer Rao Bound defines the performance of the best synchronisation system that does possibly exist. Assuming a navigation system with a chip duration of T_{chip} and a transmission bandwidth of B the variance of a synchronisation system is

$$\sigma \geq \sigma_{CRB} = \underbrace{\frac{B_{\text{Loop}}}{C/N_0 \cdot f_{\text{chip}}^2}}_{System\ Parameters} \cdot \underbrace{\frac{1}{\frac{P_{\text{norm}}}{(B/f_{\text{chip}})^2}}}_{Signal\ Parameters} \qquad (1)$$

with

$$P_{norm} = \int_{-1}^{1} S\left(\frac{f}{f_B}\right) \cdot f^2 df. \qquad (2)$$

To reduce the variance of the synchronisation jitter (equation 1) $P_{\text{norm}}/(B/f_{\text{chip}})^2$ is to be increased as much as possible. Figure 1 shows P_{norm} for several modulation schemes.

Interpreting figure 1 we see that for an root raised cosine pulse (RRC) (rectangular spectrum) the value of P_{norm} is at its maximum when B/f_{chip} is selected in the range of $(0 \ldots 1]$. This is not surprising if we take into account equation (2) since the major contributions to P_{norm} are acieved by those spectral components which are located close to the band limit. A

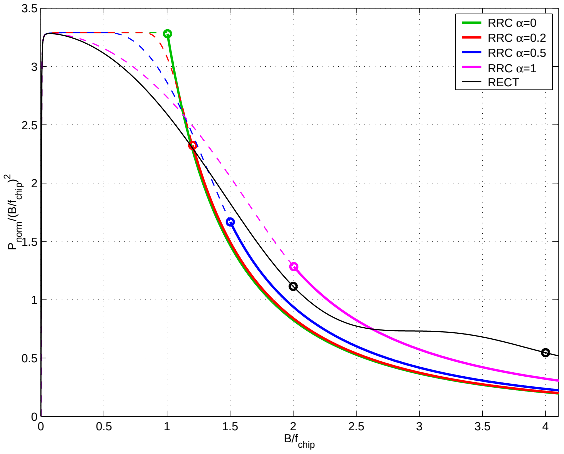

Figure 1: Inverse Cramer Rao Bound in depenency of the chip rate-bandwidth ratio for several pulse shapes.

root raised cosine pulse with an rolloff factor $\alpha = 0$ fullfills that requirement.

Increasing the rolloff factor for example to 0.2 we see that the plot no longer reaches its maximum for $B/f_{\text{chip}} = 1$. The optimal selection range is now $(0 \dots 0.8)$. Again this is not surprising as from $B/f_{\text{chip}} = 0.8$ the spectrum of the pulse is decreasing.

Increasing the rolloff more and more, the optimal selection range of P_{norm} is reduced more and more. In general it is $(0 \dots 1 - \alpha]$.

For the rectangular pulse we reach the optimum for an B/f_{chip} close to zero. That means that the optimum configuration for the rectangular pulse is an extremely high chip rate hard band-limited using a filter with a bandwith$\ll f_{\text{chip}}$.

Now another criteria has to be taken into account. Due to multipath rejection and receiver layout one prefers to have Nyquist pulses. For that reason not every B/f_{chip} value can be selected. For the root raised cosine pulses the bandwidth must equal at least the bandwidth of the pulse

$$B/f_{\text{chip}} \leq 1 + \alpha. \tag{3}$$

In figure 1 these ”‘allowed ranges”’ are marked by a thick solid line. The best value is marked with a circle. To guarantee a nyquist pulse using a rectangular pulse shape one can select

$$B/f_{\text{chip}} = 2 \cdot k,\ k = 1, 2, 3 \dots. \tag{4}$$

In figure 1 these positions are marked by a circle as well.

COMPARATIVE CANDIDATES

To select the best candidates of their family one has to select the configurations with the highest values of P_{norm}. To keep the implementation complexity in reasonable limits an $\alpha = 0.2$ is selected for the root raised cosine pulse. We select $B/f_{\text{chip}} = 1 + \alpha. = 1.2$ (figure 1 and equation (3)). On calculating we receive a chiprate f_{chip} of 16.7 MChips/s.

For the rectangular pulse shape the best point is $B/f_{\text{chip}} = 2$ (see figure 1 and equation (4)). For the given bandwidth of 20 MHz this results in a chiprate of 10 MChips/s (GPS P-code like).

Already at that stage it can be seen that there might be a receiver which performs better for the RRC pulse than for the rectangular pulse.

Figure 2 shows the pulses of the two selected candidates in the time domain, figure 3 gives their spectrum.

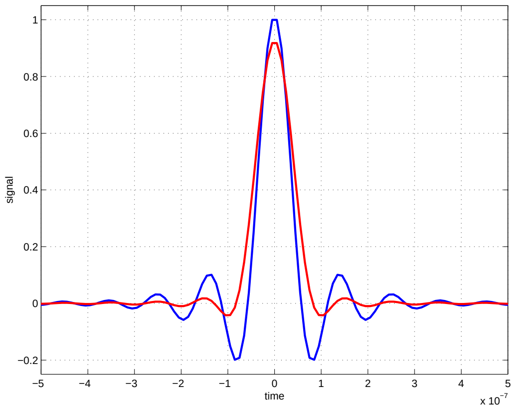

Figure 2: Pulses of the comparative candidates in the time domain - rectangular (red) RRC (blue).

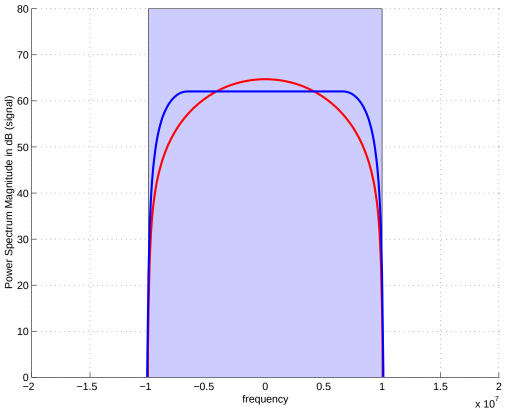

Figure 3: Spectrum of the comparative candidates - rectangular (red) RRC (blue).

RECEIVER PARAMETERS

The simulations were performed with a simulator simulating an incoherent DLL with an Costas PLL. The detailed parameters have been for both scenarios:

- DLL Loop bandwidth 2 Hz
- PLL Loop bandwidth 20 Hz
- Integration duration 2.46 ms
- Correlator spacing $\Delta = 0.1$ Chips

AWGN SIMULATIONS

Figure 4 shows the performance of an incoherent delay locked loop (DLL) receiving the signal over an AWGN channel. It can clearly be seen that the RRC pulse is much more powerful. The possible reduction of the transmission power for the same synchronisation jitter is in a range of about 1dB at an operation point of 45 dBHz. Figure 5 gives the performance for the phase estimation. It can be seen that there is no dependence on the selection of the pulse shape for the phase estimation accuracy. This fact is not surprising. If the synchronisation error ist sufficiently small the DLL despreads the signal almost correctly. The loss in power of the despreading output is very small.

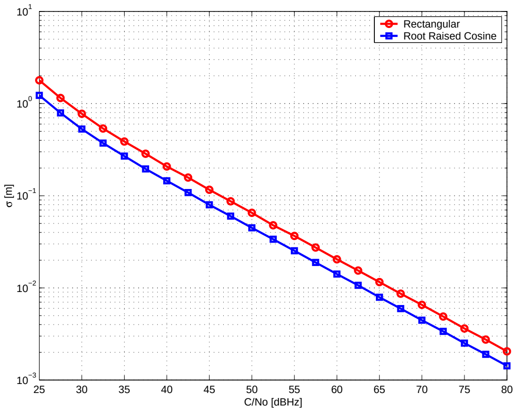

Figure 4: Simulation Results for the pseudorange estimation (DLL), AWGN Channel.

MULTIPATH SIMULATIONS

To simulate multipath the channel models defined in the ESA-Signal design study [3, 2] has been used:

1. Aeronautical en route channel
2. Aeronautical final approach channel
3. Urban (car/pedestrian)
4. channel and the rural channel.

This publication deals with the channels 2-4.

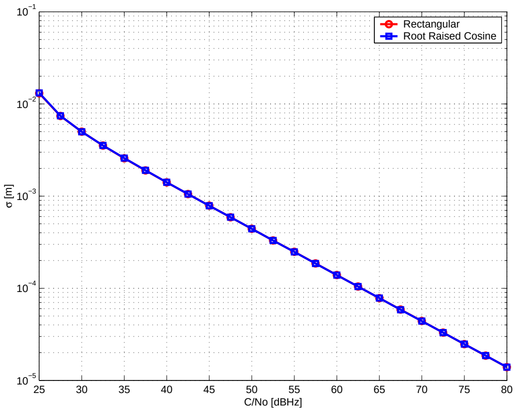

Figure 5: Simulation Results for the phase estimation, AWGN Channel.

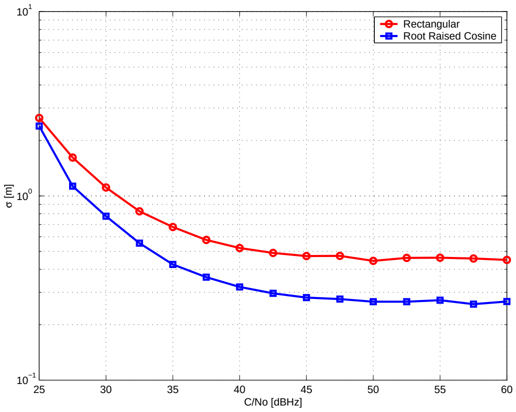

Figure 6: Simulation Results for the delay estimation, final approach channel.

Final approach channel

Path	Power	Delay	Bandwidth
Direct	0dB	-	-
Surround Echo	-10dB	-	1Hz
Ground Echo	-6dB	44ns	420Hz

Table 1: Parameters of the Final Approach Channel

Figure 6 gives the simulation result for the final approach channel. Assuming an operational point of 45 dBHz the gain of the SCR pulse is about 10 dB. For the phase estimation (see figure 7) there is no influence of the pulse shape.

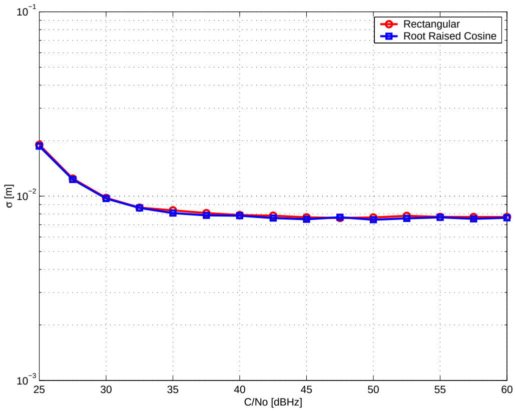

Figure 7: Simulation Results for the phase estimation, final approach channel.

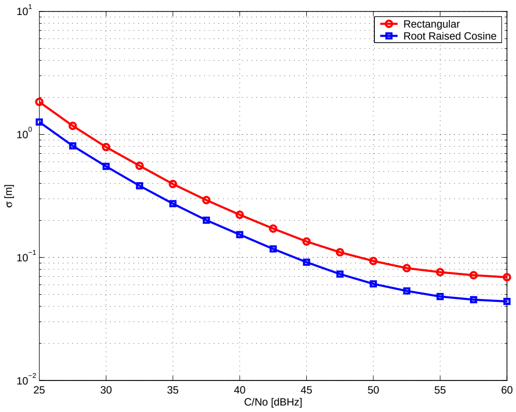

Figure 8: Simulation Results for the delay estimation, urban channel (car) .

Urban channels

The urban channels (car and pedestrian) comes up with power gains from 2.5 dB (car - figure 8) to 10 dB (pedestrian - figure 8). Again there is no influence on the phase estimation (figure 9 and 11).

Rural channel

For the rural channel the gain is not that spectacular. It is ”just” 2 dB at an operational point of 45 dBHz. It surprises no longer that there is no influence on the phase estimation accuracy.

CONCLUSIONS

All simulations for the multipath channels share the fact that the RRC Pulse performs much better than the rectangular pulse shape. The pulse shape has no influence on the synchronisation accuracy of the PLL. From a system designers point of view there should be strong arguments (e.g. the increased complexity of a system using the RRC pulse) to waist the increase in performance of the square root raised cosine impulse.

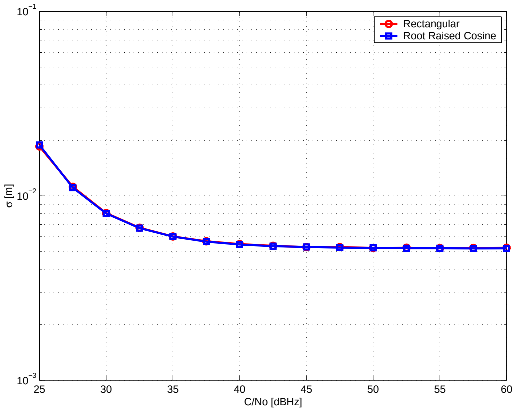

Figure 9: Simulation Results for the phase estimation, urban channel (car).

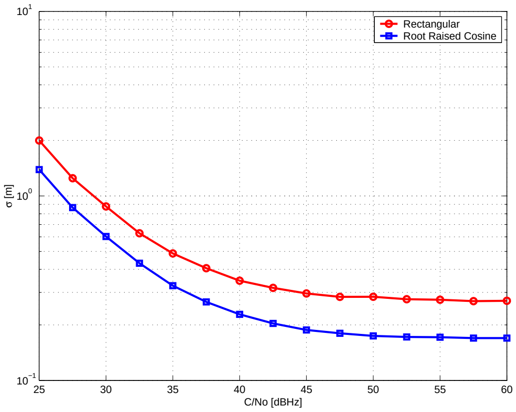

Figure 10: Simulation Results for the delay estimation, urban channel (pedestrian).

ACKNOWLEDGEMENTS

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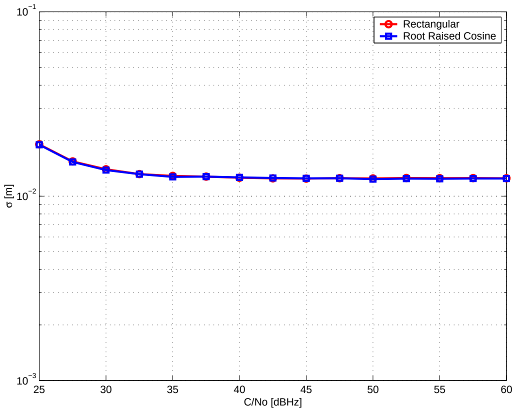

Figure 11: Simulation Results for the phase estimation, urban channel (pedestrian).

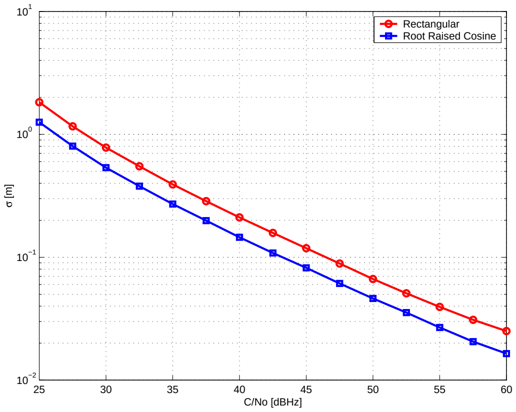

Figure 12: Simulation Results for the delay estimation, rural channel.

References

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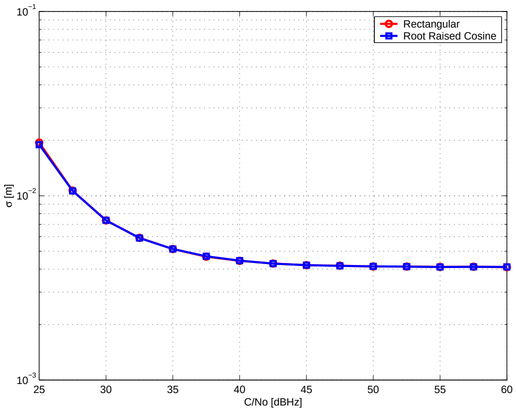

Figure 13: Simulation Results for the phase estimation , rural channel.

Path	Power	Delay	Bandwidth
Direct	0dB	-	-
Surround Echo	-7dB	-	70Hz
1. Delayed Path	-27dB	60ns	70Hz
2. Delayed Path	-27dB	100ns	70Hz
3. Delayed Path	-27dB	130ns	70Hz
4. Delayed Path	-27dB	250ns	70Hz

Table 2: Parameter of the Urban (car) Channel

Path	Power	Delay	Bandwidth
Direct	0dB	-	-
Surround Echo	-7dB	-	4Hz
1. Delayed Path	-27dB	60ns	4Hz
2. Delayed Path	-27dB	100ns	4Hz
3. Delayed Path	-27dB	130ns	4Hz
4. Delayed Path	-27dB	250ns	4Hz

Table 3: Parameter of the Urban Pedestrian Channel

Path	Power	Delay	Bandwidth
Direct	0dB	-	-
Surround Echo	-6dB	-	140Hz
1. Delayed Path	-28dB	100ns	140Hz
2. Delayed Path	-31dB	250ns	140Hz

Table 4: Parameters of the Rural Channel