Design of spectrum spreading technique applied to DVB-S2

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요 약

일반적으로 대역확산기술은 원하는 전송신호에서 요구되는 최소 나이퀴스트 대역과 관련하여 신호 대역의 인위적인 확산하는 것으로 인식된다. 대역확산은 재밍, 간섭 등의 탄력성, 신호전력의 감소 등 여러목적으로 사용된다. 본 논문에서는 대역확산은 작은 안테나, 송신 EIRP 증가없이 수신신호의 에너지를 증가시키고 링크버짓의 제한을 만족시키기 위함이다. 실제로 많은 이동환경 시나리오에서 DVB-S2 표준의 낮은 대역폭당 전송효율 형태의 전송형태에도 링크버짓을 만족시키지 못할 수 있다. 대역확산기술은 송신단의 전력제한환경하에 기존의 DVB-S2의 새로운 전송형태의 추가없이 시스템성능을 만족시킬수 있는 기법이다. 이러한 목표를 위해 대역확산기술의 설계는 스펙트럼 형상, 물리계층 성능, 링크버짓, 하드웨어 재사용, 강인성, 복잡도, 존재하는 사용 모듈과의 호환성 등이 고려된다. 제한된 기법의 구현은 현재 DVB-S2 를 완전히 만족시키는 것이 가능해진다.

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ABSTRACT

Spectrum spreading, in its general form, can be conceived as an artificial expansion of the signal bandwidth with respect to the minimum Nyquist band required to transmit the desired information. Spreading can be functional to several objectives, including resilience to interference and jammers and reduction of power spectral density levels. In the paper, signal spreading is manly used for increasing the received energy, thus satisfying link budget constraints, for terminals with low aperture antennas, without increasing the transmitted EIRP. As a matter of fact, in many mobile scenarios, even when MODCOD configurations with very low spectral efficiency (i.e. QPSK-1/4) in DVB-S2 standard, are used, the link budget cannot be closed. Spectrum spreading has been recently proposed as a technique to improve system performance without introducing additional MODCOD configurations under the constraint of fixed power spectrum density level at the transmitter side. To this aim, the design of spectrum spreading techniques shall keep into consideration requirements such as spectrum mask, physical layer performance, link budget, hardware reuse, robustness, complexity, and backward compliance with existing commercial equipments. The proposed implementation allows to fully reuse the standard DVB-S2 circuitry and is inserted as an ‘inner layer’ in the standard DVB-S2 chain.

Key Words : DVB-S2, mobile environment, spectrum spreading, DS (Direct Sequence) technique, interference mitigation

I. Introduction

The DVB(Digital Video Broadcasting) steering board approved the new study mission to evolve the TM(Technical Module)-RCS(Return Channel via Satellite) standard providing the challenging mobile broadband service in 2006.[1] There is currently an emerging market for provision of broadband services of the nature handled by DVB-RCS to mobile terminals. With demand for mobile broadband interactive service based on DVB-S2/RCS, successful trials and implementation have already been realized using mobile terminals mounted in trains, ship, and aircraft. This is paralleled by the addition of challenging mobility support feature to DVB-RCS.[2][3][4] These include real-time handovers between satellite spot-beams, spectrum spreading features to meet regulatory constraints for mobile terminals, and countermeasures against shadowing and blocking of the satellite link. Among them, we focus on the option for spreading; this is only relevant if smaller size antennas are to be used on moving platforms, such as vehicles. [5]

2. Research rationale

DVB-RCS+M is designed for operation in Ku(11-14GHz) and Ka band (20-30GHz). Indeed,

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this design choice allows to exploit the existing DVB-RCS and S2 schemes and to use small directive antennas, thus reducing the practical deployment in ODU (Outdoor Unit) and operational costs. However, the drawback is that specific interference countermeasures are needed because these bands are allocated to MSS(Mobile Satellite System) service with a lower priority(on a secondary basis) over FSS(Fixed Satellite System), thus imposing more stringent limitation on the power spectrum emission (the off-axis power flux density) and a lower protection from FSS interference. The way to solve the interference mitigation devised by the RCS standard is the adoption of a spreading technique. In this paper, we dominantly deal with application of spreading technique based on DS(Direct Sequence) approach in the FL(Forward Link) compatible with conventional S2 waveform.

3. DS Spreading in FL DVB-RCS+M

3.1. Overview

A DVB-S2 forward link transmission can be spread in bandwidth using the provisions in this clause. Such spreading is applied in two stages: spreading and scrambling. The first operation, spreading, multiplies every (I+jQ) symbol by a sequence of chips to enlarge the bandwidth of the signal. The number of chips per symbol is called the Spreading Factor (SF). When SF = 1, the transmission is a conventional DVB-S2 signal. The second operation, scrambling, applies a scrambling code to the spread signal. The processing is illustrated in Figure 3.1. Spreading shall be applied on a PLFRAME basis. Each symbol in a PLFRAME, including the PLHEADER and pilot symbols if used, shall be spread by a repetition of a real-valued spreading code $C(i)$. The output of the spreading for each symbol on the I and Q branches shall thus be a sequence of SF chips corresponding to the spreading code chip sequence, multiplied by the corresponding, real-valued symbol component value. The spreading code sequence shall be time-aligned time with the symbol boundary.

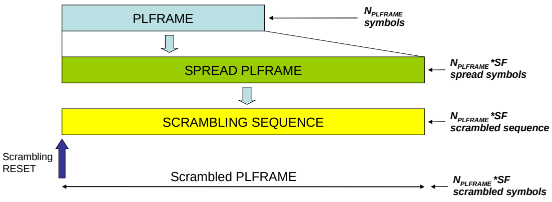

Figure 3.1: Forward link spectrum spreading

If $\{d[k]\}$, $k = 0, 1,\ldots, N_{PLFRAME}-1$, represents the ($I$+$jQ$) symbols of the PLFRAME, where $N_{PLFRAME}$ is the number of symbols in one PLFRAME, then the spreading operation yields the spread sequence $s(i)$:

$$s(i) = d(\lfloor i/SF \rfloor)C(\mathrm{mod}(i, SF)) \quad \text{for } i = 0, 1, \ldots, (N_{PLFRAME} \times SF)-1 \qquad (1)$$

Spreading codes C(i) are defined for spreading factors of 1, 2, 3 and 4 and are signalled in the Satellite Forward Link Descriptor.. In terms of the reference modulator signal flow defined in DVB-S2 [2], the spreading shall be performed immediately prior to the physical layer scrambling. The second operation, scrambling, shall replace that defined for physical layer scrambling of [2] and shall be achieved through the use of the same method, except that the length of the scrambling sequence is here equal to NPLFRAME × SF, rather than NPLFRAME. The scrambling sequence shall be aligned with the PLFRAME epoch, and it shall be re-initialized at the beginning of each PLFRAME.

The sequence of complex valued chips shall be scrambled (complex chip-wise multiplication) by the complex-valued scrambling code, w(i), defined in [2], when SF is greater than 1. The Spread PLFRAME duration depends on the selected modulation and the adopted spreading factor. The scrambled symbols, z(i), shall be obtained by directly multiplying the spread symbols, s(i), by the scrambling sequence, w(i), as follows:

$$z(i) = s(i) \times w(i \text{ modulo } 66420),\ i=0,1,2,\ldots, (N_{PLFRAME} \times SF)-1 \qquad (2)$$

After scrambling, the signal $\{z(i)\}$ shall be square root raised cosine filtered as described in [2]. It is mandatory to define an explicit scrambling sequence in the corresponding satellite forward link descriptor when SF is greater than 1.

3.2. Design Description

This approach consists in using a matched filter after the square root raised cosine filter. Spreading sequence is then applied to the symbols and resulting signal is filtered using the common square root raised cosine filter described in DVB-S2 standard. At the receiver side, dual operations must be performed. It should be remarked that this solution does not touch the standard DVB-S2 hardware circuitry, allowing standard chips to be reused accordingly like

Figure 3.2. The Figure 3.2 shows the typical Modulator/Demodulator structure. In the case of the application of maximum spreading factor (increasing chip rate), it could be assumed that the use of 2 or 3 over-sample clock is possible. Above all, this solution is available to reuse DVB-S2 hardware circuitry. Using long sequences, this approach can preserve control over the spectral properties, since the outgoing signal presents the same spectral shaping of conventional DVB-S2 signal. Of course, the bandwidth of the produced signal is directly linked to the chip rate. As we can see in Figure 3-2, it requires an additional Matched Filter, sampler, and Square Root Raised Cosine Filter are needed both at the transmitter and at the receiver side. In any case, the reuse of DVB-S2 hardware existing commercial equipment and the possibility to keep DVB-S2 signal spectrum properties makes this solution attractive.

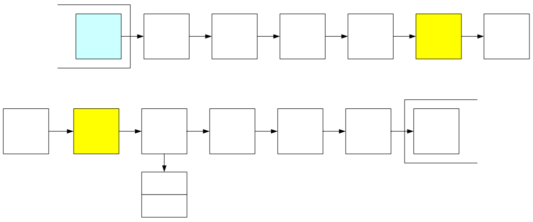

Figure 3.2: DS-spreading after Matched-Filter

3.3. Design implementation of DS-SS

It is assumed that DS spectrum spreading functional block will be occupied at the internal portion of conventional DVB-S2 modulator block. It would be better to implement the spreading in digital inside the modulator rather than after the DAC as it will require another ADC/DAC plus other logic. At the transmitter, the way to find optimum Matched filter sampling time should be clear. In this text, the simple approach is proposed. In the Figure 3.3, the sampling point A stands for the optimum sampling point, The remaining like B, C and D are oversampling points under the assumption of 4 oversampling operation. Like Figure 3.4, it should be initialized to remove the dummy symbol values that they cause the filtered delay by matched filter at the first PL frame. The delay values depend on the number of filter tap. And, then it should be accumulated the absolute values of the difference between the absolute values of matched filtered output signals and original signal level with real and imaginary signals, respectively. The sampling points with the minimum value at the every sampling time are the desired ones. C1, C2, C3, C4 mean that the accumulated values calculated at the 4 oversampling points.

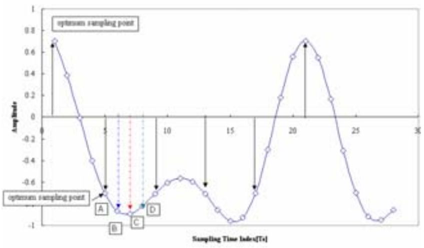

Figure 3.3: DS-spreading signal waveform

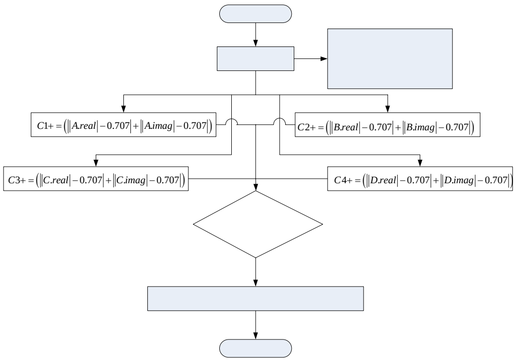

Figure 3.4: The proposed method to find the optimum sampling point

4. Performance evaluation [6]

4.1. Introduction

In this section, the impact of the DS-SS technique on the DVB-S2 FL performance is analyzed: on-board IMUX/OMUX filters, HPA non-linear distortion, Rice propagation channel and AWG noise are considered. When adjacent satellites are present the effect of the resulting interference are kept into consideration ad reported in Figure 4.1. In particular, the attenuator block allows to take into account different interference levels resulting from different orbit spacings and antenna C/I.

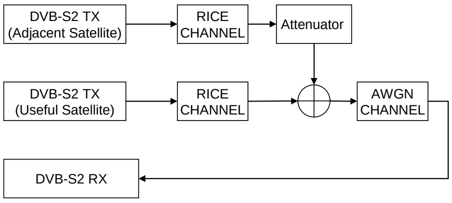

Figure 4.1 Block Diagram modifications to take into account adjacent satellite interference

DVB-S2
Modulator

4.2. Channel impairments characterization

In this section the channel impairments simulation blocks adopted to reproduce the baseline requirement condition are described.

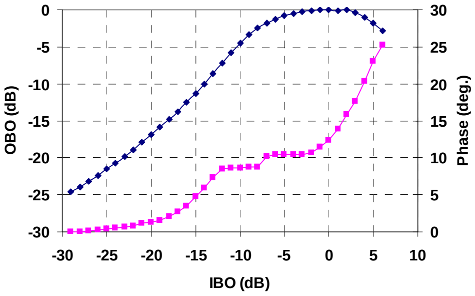

Figure 4.2 Considered HPA AM/AM and AM/PM characteristics for Ku-band

- Non-linearities impact
  - ○ The linearized TWTA for Ku-band proposed in DVB-S2 specification has been considered. The AM/AM and AM/PM characteristics are reported in Figure 4.2
- Phase noise impact
  - ○ The following phase noise mask has been considered
  - ○ The simulations reported in this section take into account the impact of phase noise by assessing the differential impact that phase noise has on the despreading operation, i.e. genie-aided phase noise estimation has been assumed at symbol level, leaving the impact of phase noise at chip level only.

● 100 Hz	● -45dBc/Hz
● 1000 Hz	● -65dBc/Hz
● 10000 Hz	● -80dBc/Hz
● 100000 Hz	● -95dBc/Hz
● 1e+006 Hz	● -105dBc/Hz
● >1e+007 Hz	● -115dBc/Hz

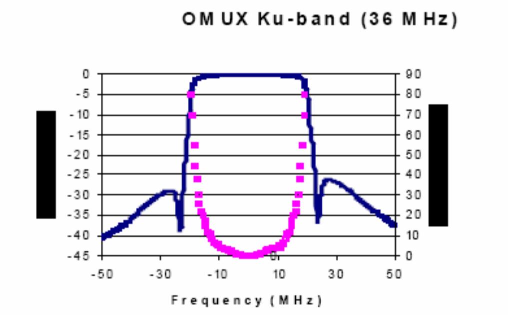

Figure 4.3 Considered OMUX frequency response

- OMUX impact
  - ○ The considered on-board OMUX follows the DVB-S2 specification as reported in

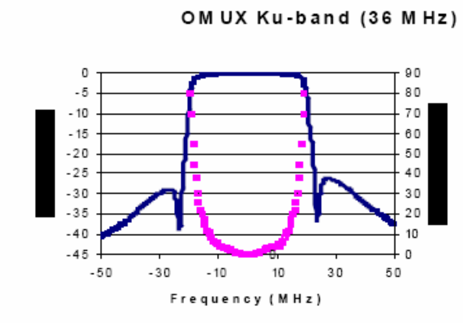

Figure 4.3.

- Co-channel Interference
  - ○ C/I =0, 3 and 6dB.
  - ○ The co-channel interference occupies the whole 36 MHz BW.

4.3. Performance in ideal condition (no interference, ideal satellite payload)

First of all, to validate the software implement-tation, simulations in ideal condition have been performed. In Figure 4, the resulting Bit Error Rate is plotted as a function of Eb/N0 for MOD-COD QPSK ¼ with long packets (64800 bits) and spreading factor 2. The curve refers to Ideal Channel condition and it has been obtained using the following parameters:

- AWGN channel
- Linear HPA
- No interference from adjacent satellites

Under such conditions, spreading should not introduce any Eb/N0 performance difference with respect to the standard DVB-S2 system. Since the curve in Figure 4.4 overlaps with the corresponding reference curve in the DVB-S2 standard, the validation can be considered successful.

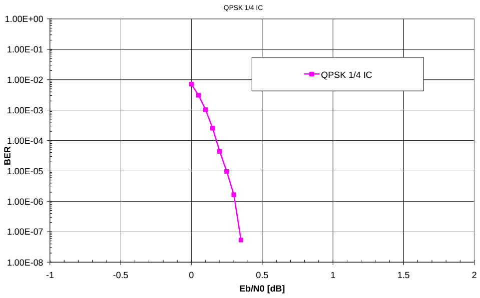

Figure 4.4 Bit Error Rate vs. Eb/N0 in ideal condition for QPSK ¼, Spreading factor 2.

A. Robustness to non linear power amplification

Two Input Back-Off (IBO) values have been considered, to take into account different operating conditions. Figure 4.5 shows the loss due to the non linear distortion. Curves with triangular and rhombus markers refer to HPA with IBO=2 and IBO=0.5, respectively. In these cases there is a loss of about 0.2 dB and 0.25 dB, for IBO 2 and 0.5 dB, respectively (due to the distortion introduced by HPA) with respect to the linear amplification condition. In the same Figure 4.5, the robustness to non-linear distortion is compared for the spread and non-spread signals. As it can be seen, signal spreading slightly increases the robustness to non-linear distortion. In Figure 4.6, the Power Spectral Density of the signal outgoing from the HPA is shown. As it can be seen, the spectral regeneration introduced by the non linearity related to the power amplifier is significant. However, thanks to the presence of the on-board multiplexers, the unwanted spectral regrowth is removed. Regarding the satellite amplifier operating point, which relates directly to the available EIRP, when the satellite amplifier is operated at an IBO equal to 0.5 dB, the corresponding OBO is as low as 0.4 dB. This low value can be achieved since the amplification of a single carrier signal is considered, and the QPSK modulated signal is very resilient to non linear distortion. Being the E_b/N_0 degradation equal to 0.25 dB, the corresponding total degradation is thus equal to 0.65dB at BER equal to 10^{-6}.

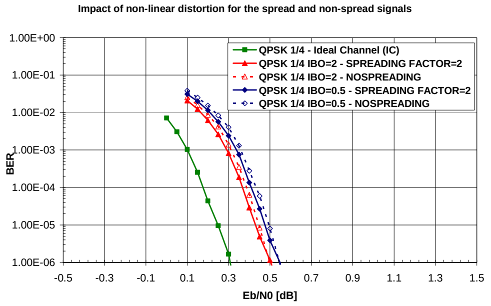

Figure 4.5: Comparison between spread and not spread signal with non linear HPA

B. Impact of Phase Noise on despreading

Phase noise has been considered in presence of non-linear amplification. The following scenario has been considered:

- Chip Rate → 27.5Mchip/sec (Roll-off=0.35, BW=36MHz)
- HPA IBO → 0.5 dB
- Phase Nose Mask as described in the section 4.2.
- Spreading Factor 2, 4.
- AWGN propagation conditions.

Figure 4.7 shows the impact of Phase Noise on BER performance in AWGN propagation conditions. As it can be seen, the marginal impact of phase noise on the despreading operation is negligible, being lower than 0.1 dB. As discussed in 4.2, the differential impact that phase noise has on the despreading operation has been assessed, i.e. genie-aided phase noise estimation has been assumed at symbol level, leaving the impact of phase noise at chip level only.

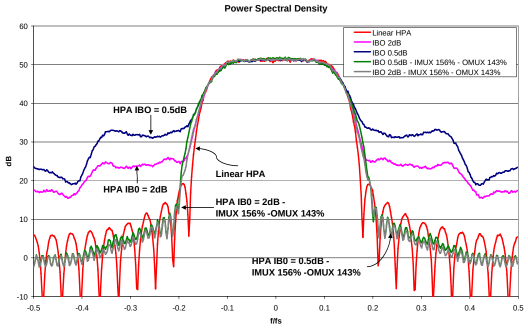

Figure 4.6 Power Spectral Density after power amplifier, spreading factor 2

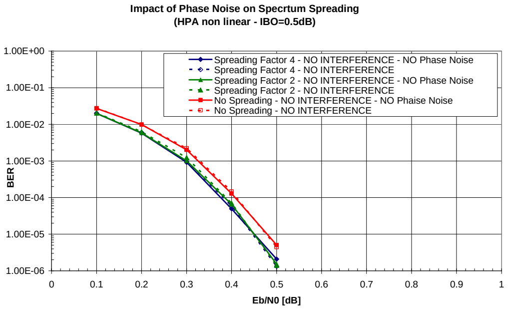

Figure 4.7 Impact of phase noise on the despreading operation

C. Impact of adjacent channel interference

This section deals with the assessment of the robustness of the DVB-S2 signal with spreading to the interference coming from adjacent satellites transmitting in the same frequency bands. The interferers are supposed to be using standard compliant DVB-S2 waveforms, thus not considering the use of spectrum spreading techniques. A chip rate equal to 27.5 Mchip/s is assumed for the useful signal, while the interfering signals are transmitting at a symbol rate equal to 27.5 Mchip/s, so that the considered signals have, in ideal conditions, the same spectral allocation. The following parameters have been assumed:

- Chip Rate → 27.5Mchip/sec (36MHz)
- HPA IBO → 0.5 dB
- AWGN propagation conditions.
- Phase Nose Mask as described in section 4.2.
- QPSK interfering signal.
- C/I =0, 3 and 6dB.

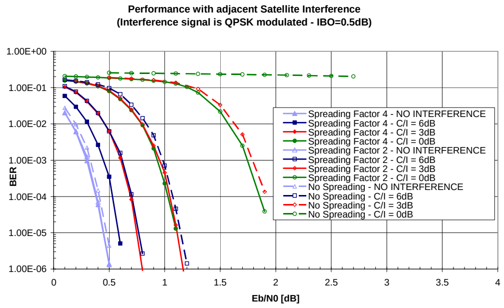

Figure 4.8: Impact of co-channel interference and non linear amplification.

Figure 4.8 presents the performance in the presence of co-channel interference for two different spreading factors, namely 2 and 4, in comparison with the signal without spreading. As it can be seen, the adoption of spreading factor 4 results in a much stronger robustness to interference. In particular, increasing spreading factor by 2 leads a gain in terms of interference resilience of at least 3dB. Regarding the impact of different modulation formats, an Adjacent Satellite Interference using 16APSK modulation has also been considered, and compared to the QPSK case. No significant difference between the two considered interfering modulations has to be noted.

D. Impact of terminal mobility

To assess the performance of spread spectrum techniques in the railway environment, the following parameters have been considered to simulate the LOS railway scenario:

- Chip Rate → 27.5Mchip/sec (36MHz)
- Train speed → 350 Kph
- Rice Factor → 20 dB.
- HPA IBO → 0.5 dB
- Phase Nose Mask as described in section 4.2

The performance under these propagation conditions, reported in Figure 4.9, has a behavior analogous to the case without mobility. Further, there is an additional effect due to the fact that constant signal bandwidth is considered, resulting in a baud rate that is reduced of a factor equal to the spreading factor (2 and 4, respectively). In particular, as the spreading factor increases, the channel correlation seen at the symbol level (i.e. after despreading) decreases, resulting in higher time diversity that improves code performance.

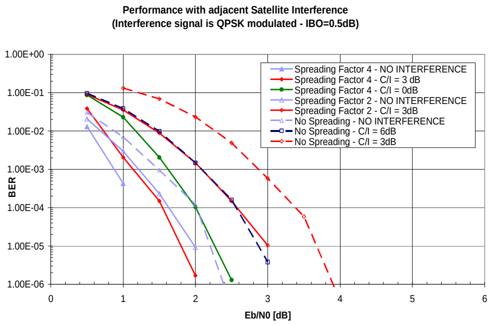

Figure 4.9: Impact of terminal mobility for different spreading factors and interference levels

5. Conclusions

This presents DS-SS technique for application to the forward link of a mobile DVB-RCS system, considering the DVB-S2 physical layer. Based on the outcomes of this study, the following key points apply: First, it is possible to fully reuse of existing DVB-S2 standard. Second, also tight spectrum control and no power spectral density modifications with respect to standard DVB-S2 waveforms. Independence of spectral characteristics from the adopted spreading factor. For a given occupied bandwidth, the only change is baud rate reduction. Third, it is very strong robustness to non linear distortion effects with respect to the standard DVB-S2 waveform. Total degradations as low as 0.65 dB can be attained, almost invariantly with respect to the spreading factor at BER equal to 10^{-6}. Lastly, it shows the improvement of adjacent Satellite Interference rejection increasing of 3dB for each spreading factor doubling.

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