SLS-RFM_19-21

Telemetry randomizer

(High Order Modulations and random OID)

Roberto Garello (garello@polito.it)

Politecnico di Torino

Massimo Battaglioni, Marco Baldi, Franco Chiaraluce

Università Politecnica delle Marche

Massimo Bertinelli, Gian Paolo Calzolari, Andrea Modenini, Enrico Vassallo

European Space Agency

CCSDS SLS-RFM WG MEETING

Darmstadt, Germany, 21-24 October 2019

Summary

1. Introduction
2. Random OID frames generation
3. Random OID frames and 8-cell randomizer
4. Random OID frames and High Order Modulations
5. Impact of coding
6. Conclusions

1. Introduction

Telemetry randomizer

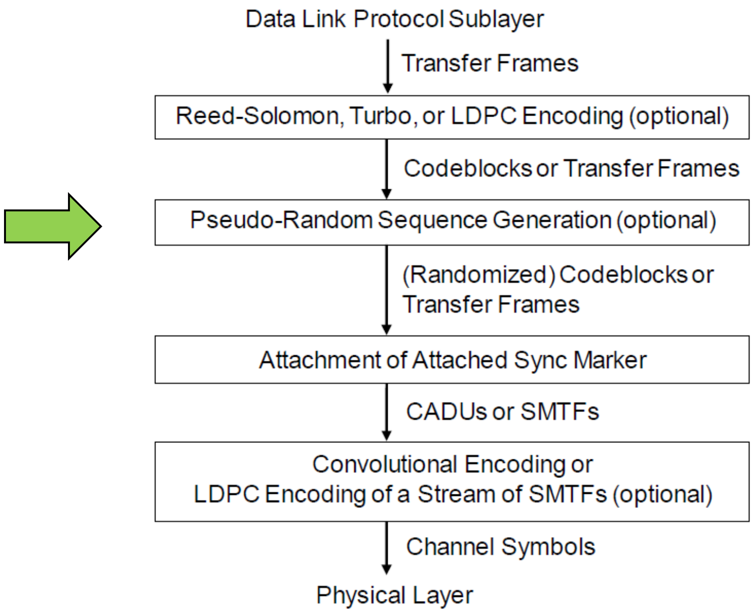


Figure 2-2: Internal Organization of the Sublayer at the Sending End

NASA proposed to change the current 8-cell LFSR randomizer into a new 17-cell randomizer

Previous meeting 1/2

CCSDS SLS-RFM WG MEETING
Mountain View, California, United States, 6-9 May 2019

Mountain View, California, United States

6-9 May 2019

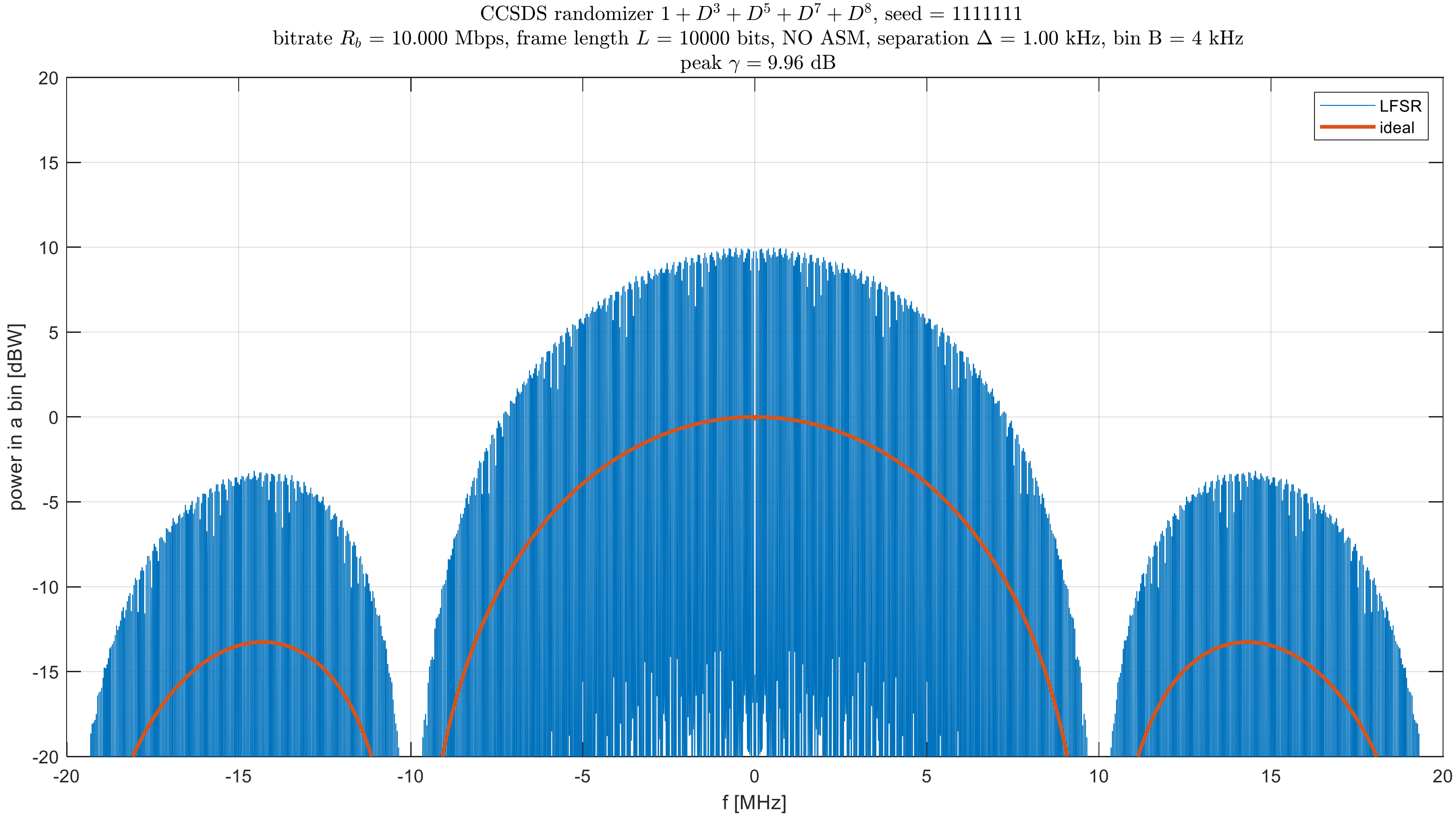
From minutes of meeting:

The main message is that the NASA proposed **PN17 randomizer is obviously advantageous over the current standard PN8** and would **meet all RFM 401-B requirements** but still **does not guarantee compliance with ITU limits** when **all-zero OID frames** are transmitted. The only solution is to use in addition an asynchronous free-running 32-bit **randomizer for OID frames.**

CCSDS 8-cell randomizer

Bit rate R_b = 10 Mbps
Frame length L =10,000
Total length L_T = 10,000
Spurious separation $\Delta = R_b/L_T$ = 1 kHz

Measurement band = 4 kHz
2-PSK
NO ASM
OID CADU with all-zero payload



- Large extra-power peak γ = 9.96 dB

Taken from SLS_RFM_19_03, p. 51

NASA 17-cell randomizer

Bit rate R_b = 10 Mbps

Frame length L =10,000

Total length L_T = 10,000

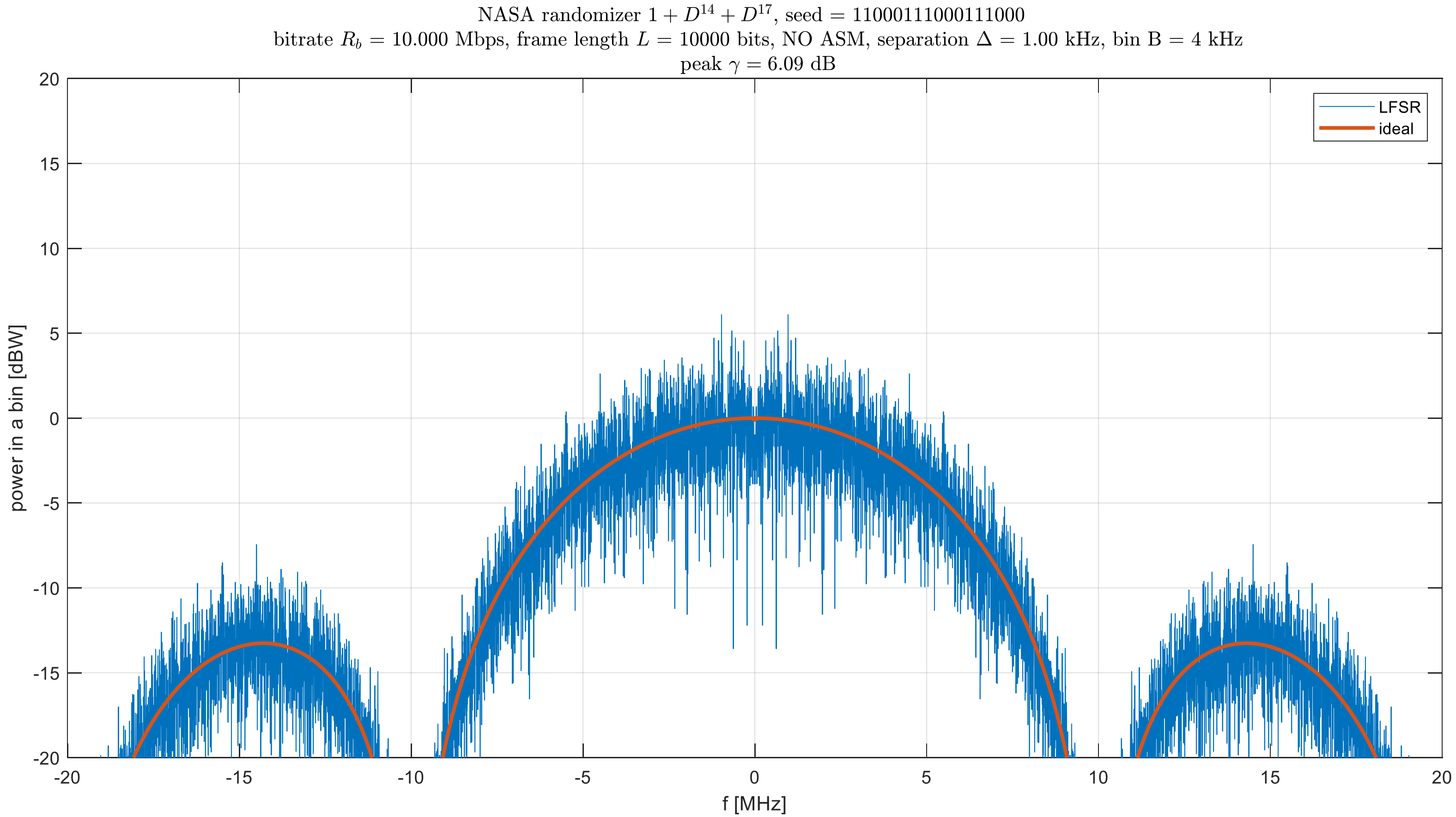
Spurious separation $\Delta = R_b/L_T$ = 1 kHz

Measurement band = 4 kHz

2-PSK

NO ASM

OID CADU with all-zero payload



- Lower extra-power peak $\gamma \approx 6$ dB

Taken from SLS_RFM_19_03, p. 52

NASA 17-cell randomizer

Bit rate R_b = 10 Mbps

Frame length L =10,000

Total length L_T = 10,000

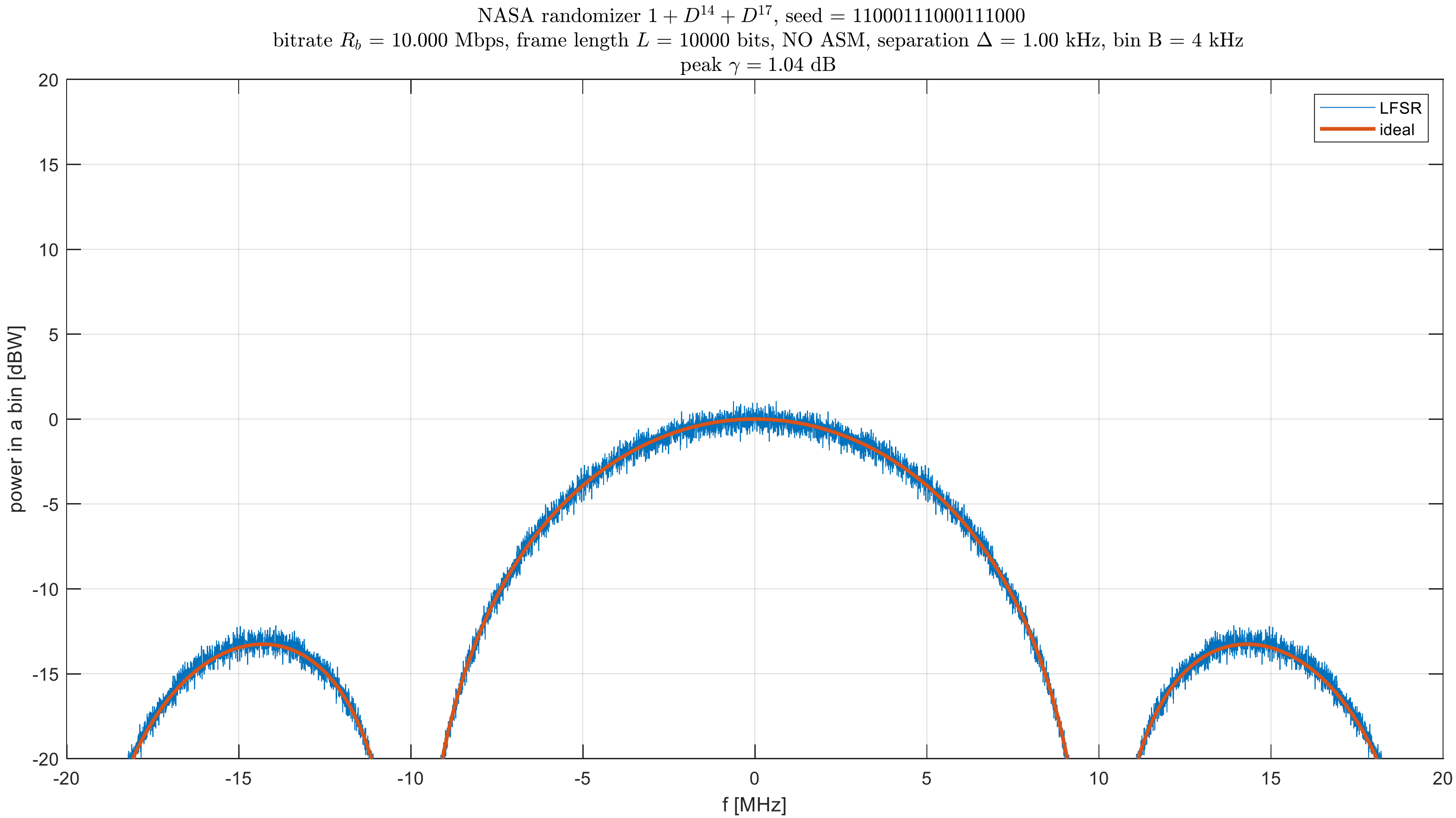
Spurious separation $\Delta = R_b/L_T$ = 1 kHz

Measurement band = 4 kHz

2-PSK

NO ASM

OID CADU with random pattern



- Nearly-ideal spectrum

Taken from SLS_RFM_19_03, p. 53

Previous meeting 2/2

CCSDS Spring 2019 Meeting
Mountain View (US), 06-09 May 2019

SLS C&S Working Group Minutes of the Meeting

CCSDS SLS-RFM WG MEETING
Mountain View, California, United States, 6-9 May 2019

Mountain View, California, United States

6-9 May 2019

Besides, as an outcome, **the way to actually randomize the OID** will be proposed (in coordination with SLS-SLP WG owner of the relevant recommended standards)

It was not clear **if the current PN8 randomizer would be sufficient** for ITU compliance in presence of **randomized OID frames.**

Also **extension to higher order modulation** is needed before any conclusions can be reached.

An input to the Fall 2019 meeting by ESA is planned and will address these issues

2. Random OID generation

Random OID frame generation: LFSR choice

We propose to fill the data field of OID frames with the bits generated by

a 32-cell LFSR with polynomial $1 + D + D^2 + D^{22} + D^{32}$

- The period of this polynomial is $2^{32}-1$ = 4,294,967,295 bits.
- Longest run is 32 bits
- Number of cells is a multiple of 8

Note: a smaller polynomial (e.g. a 24-cell LFSR) is probably enough for our purposes. Anyway, we believe that nowadays LFSR implementation complexity is negligible for this numbers of cells.

Random OID frame generation: LFSR initialization

Different alternatives are possible. Among them:

1. Initialize the LFSR at the device set up with an all-one seed and never restart it.

2. Reinitialize the LFSR every day with a random seed (e.g., generated from time and date) or a fixed (e.g., all-one) seed.

3. Reinitialize the LFSR every time the spacecraft starts to transmit with random or fixed seed.

In any case, the LFSR must not be restarted every single frame.

Other solutions are possible. We believe they show no significant differences concerning our goal of satisfying the ITU limits.

For simplicity, we suggest the first solution.

3. Random OID and 8-cell randomizer

Action

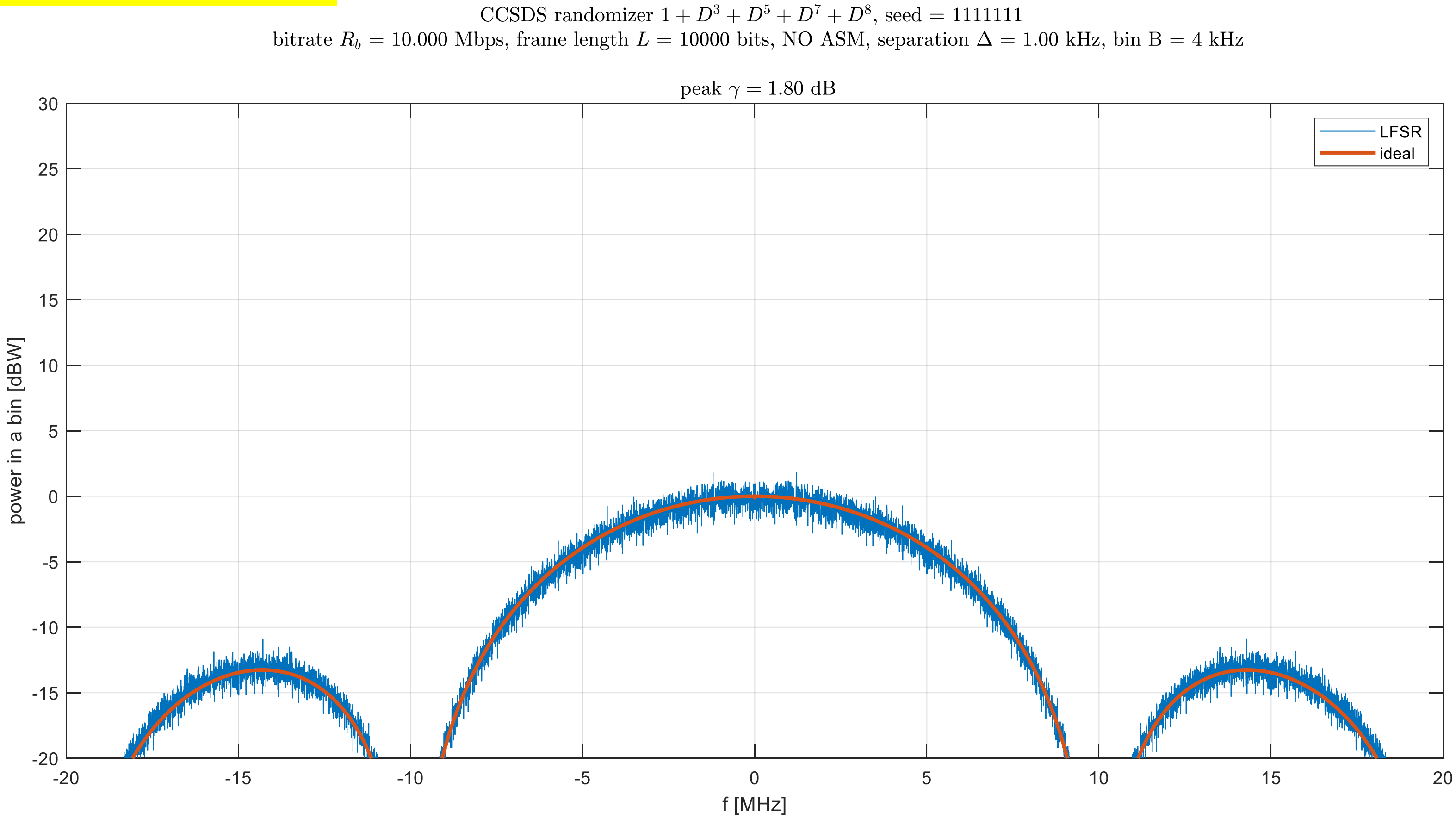
From minutes of meeting:

It was not clear **if the current PN8 randomizer would be sufficient** for ITU compliance in presence of **randomized OID frames.**

Random OID and CCSDS randomizer

OID CADU with random pattern
Bit rate R_b = 10 Mbps
Frame length L =10,000
NO ASM
CCSDS 8-cell randomizer

2-PSK
Measurement band = 4 kHz
Observation window W = 10 ms



- Nearly-ideal spectrum with the 8-cell randomizer, too.

Considerations

It seems that the 8-cell randomizer is enough to reduce PFD peaks when random OID frames are transmitted.

Despite this, we strongly suggest to update the randomizer to the new 17-cell LFSR, for at least these two reasons:

1. **The telemetry Transfer Frame data field might not contain random-like segments → problems when you transmit data CADUs (see following discussion on code impact).**

2. **For some reason the OID frames might be non-randomized and filled by zeros. In this case the new LFSR will limit the impact of spurious on spectrum.**

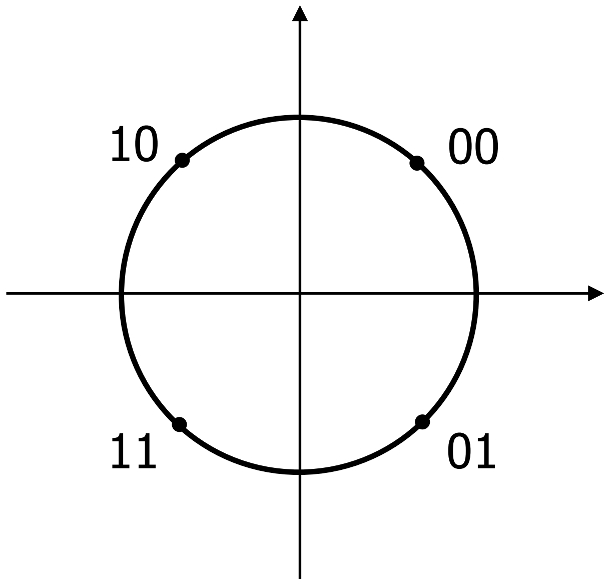
4. Random OID and High Order Modulations

High Order Modulations

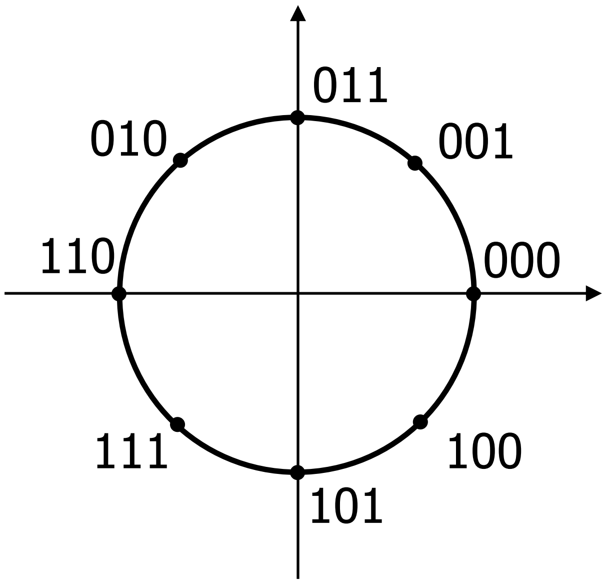
Until now, we have focused on 2-PSK modulation.

What about high order modulations? Is the 17-cell LFSR able to obtain nearly-ideal spectrums for these constellations, too?

4-PSK



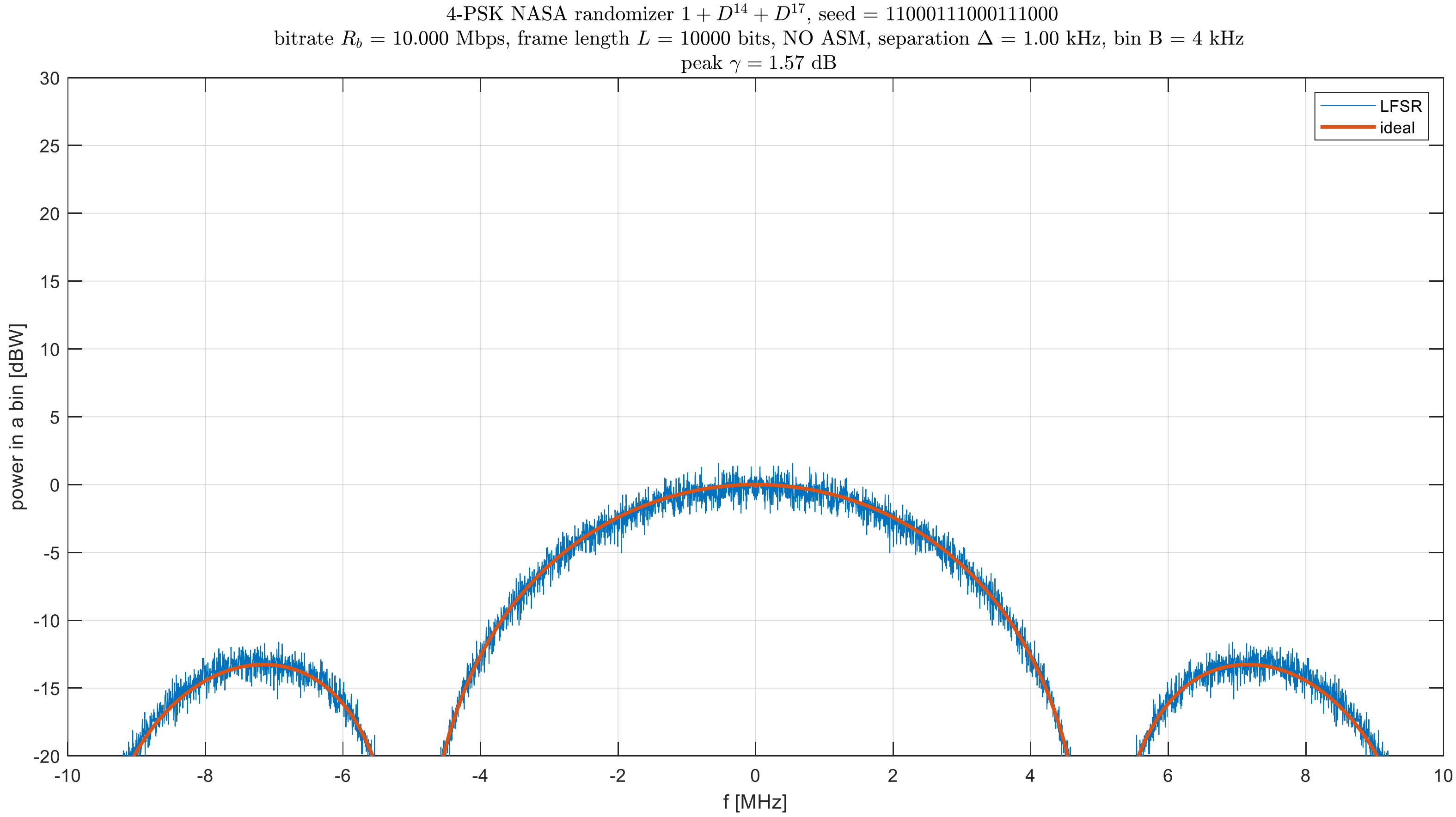
8-PSK



Random OID and 4-PSK

OID CADU with random pattern
Bit rate R_b = 10 Mbps
Frame length L =10,000
NO ASM
NASA 17-cell randomizer

4-PSK
Measurement band = 4 kHz
Observation window W = 10 ms



➢ Nearly-ideal spectrum

Random OID and 8-PSK

OID CADU with random pattern

Bit rate R_b = 10 Mbps

Frame length L =10,000

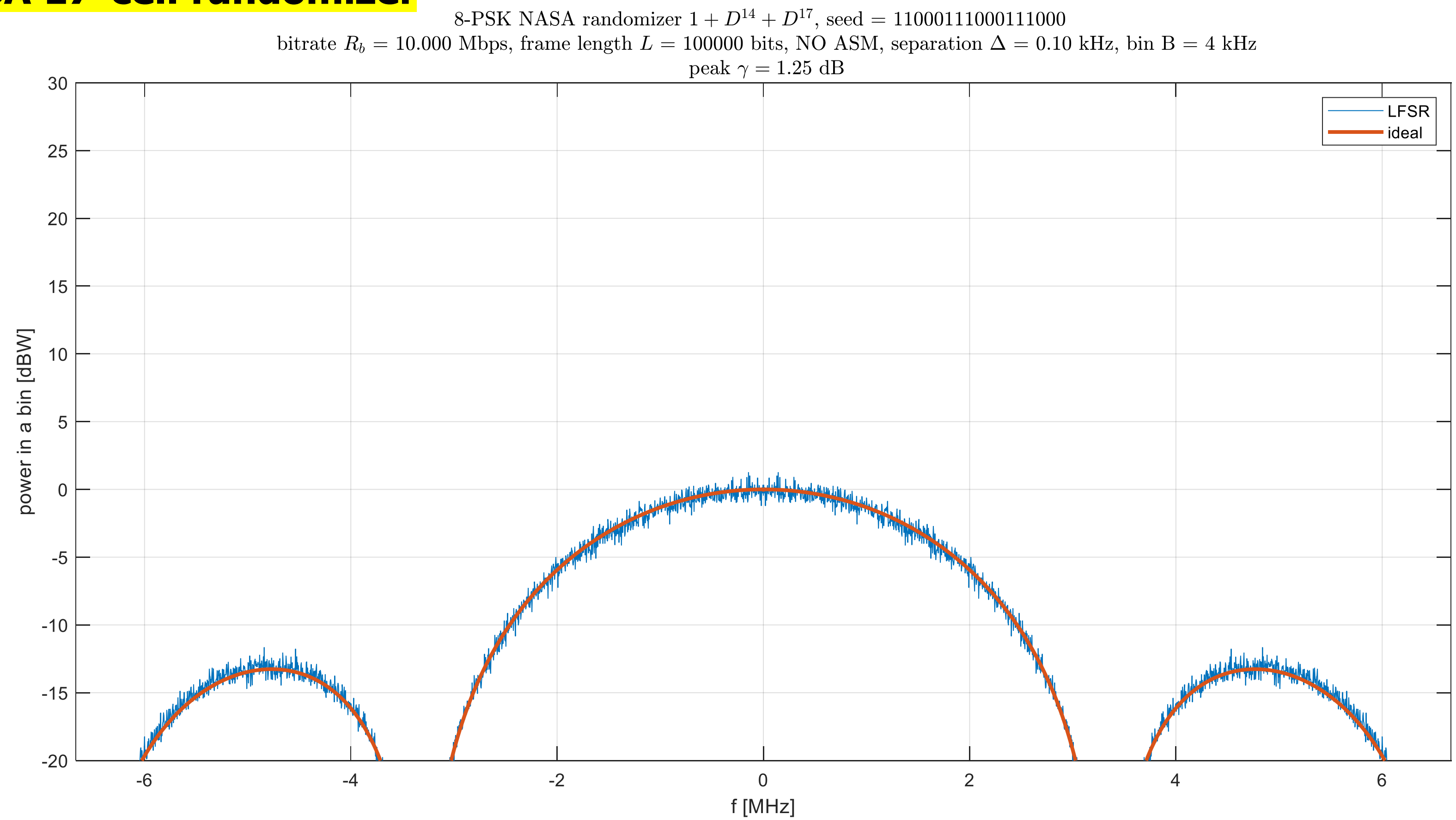
NO ASM

NASA 17-cell randomizer

8-PSK

Measurement band = 4 kHz

Observation window W = 10 ms



➢ Nearly-ideal spectrum

Considerations

When random OID frames are transmitted, the 17-cell randomizer looks enough to obtain nearly-ideal spectrums when High Order Modulations are transmitted, too.

4. Impact of coding

Encoded CADUs

Untill now, we have focused on OID frames.

What about Transfer Frames transmitting Telemetry data?
Is the 17-cell LFSR able to reduce the peaks when encoded CLTUs are transmitted, too?

Previous study showed that <u>when information sequences are random</u>, turbo encoded sequences look random, too [R1]. Then turbo-coded CADUs generated from TFs with random payload should have no problems. What about LDPC-coded CADUs generated from TFs with random payload?

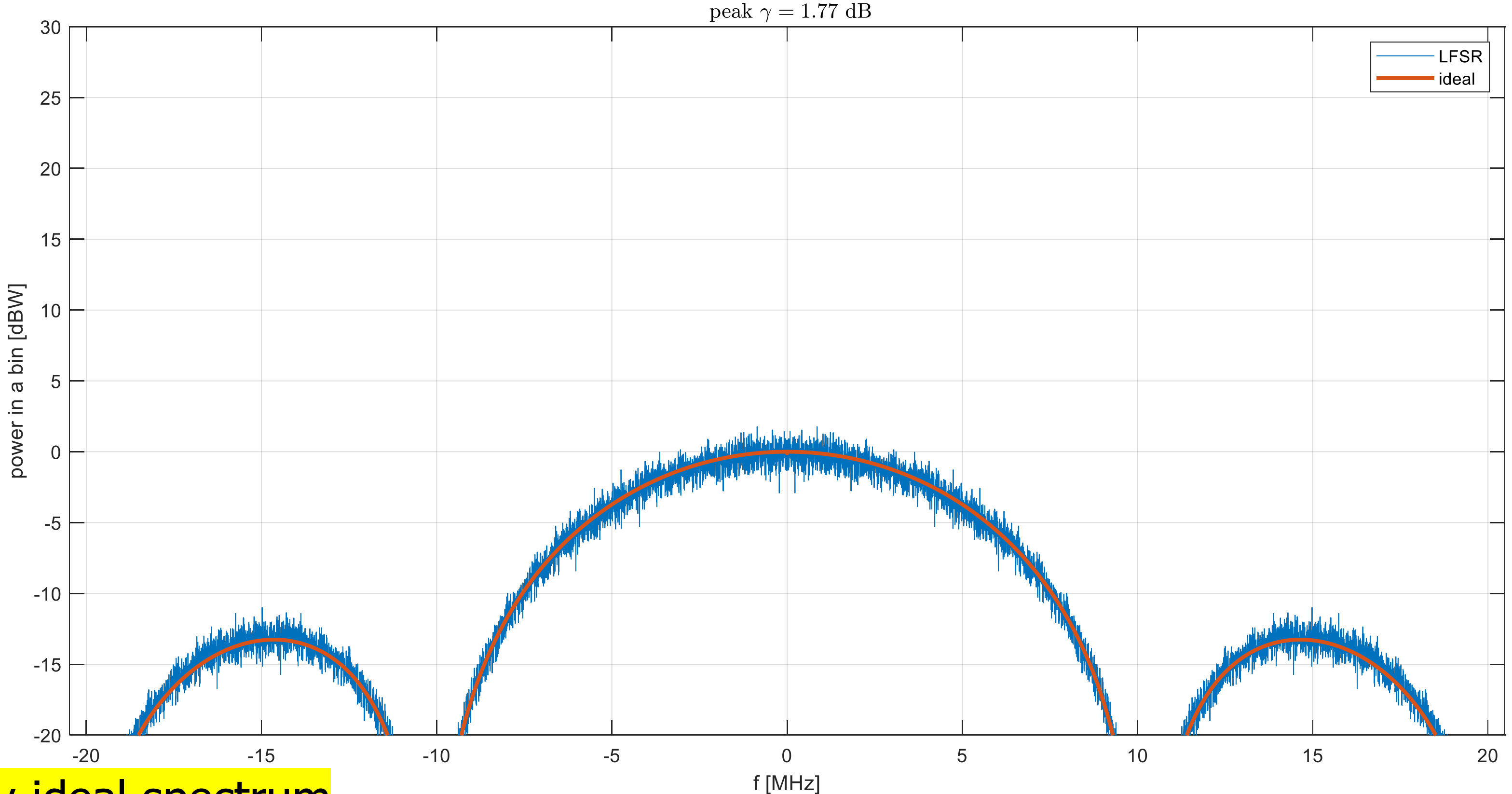
[R1] Gian Paolo Calzolari, Franco Chiaraluce, Roberto Garello, and Enrico Vassallo. "Symbol synchronization properties of CCSDS turbo codes". International Journal of Satellite Communications, September 2002, vol. 20, n. 5, pp. 379-390.

TF with random payload + LDPC(2048,1024)

Tranfer Frame with random payload
Bit rate R_b = 10.24 Mbps
Frame length L = 1024 bits
LDPC(2048,1024)
NO ASM
NASA 17-cell randomizer

2-PSK
Measurement band = 4 kHz
Observation window W = 10 ms

2-PSK LDPC(2048,1024) NASA randomizer $1 + D^{14} + D^{17}$, seed = 11000111000111000
bitrate R_b = 10.240 Mbps, frame length L = 102400 bits, NO ASM, separation Δ = 0.10 kHz, bin B = 4 kHz
peak γ = 1.77 dB



- Nearly-ideal spectrum

Considerations

In the considered simulations, the 17-cell randomizer was enough to obtain a nearly-ideal spectrum, when LDPC encoded TFs with random payload were considered.

(This confirms the LDPC output sequences have good properties in terms of randomness.)

Note: TFs with non-random payload

If the Transfer Frames to be transmitted have a non-random payload, some problems may arise at high rates.

Suppose, for example, that a sequence of TFs with the same payload is transmitted. Actually, the TFs are slightly different, because some bits in the TF header (at least the frame counter) and in the CRC are different.

When encoded, since the code is systematic, a large portion of the consecutive codewords is equal (in the information part, while the redundancy part is different).

Since the randomizer is restarted every CADU, a large portion of the consecutive CADUs is equal. This periodicity induces peaks in the spectrum. If the bit rate is high, these peaks may be high.

If the bit-rate is low, peak amplitude is limited (see the Appendix for an example). Usually, the transmission of TFs with fixed or slowing changing payload should concern low rate channel, only.

Note that the problem cannot be solved without changing the rule of restarting the randomizer every CADU.

5. Conclusions

Conclusions

- Some solutions for random OID frame generation have been presented.
- Even if 8-cell randomizer is probably enough for random OID frames, we suggest to change to 17-cell randomizer.
- The new randomizer performs well with high-order modulations, too.
- The new randomizer performs well with encoded CADU carrying TFs with random payload, too.

Contacts

- Roberto Garello – Politecnico di Torino – garello@polito.it

- Massimo Battaglioni – Università Politecnica delle Marche – m.battaglioni@univpm.it
- Marco Baldi – Università Politecnica delle Marche – m.baldi@univpm.it
- Franco Chiaraluce – Università Politecnica delle Marche – f.chiaraluce@univpm.it

- Gian Paolo Calzolari – ESA/ESOC – gian.paolo.calzolari@esa.int
- Enrico Vassallo – ESA/ESOC – enrico.vassallo@esa.int

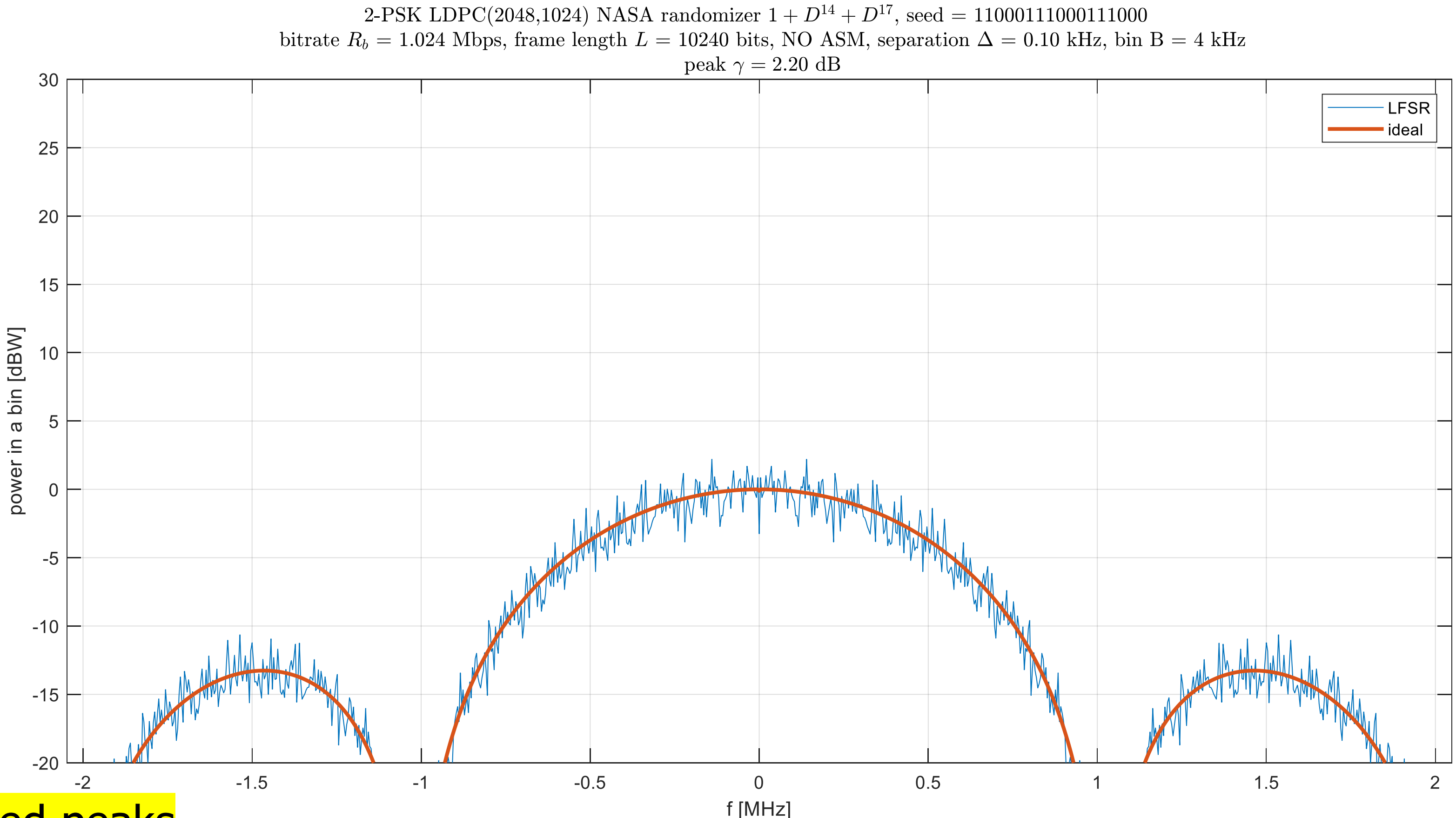
This document has been developed under ESA study "Telemetry Randomizer for High Data Rates".

Appendix

TF with fixed payload + LDPC(2048,1024) 1/2

Transfer Frame with fixed payload
Bit rate R_b = 1.024 Mbps
Frame length L =1024 bits
LDPC(2048,1024)
NO ASM
NASA 17-cell randomizer

2-PSK
Measurement band = 4 kHz
Observation window W = 10 ms

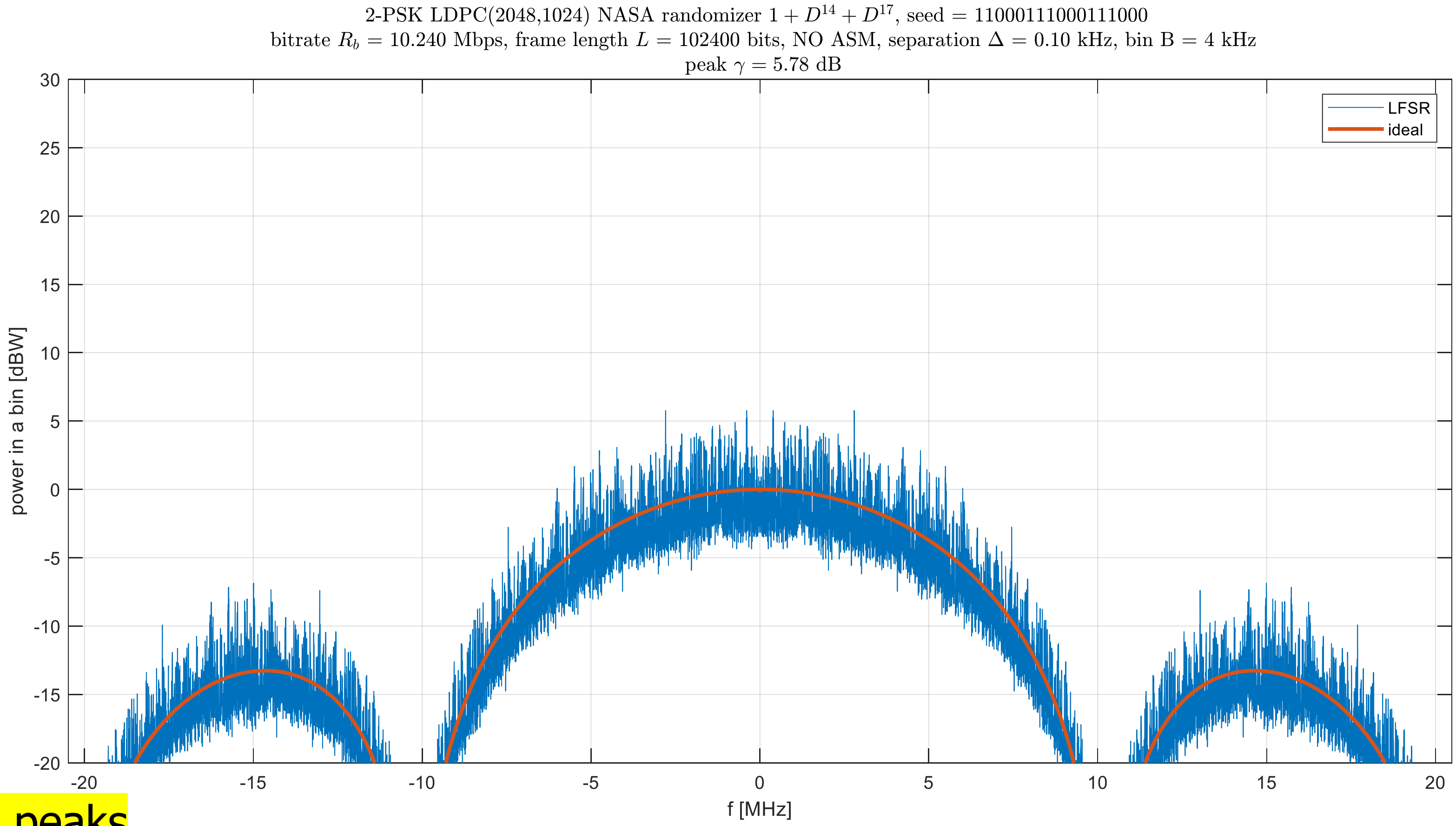


- Limited peaks

TF with fixed payload + LDPC(2048,1024) 2/2

Transfer Frame with fixed payload
Bit rate R_b = 10.24 Mbps
Frame length L =1024 bits
LDPC(2048,1024)
NO ASM
NASA 17-cell randomizer

2-PSK
Measurement band = 4 kHz
Observation window W = 10 ms



- High peaks

To be added for meeting presentation:

- Results with resolution band B = 1 MHz
- Results for APSK