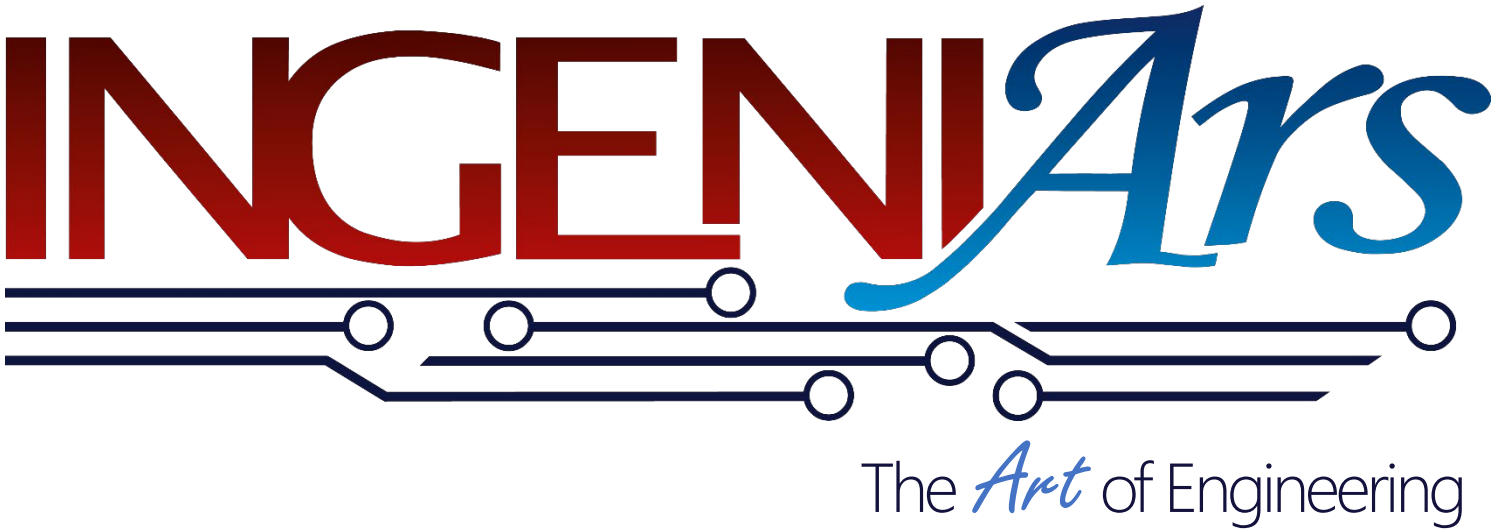


Breadboard for Simultaneous Transmission of HoM Telemetry and PN Ranging

SLS-RFM_24-14

IngeniArs

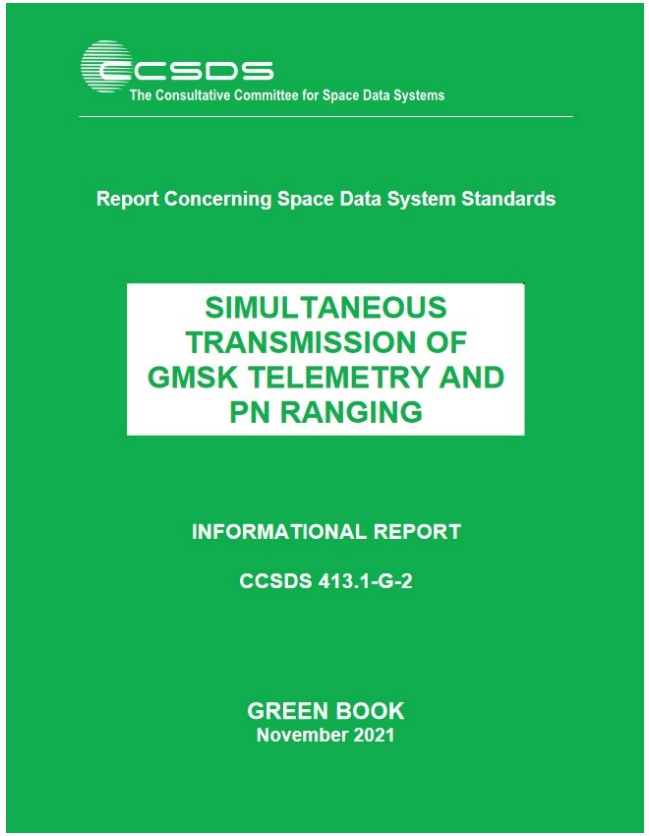
IngeniArs was founded in 2014 as **innovative start-up** and **University of Pisa spin-off company**. IngeniArs is a growing company counting talented and highly qualified graduates and PhDs in the field of electronic, informatic engineering and business development. One of the main topics is space is telecommunication.

HoM Activities and Projects:

- CCSDS 131.2-B Transmitter IP Core (ESA Portfolio)
- CCSDS 131.2-B Gbaud Transmitter IP Core
- CCSDS 131.2-B Receiver for Science
- CCSDS 131.2-B Receiver IP Core (ESA Portfolio)

Overview – Background

Follows the path of CCSDS 413.1-G for simultaneous transmission of GMSK + PN-Ranging



GMSK + PN-Ranging

Constant envelope modulation, 1-bit per symbol

GMSK BTs = 0.5, modulation index 0.222 → spectral efficiency (uncoded) ≈ 0.96 bit/Hz *

High-order modulations have higher spectral efficiency, but penalty on PN-Ranging and TWTA (e.g., need higher back-off w.r.t GMSK)

High Order Modulation TM + PN-Ranging

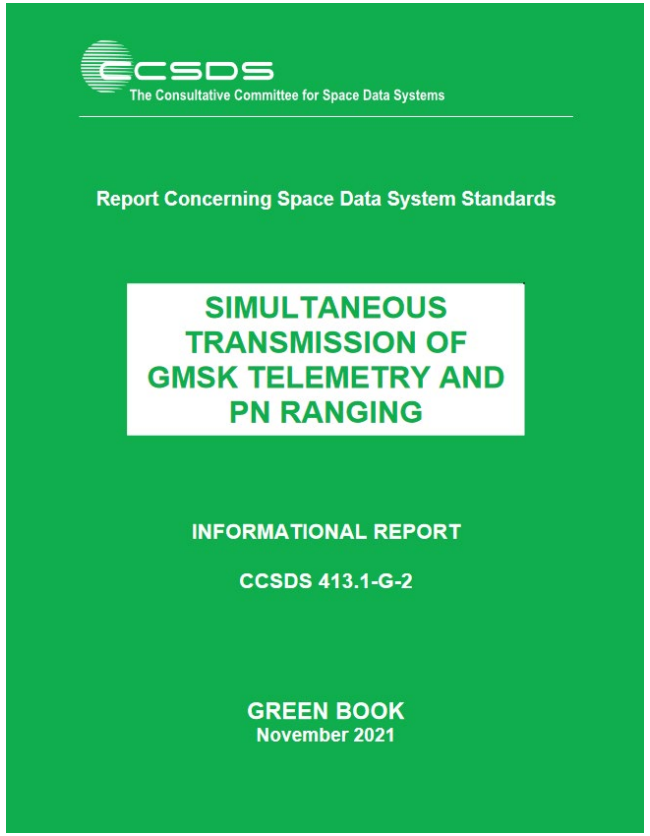
Non constant envelope modulations, multiple transmitted bits per symbol
Possibility to use adaptive coding and modulation (ACM) to optimize link budget

QPSK, roll-off 0.35, modulation index 0.222 → spectral efficiency (uncoded) ≈ 1.55 bit/Hz *
8PSK, roll-off 0.35, modulation index 0.222 → spectral efficiency (uncoded) ≈ 2.32 bit/Hz *
16-APSK, roll-off 0.35, modulation index 0.222 → spectral efficiency (uncoded) ≈ 3.22 bit/Hz *
32-APSK, roll-off 0.35, modulation index 0.222 → spectral efficiency (uncoded) ≈ 4.09 bit/Hz *
64-APSK, roll-off 0.35, modulation index 0.222 → spectral efficiency (uncoded) ≈ 5.08 bit/Hz *

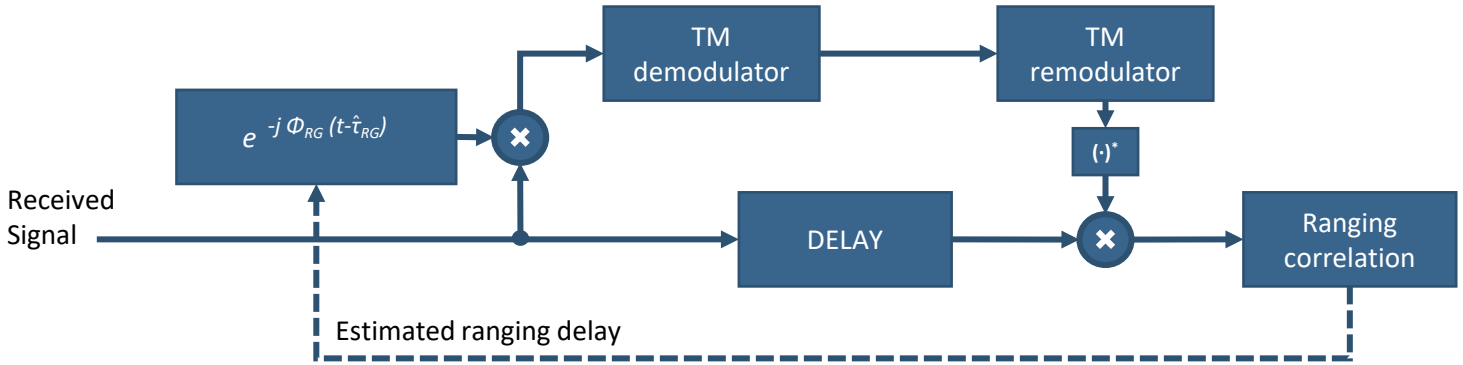
* “Study of Advanced Techniques for Simultaneous Transmission of PN Ranging and High Bit Rate”, B.Ripani (considering 99% bandwidth)

Overview – Background

Follows the path of CCSDS 413.1-G for simultaneous transmission of GMSK + PN-Ranging



High level Diagram of HoM Telemetry + PN-Ranging Receiver

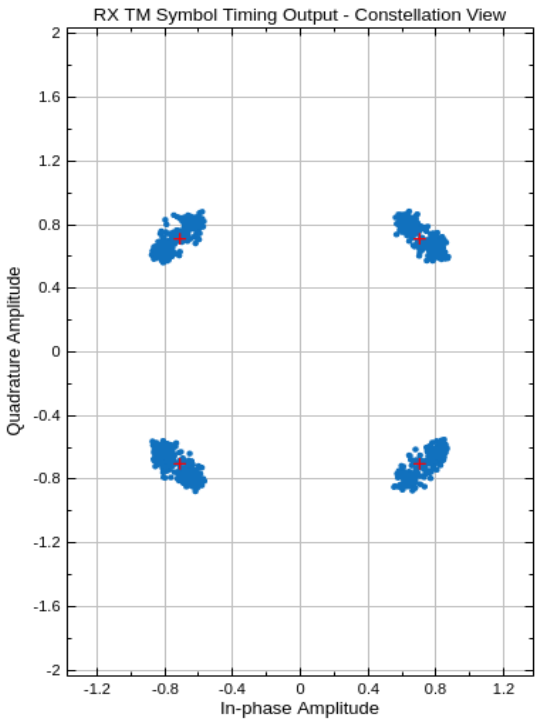


Approach:

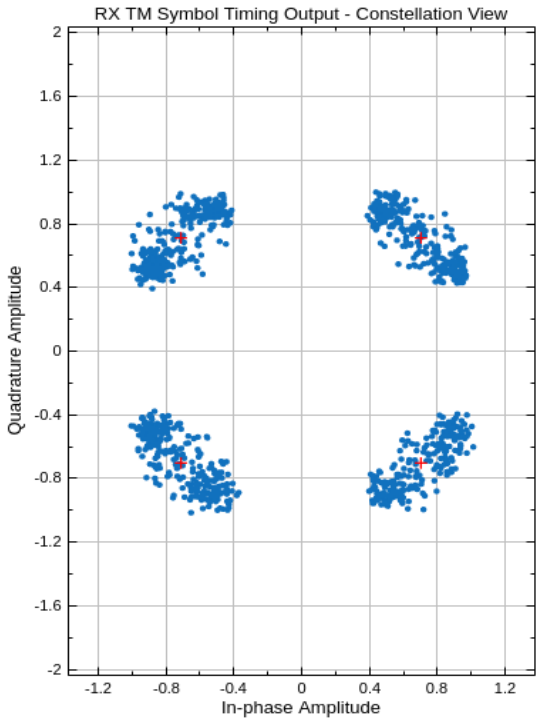
- Consider Φ_{RG} negligible compared to Φ_{TM}
- Perform telemetry demodulation, remodulation and cancellation
- Perform ranging acquisition, code delay estimation and cancellation

Overview – Background – HoM Effects

HoM TM + PN-Ranging – Modulation Index

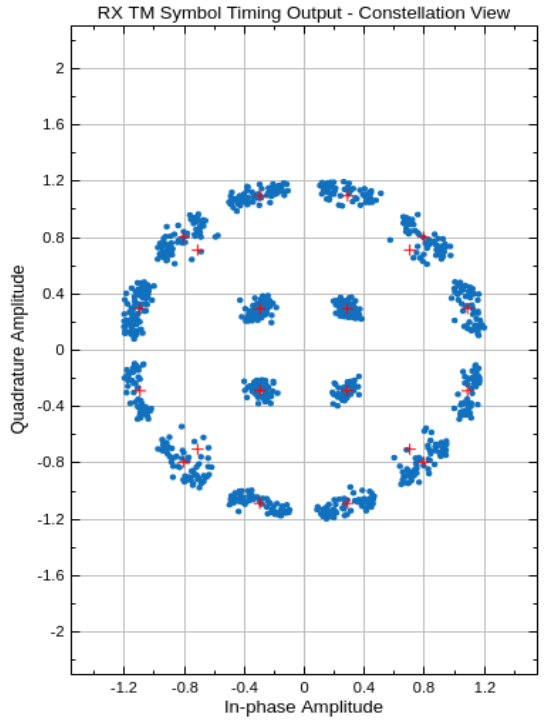


QPSK - m_{IDX} = 0.20

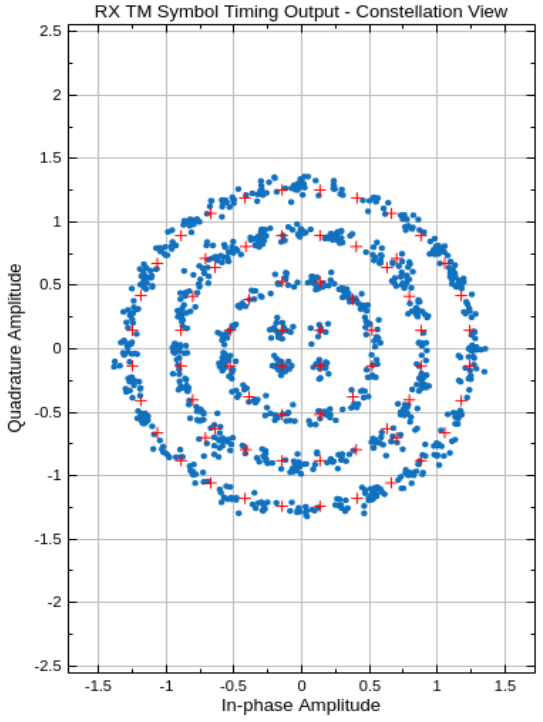


QPSK - m_{IDX} = 0.40

HoM TM + PN-Ranging – Constellation Order



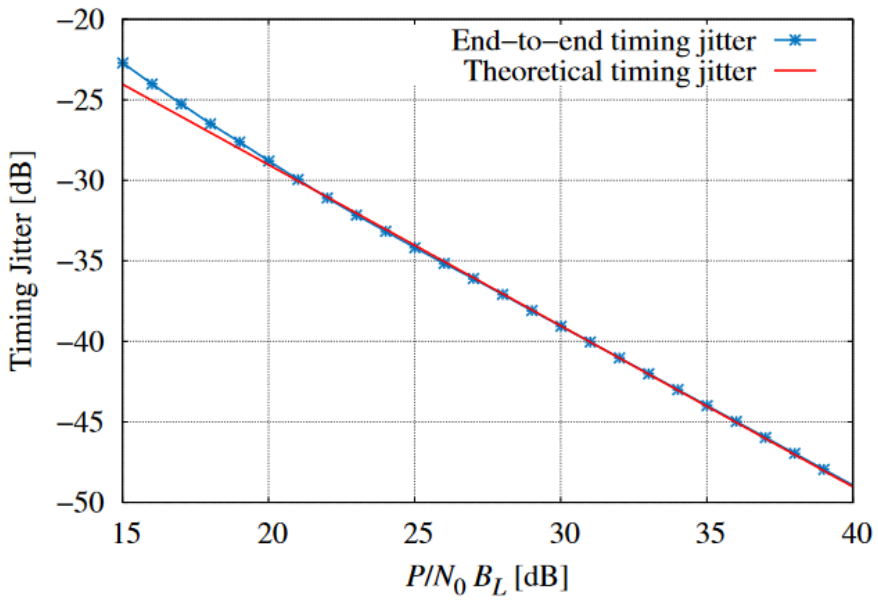
16-APSK - m_{IDX} = 0.20



64-APSK - m_{IDX} = 0.20

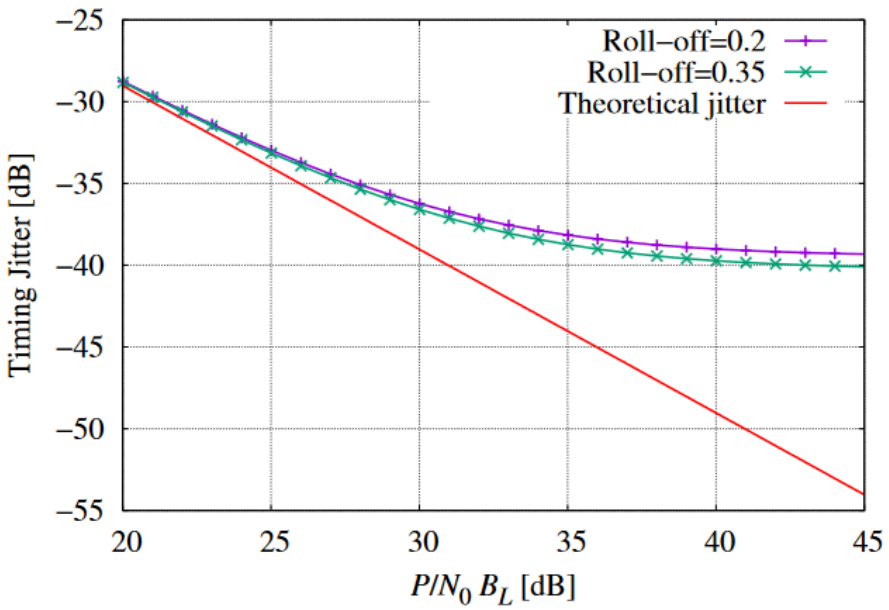
Overview – Background – HoM Effects

GMSK TM + PN-Ranging – RG Jitter



Telemetry cancellation leaves a pure ranging signal, so ideal jitter curves are obtained*

HoM TM + PN-Ranging – RG Jitter



telemetry cancellation leaves a residual on top of the ranging signal, creating a jitter floor*

*Data from “Study of Advanced Techniques for Simultaneous Transmission of PN Ranging and High Bit Rate”, B.Ripani

Main High Order Modulation (HoM) Standards

Main «High Order Modulation» Standards for space applications

DVB-S2 Standard

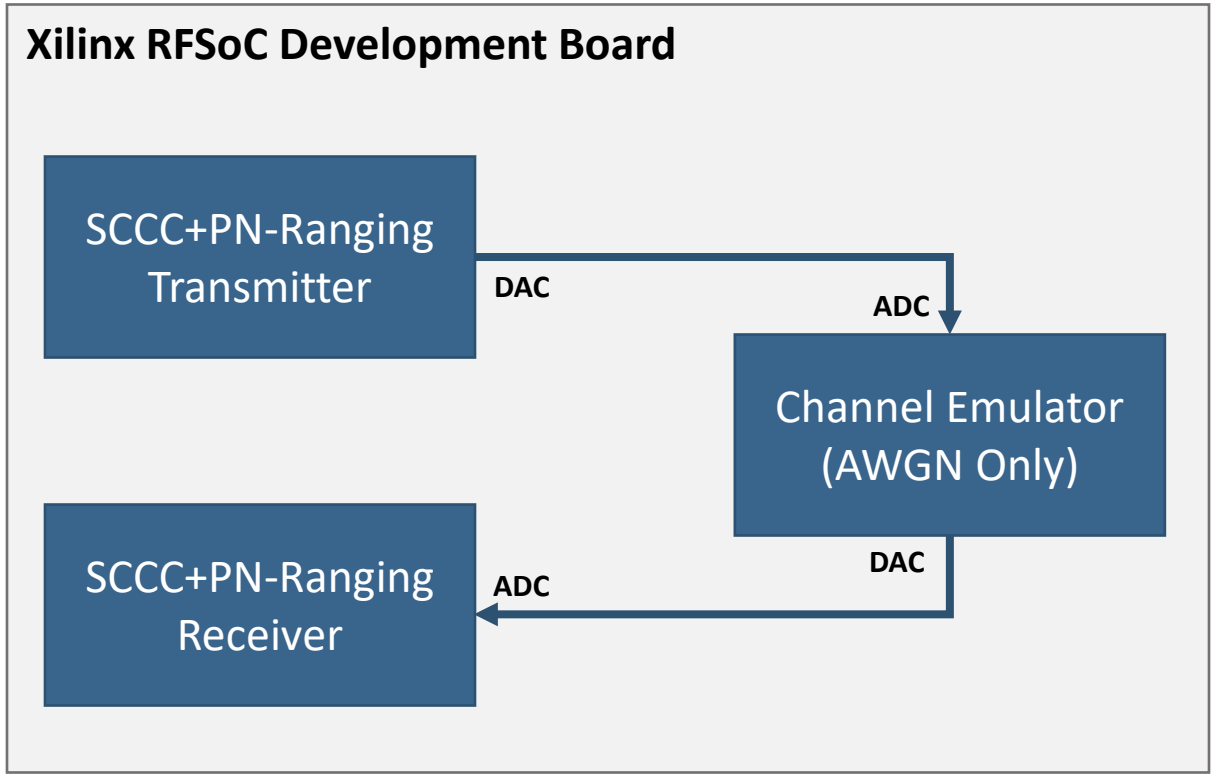
- BCH+LDPC coding
- VCM/ACM Capable
- SRRC Roll-off 0.20, 0.25, 0.35
- QPSK, 8PSK, 16-APSK, 32-APSK

CCSDS 131.2-B Standard

- SCCC coding
- VCM/ACM Capable
- SRRC Roll-off 0.20, 0.25, 0.30, 0.35
- QPSK, 8PSK, 16-APSK, 32-APSK, 64-APSK

Case Study – CCSDS SCCC

Implement a breadboard for simultaneous transmission of
CCSDS 131.2-B (SCCC) Telemetry and CCSDS 414.1-B (PN-Ranging) Ranging

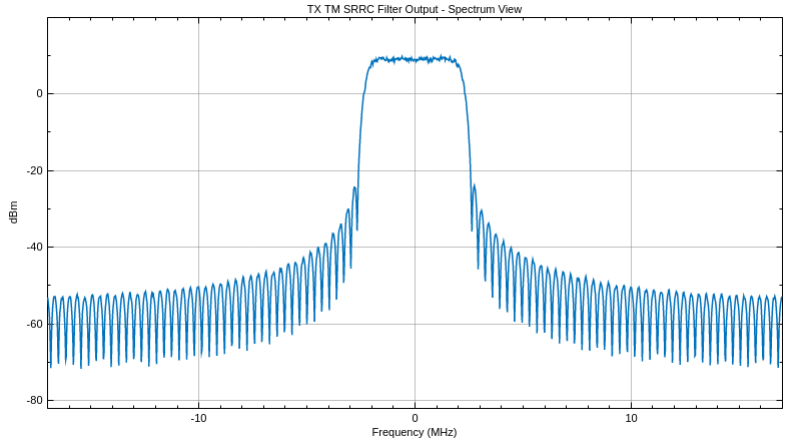


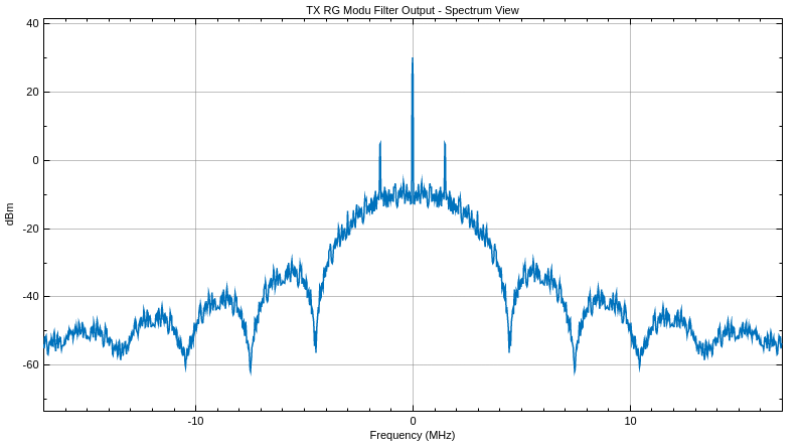
Objective: Bring the idea developed in

«On the use of PN Ranging with High-rate Spectrally-efficient Modulations»
by B.Ripani, A.Modenini, R.Garello, G.M.Capez, G.Montorsi

to an actual FPGA implementation that includes all the synchronization blocks, the telemetry decoder, the cancellation algorithms, and quantization effects

Activity – Transmitter Overview





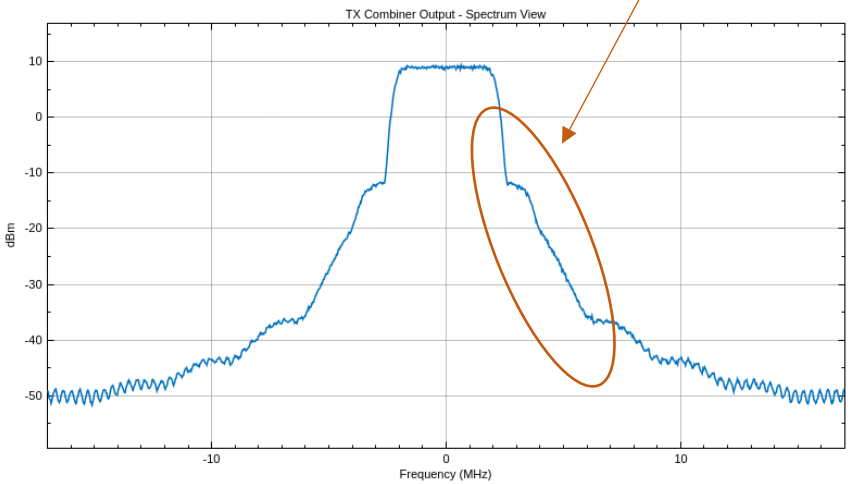
TM SIGNAL
(4.250 Msym/s)

I
Q

RG SIGNAL
(2.987 Mchip/s)

I
Q

TM + RG SIGNAL



Shoulder-like effect: ranging clock tones convolution with SRRC

$BW_{99\%} \approx 4.67$ MHz

depends on TM roll-off = 0.20,
RG mod. index = 0.20 rad-pk,
RG code type = T2B

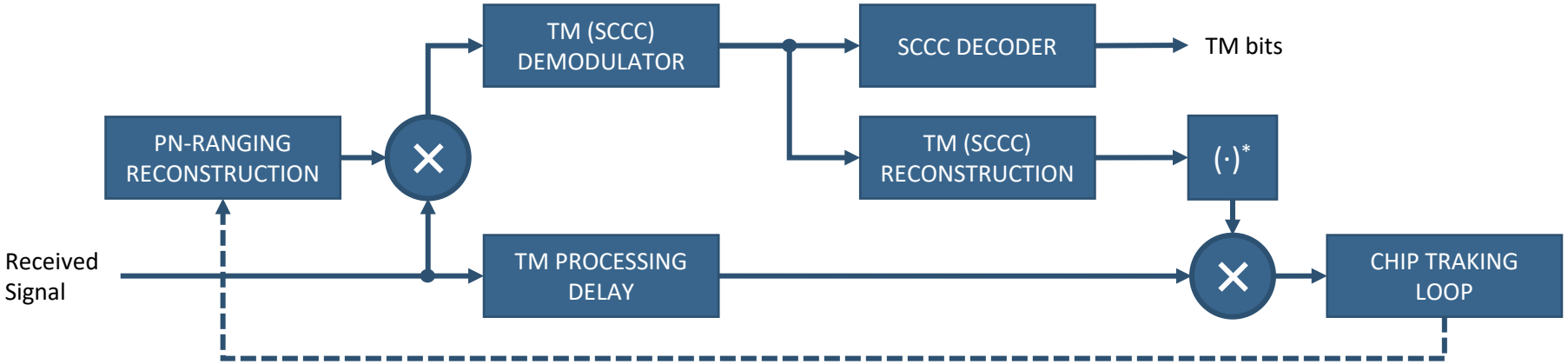
Activity – Receiver Overview

The receiver has to follow a sequence of operations similar to that of CCSDS 413.1-G

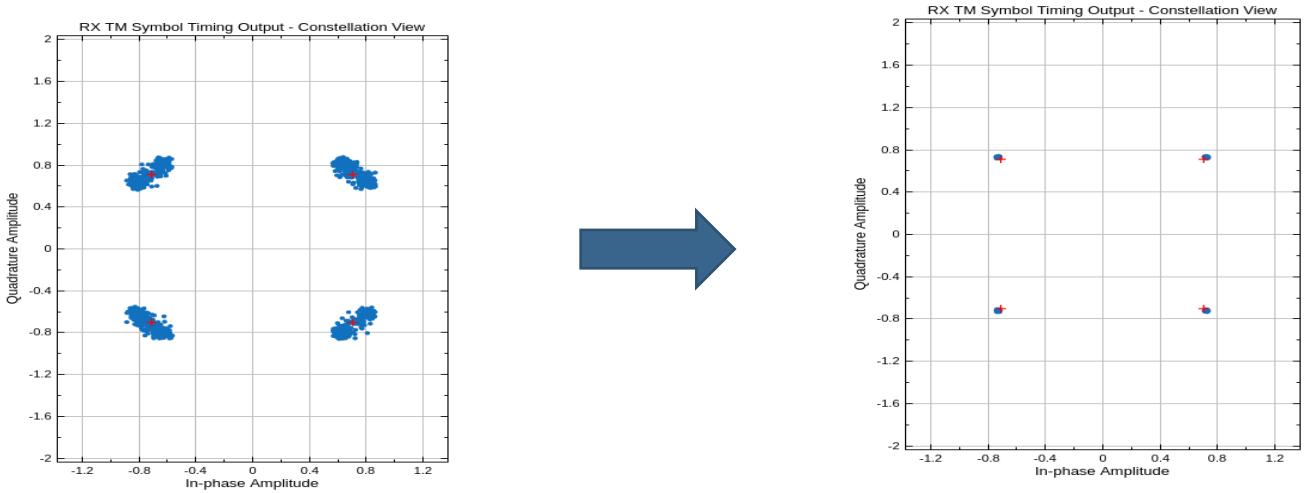
1. Acquire telemetry signal (impaired by the ranging signal)
2. Perform telemetry reconstruction
3. Perform telemetry cancellation
4. Acquire ranging signal (impaired by residual cancellation)
5. Perform ranging reconstruction
6. Perform ranging cancellation

Compensate latency of telemetry demodulator and reconstruction

Exploit cyclical behavior of the ranging code epoch (length 1009470 chips)



Activity – Receiver Overview

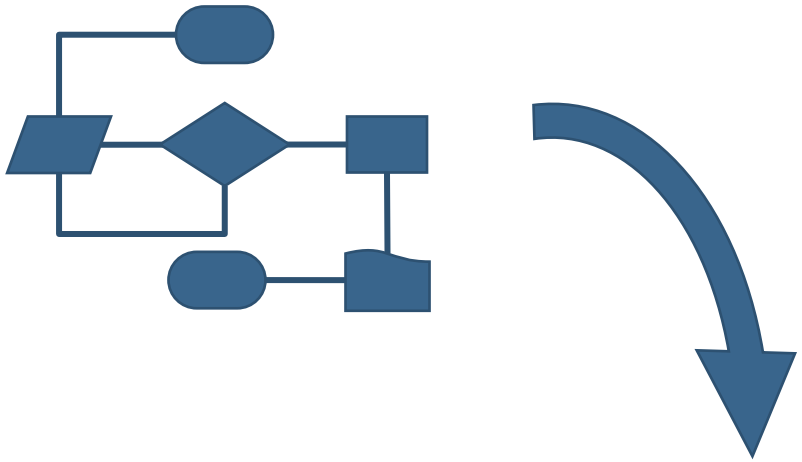


Main breadboard analysis tasks:

- Guarantee high lock probability at low Es/N0 (same range as CCSDS SCCC)
  - *High probability of TM lock and stability of frequency, phase, SNR estimates*
  - *High probability of RG lock, highly dependent of the residual BER on the telemetry*
- Guarantee precise time alignment on both telemetry and ranging cancellations
  - *Telemetry delay calibration, considering asynchronous input sampling*
  - *Doppler estimation for feedforward ranging estimation cancellation*
- Guarantee instantaneous change of ModCod to mantain lock on ACM switches

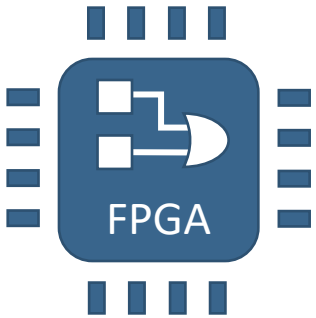
Simulation Model

Simulator to model the algorithms used for synchronization and cancellation



Model algorithms that that can be actually implemented in FPGA

No genie-aided algorithms



TELEMETRY ACQUISITION

- Symbol rate adaptation
- Phase recovery
- Gain recovery
- Timing recovery
- Frequency recovery
- SNR estimation

RANGING ACQUISITION

- Chip rate adaptation
- Phase recovery
- Timing recovery/estimation
- Frequency recovery

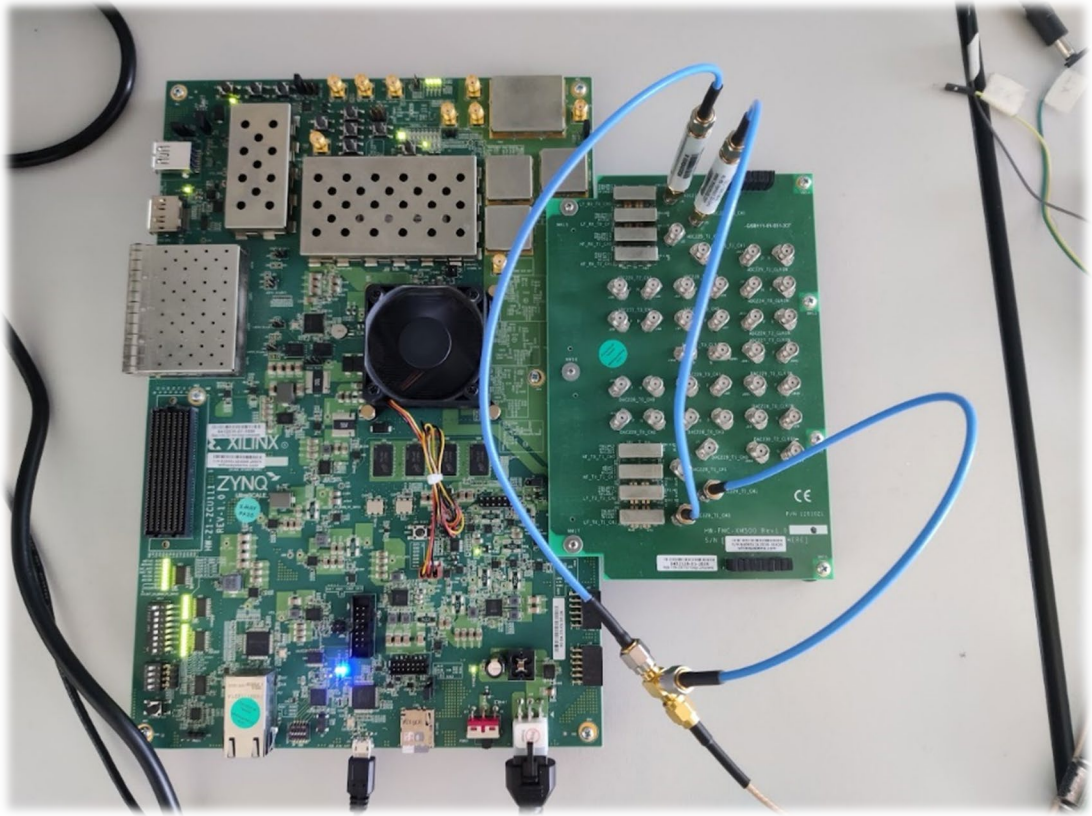
TELEMETRY RECONSTRUCTION/CANCELLATION

- Timing error application
- Cancellation time align

RANGING RECONSTRUCTION/CANCELLATION

- Epoch time estimator
- Cancellation time align

Breadboard Overview



FPGA Breadboard:

- Based on a single board (ZCU111)
- Uses 2 ADCs and 2 DACs
- Host-PC for M&C

Fixed Parameters:

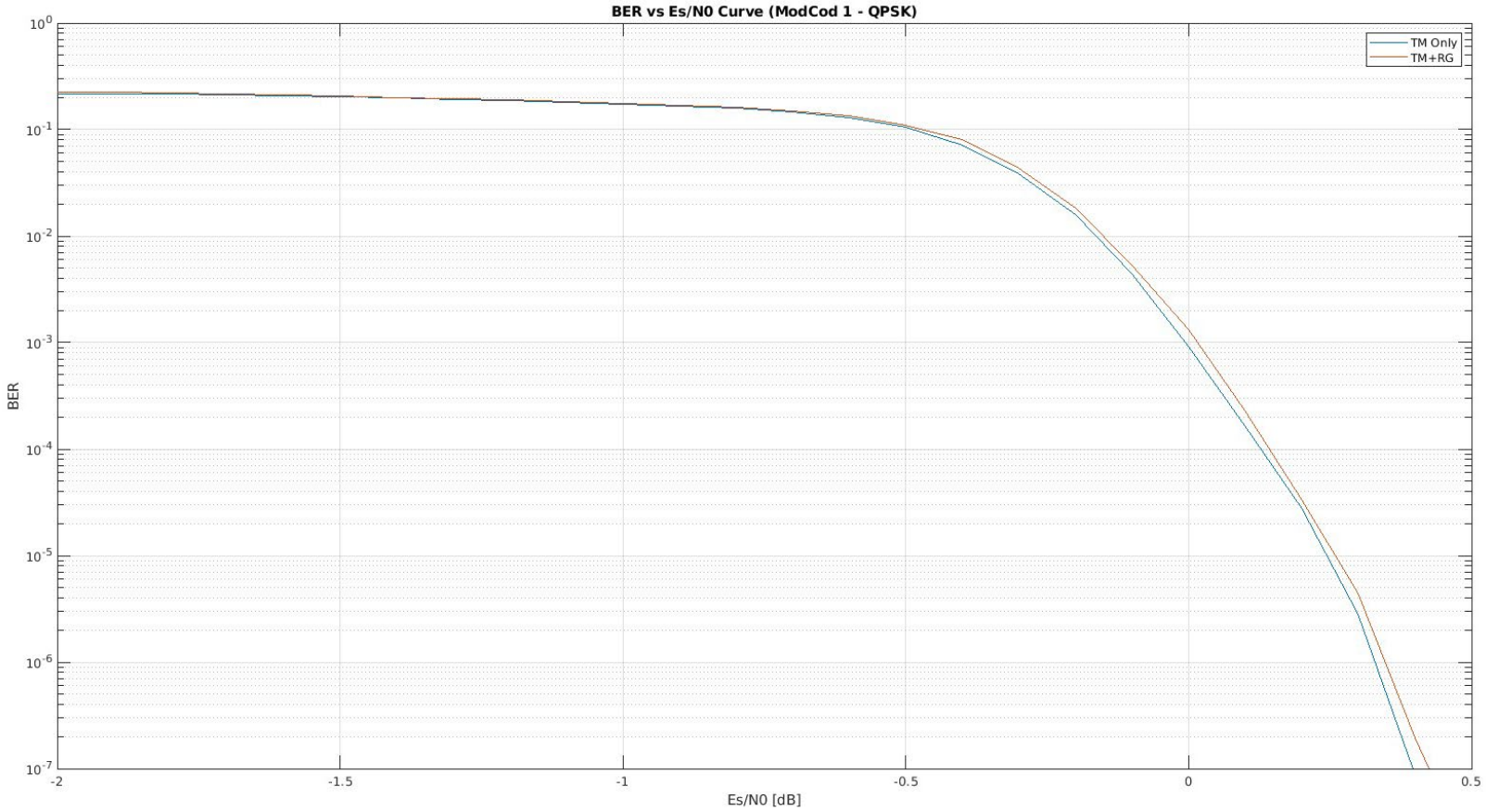
- Telemetry
  - 4.25 Msym/s
  - Roll-off 0.25 (synthesis)
- Ranging
  - 2.987 Mchip/s

Breadboard – Transmitter

4.250 Msym/s, 2.987 Mchip/s, TM roll-off 0.20, RG mod. index 0.20 rad-pk, RG code type T2B

4.250 Msym/s, 2.987 Mchip/s, TM roll-off 0.20, RG mod. index 0.70 rad-pk, RG code type T2B

Breadboard – Receiver – Telemetry BER Curves



≈ 3.0 Mbit/s net throughput @ 5MHz channel

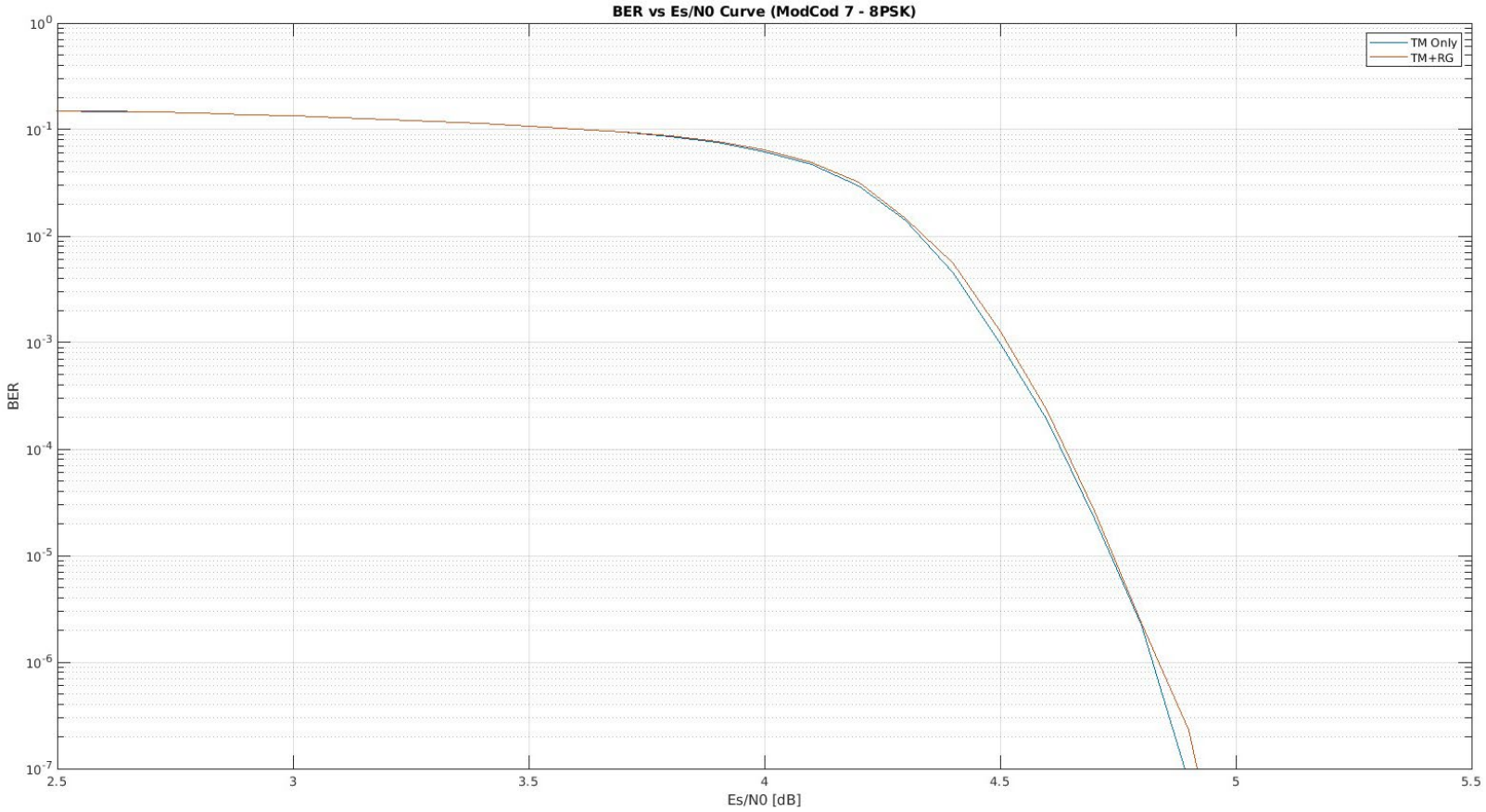
BER - ModCod 1 (QPSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

E_S/N_0 Loss @ BER = 10^{-6}
0.0181 dB

Breadboard – Receiver – Telemetry BER Curves



≈ 5.9 Mbit/s net throughput @ 5MHz channel

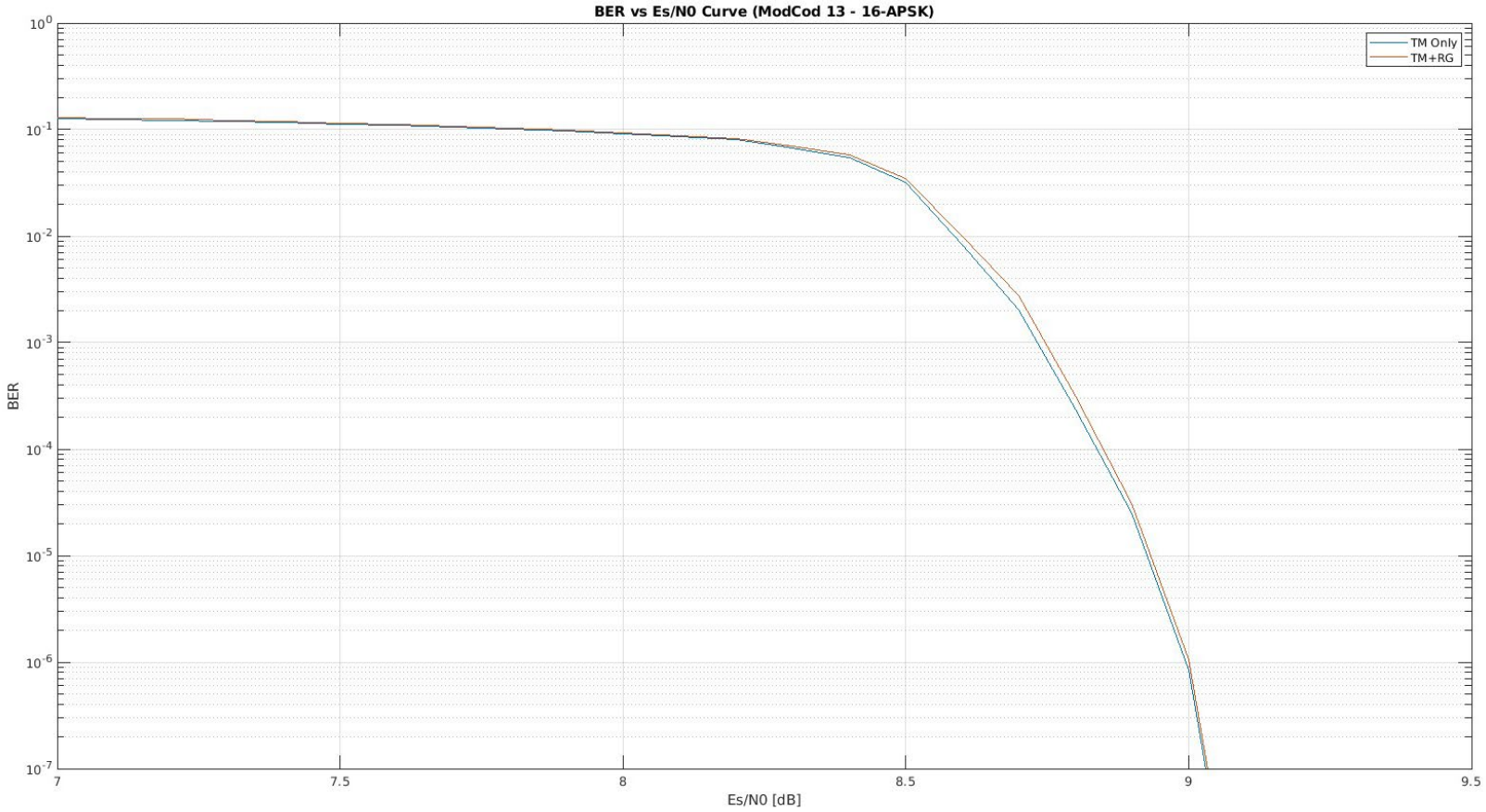
BER - ModCod 7 (8PSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

E_S/N_0 Loss @ BER = 10^{-6}
0.0124 dB

Breadboard – Receiver – Telemetry BER Curves



≈ 10.0 Mbit/s net throughput @ 5MHz channel

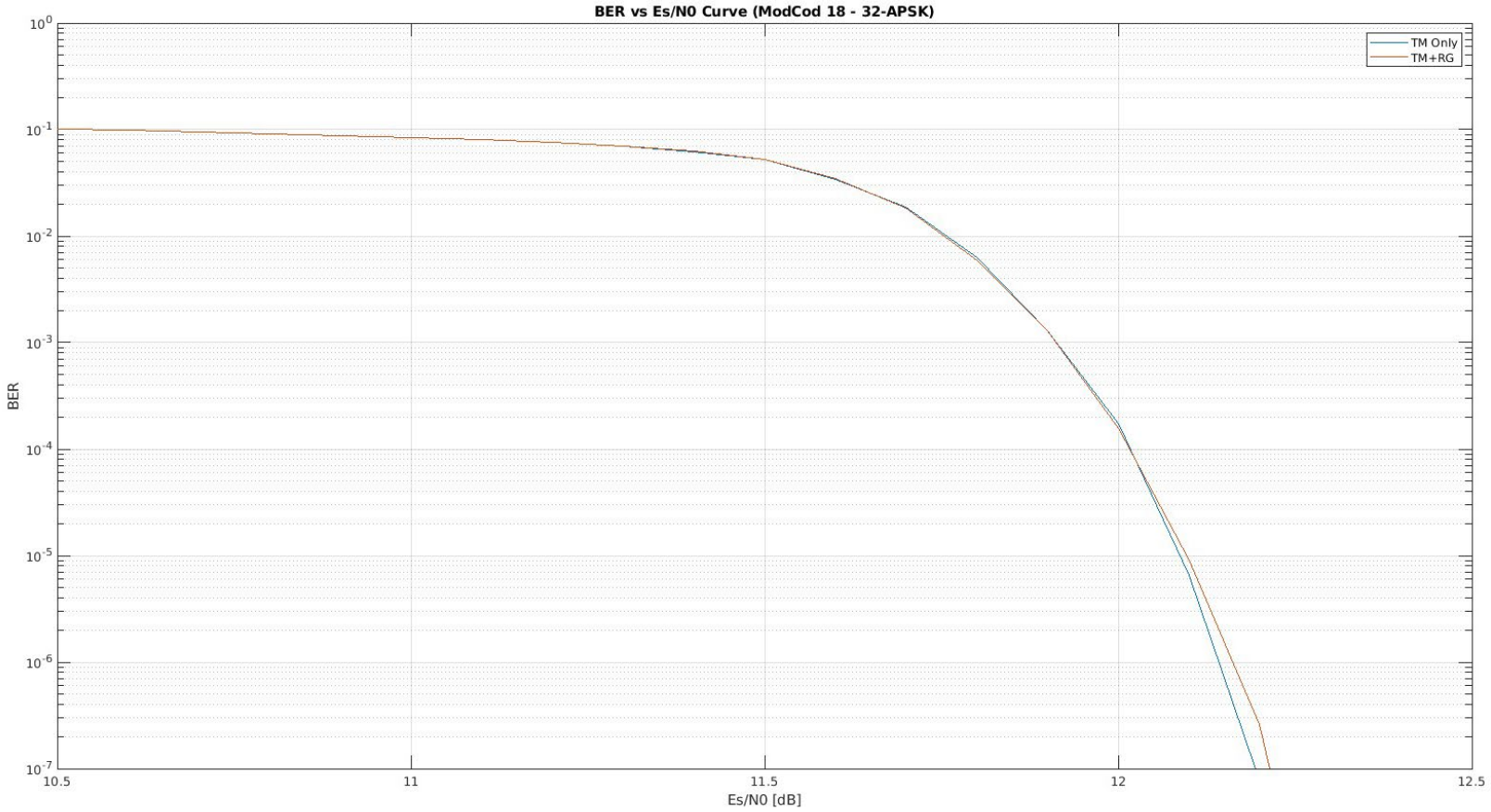
BER - ModCod 13 (16-APSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

E_S/N_0 Loss @ BER = 10^{-6}
0.0059 dB

Breadboard – Receiver – Telemetry BER Curves



≈ 13.6 Mbit/s net throughput @ 5MHz channel

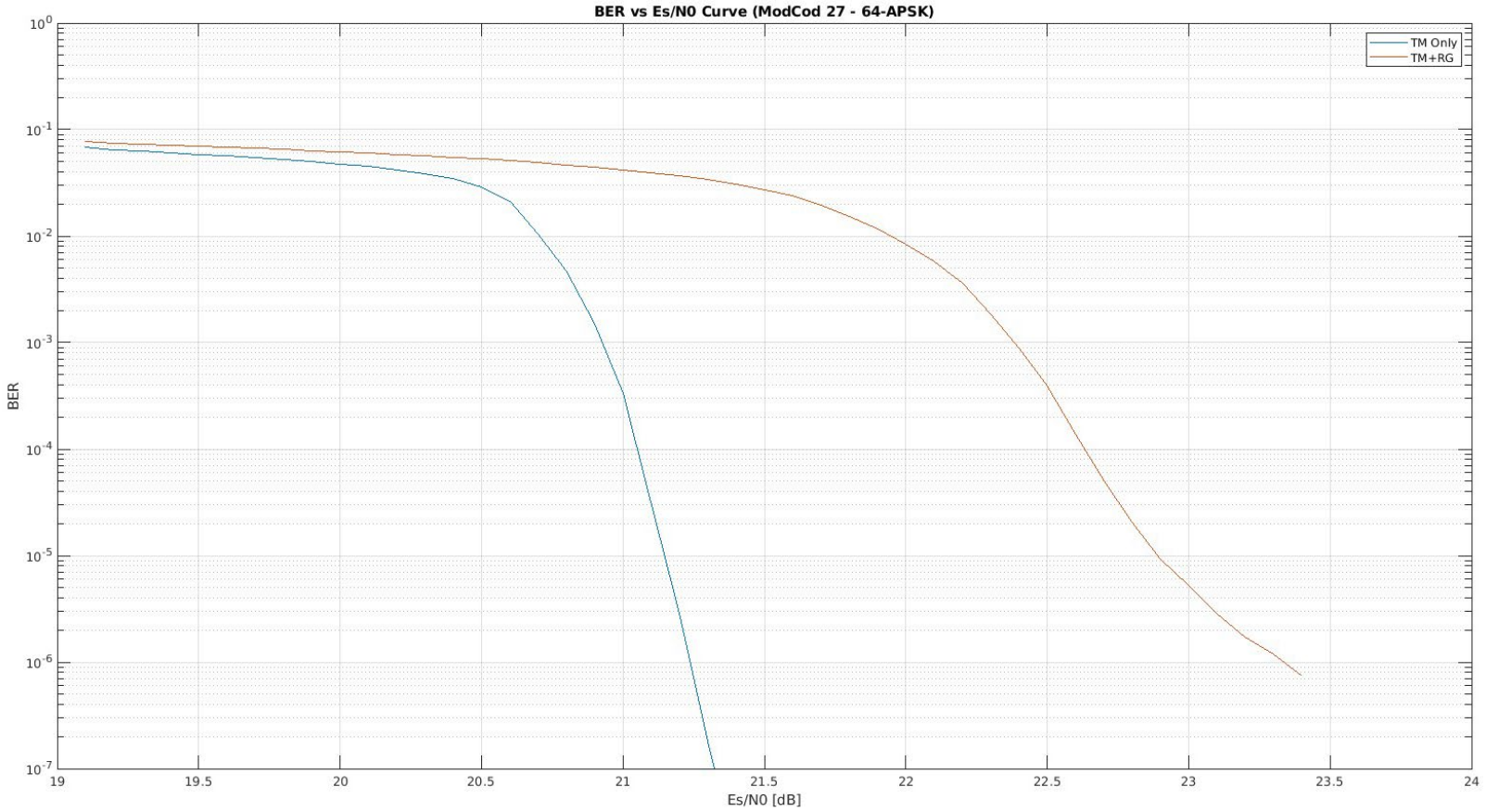
BER - ModCod 18 (32-APSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

E_S/N_0 Loss @ BER = 10^{-6}
0.0197 dB

Breadboard – Receiver – Telemetry BER Curves



≈ 22.9 Mbit/s net throughput @ 5MHz channel

BER - ModCod 27 (64-APSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

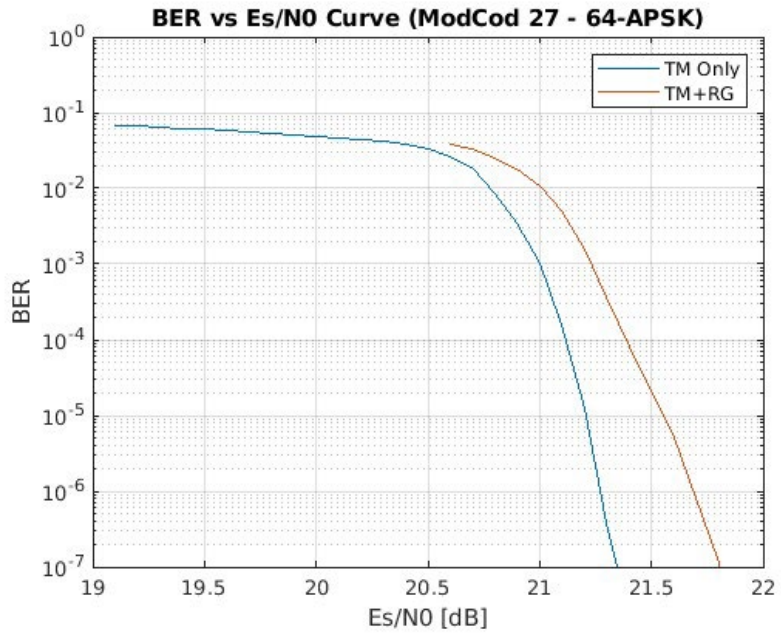
E_S/N_0 Loss @ BER = 10^{-6}
2.100 dB

Breadboard – Receiver – Limitations

TM loss on 64-APSK + PN-Ranging higher that established 0.5dB threshold

Mitigation strategy:

- Reduce the modulation index to 0.1 rad-pk, as the ranging at such high SNR is near the saturation region where it's limited by the residual amplitude modulation from the TM cancellation



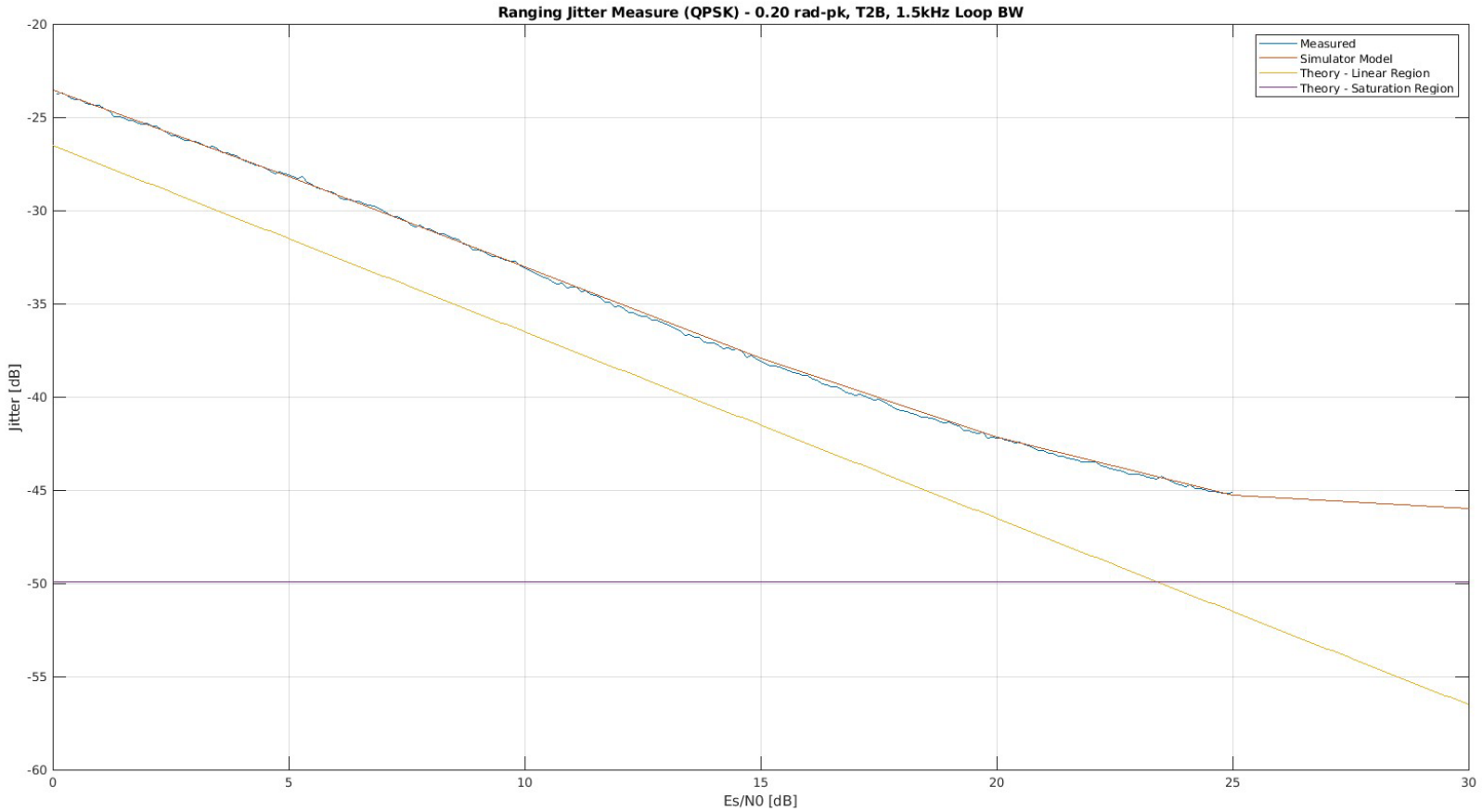
BER - ModCod 27 (64-APSK)

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.10 Modulation Index

E_S/N_0 Loss @ BER = 10^{-6}
0.41 dB

Breadboard – Receiver – Ranging Jitter



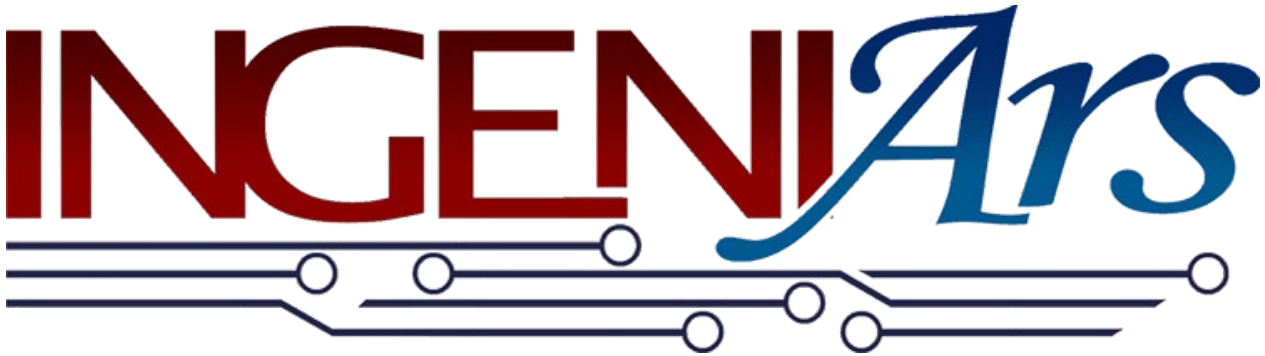
Ranging Jitter - QPSK

SCCC+PN-Ranging Transmission

- TM
  - 4.25 Msym/s
  - Roll-off 0.25
- RG
  - 2.987 Mchip/s
  - T2B Ranging Code
  - 0.20 Modulation Index
  - CTL Bandwidth 1.5 kHz

Implementation loss around 3dB for both the linear and saturation regions

Conclusions



Thank you for your time

SLS-RFM_24-14

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info@ingeniars.com