SDR TT&C Modem
Software-Defined Radio TT&C Modem for RF-SCOE and Ground Segments

Brochure

Atos IT Solutions and Services GmbH Austria

Brochure

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1 Overview

1.1 Objectives

The aim of this activity was to develop and test a prototype of a Telemetry, Tracking, and Control (TT&C) Modem based on the advanced Software-Defined Radio (SDR) technology to be used in RF-SCOE systems and mission Ground Segments.

The modem is designed to support Near Earth missions and in particular Earth orbiting satellites from LEO to GEO/GTO altitudes and orbital velocities. The target was to build an SDR-based TT&C modem that can be used within RF-SCOE subsystems and ground segments.

As shown in Figure 1, a TT&C modem in a ground segment *sends* telecommands (+ranging) and *receives* telemetry (+ranging). Whereas a TT&C modem for an RF-SCOE subsystem, which emulates a spacecraft, *receives* telecommands (+ranging) and *sends* telemetry (+ranging). In both scenarios, the TT&C modem assembles a combination of hardware and software components.

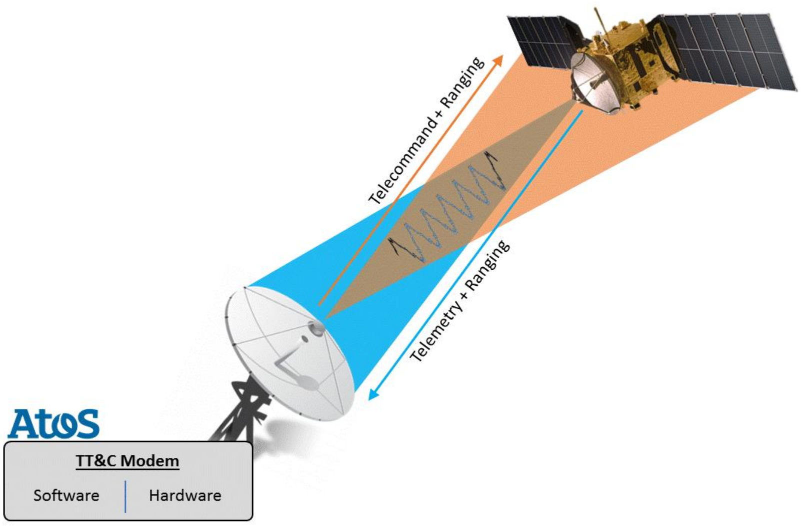


Figure 1: Illustration of a TT&C modem within a ground segment

The fundamental concept behind software-defined radio is transforming traditionally analog radio communication components, such as filters, demodulators, decoders, etc, to software components running under General Purpose Processors (GPP). The Analog-to-Digital Converter (ADC) in the receiving path and the Digital-to-Analog Converter (DAC) in the transmitting path, with additional minimal analog circuitry, bridge the gap between the analog frontend and the digital (software) backend.

1.2 Technical Description

The Telemetry, Tracking and Control (TT&C) Modem is the direct counterpart on ground to the transponder on the spacecraft, translating digital Telecommands (TC) to radio frequency (RF) and receiving Telemetry (TM) in RF from the spacecraft.

Thanks to Software-Defined-Radio (SDR) technology and to the ever-growing processing capabilities of modern General Purpose Processors (e.g. Intel i7 type CPUs), it is now possible to run the various signal processing modules of a TT&C modem (e.g. mixers, filters, modulators/demodulators, detectors, etc.) by means of software on a standard commercial-off-the-shelf (COTS) computer, and to do this in real-time. Therefore, the innovative SDR methodology significantly will allow to reduce the costs of and lead time for recurrent units and therefore the operational cost while achieving a high system quality due to the digital processing.

In this activity a SDR modem prototype was developed and verified in laboratory environment, including loop back transmission of Telemetry/Telecommand, with suppressed carrier modulation (BPSK, QPSK) and remnant carrier modulation (SP-L/PM). BER performance is investigated by injecting noise into the loopback path and the results are compared with the theoretical optimum. CADU and CLTU assembly on the transmitter side and frame synchronization and disassembly on the receiver side is provided. Reed Solomon encoding/decoding, convolutional encoding and Viterbi decoding are implemented. All functionalities are tested in interoperability tests with a certified TT&C Modem at zero BER. The obtained BER performance showed good results with low/moderate degradation from the theoretical curves, typically between 0.3 and 0.7 dB. The interoperability tests demonstrate the error free communication with the certified modem.

1.3 Design Specification

The selection of a suitable SDR HW platform and definition of the HW/SW architecture of the modem was made based on review of the available COTS platforms. The actual modem prototype was implemented based on the PothosWare SW platform and the Ettus USRP X310 SDR HW. A further, low cost, SDR HW alternative investigated in the project was the bladeRF-2.0.

The X310 is equipped with two SPF+ 10GbE modules for fast data transfer (IQ samples) from and to the SDR controller. The bladeRF-2.0 is connected to the SDR controller over USB3 interface.

A block-diagram illustration of the hardware setup using the X310 is shown in Figure 2

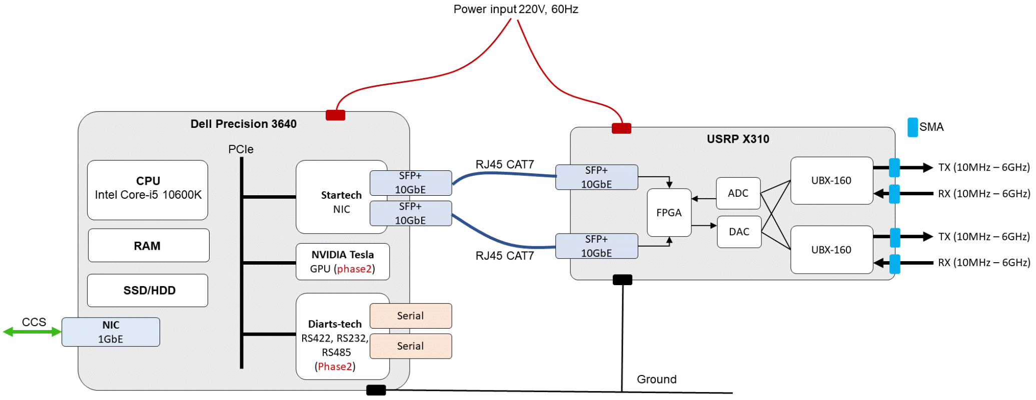


Figure 2: Hardware design of the SDR TT&C modem using the USRP X310

The PothosWare SW environment is an open source framework and products developed inside it can be used commercially. The overall PothosWare framework component and its relative interconnection are illustrated in Figure 3

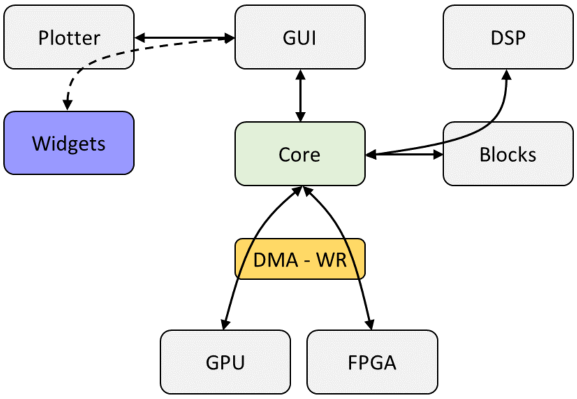


Figure 3: The framework architecture

1.3.1 CLTU Loopback

The CLTU loopback presented in Figure 4 is split as follows:

- horizontally to two sections, a telecommand transmitter at the ground station side and a receiver at the spacecraft side. Note that a telecommand CLTU is defined before modulation or after the demodulation process.
- Vertically to two sections, Atos software representing the software modem, and the RF COTS hardware responsible for RF conversion, digital to analog or analog to digital (expressed by block 5 and 5'
- Blocks 4 and 4' represent the Linux-based hardware driver for exchanging binary IQ data between the COTS hardware and DSP software
- A BER block 1'' that measures error rate under realistic RF channel and a real RF hardware

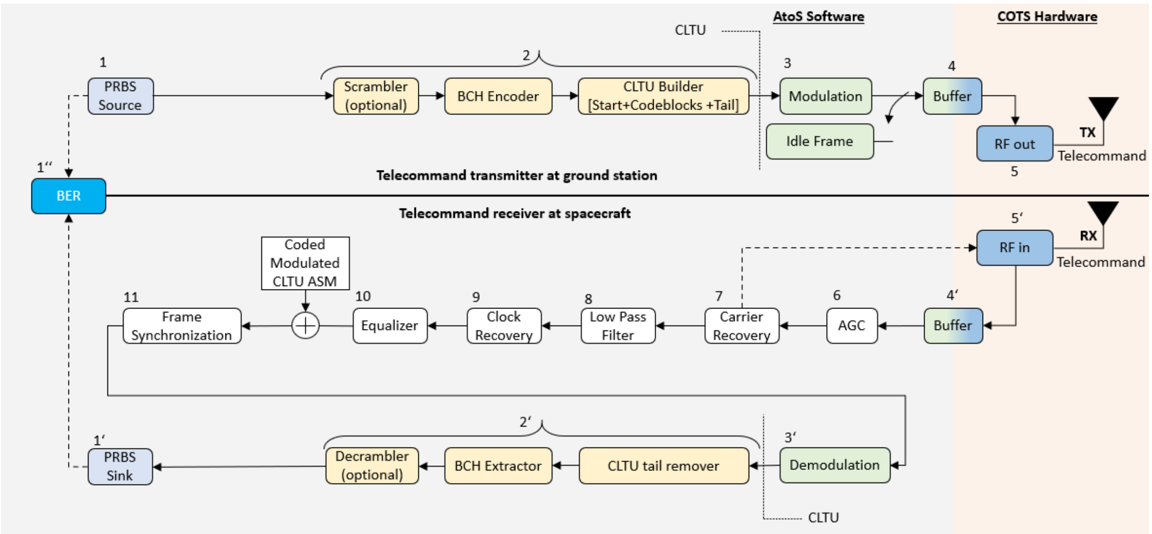


Figure 4: CLTU Telecommand Communication Loopback

1.3.2 CADU Loopback

Figure 5 description is similar to the CLTU telecommand communication loopback. However, its horizontal splits are a CADU telemetry transmitter at the spacecraft side and a receiver at the ground station side. Note that a telemetry CADU is defined before modulation or after the demodulation process

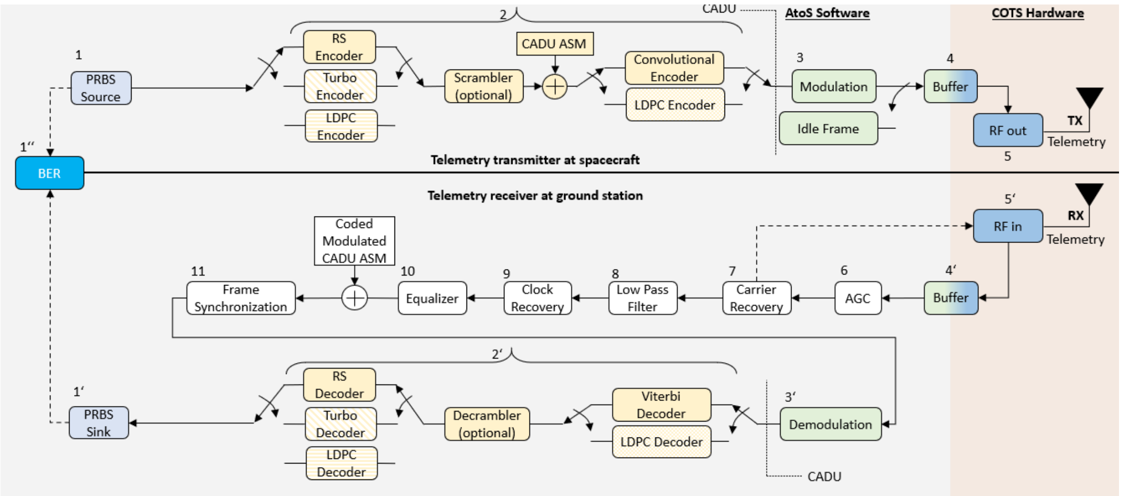


Figure 5: CADU Telemetry Communication Loopback

The closed loop BER performance of the SDR Modem with added noise was investigated. The observed degradation from the theoretical optimum was shown to be approximately 1dB or better. The observed degradation from the theoretical BER curves is summarized in the following table:

Table 1: Observed Degradation

Modulation type	Symbol rate [ksps]	Measured BER	Theoretical Es/N0 [dB]	Observed degradation from theoretical Es/N0 [dB]
BPSK uncoded	60	$6.6 \cdot 10^{-4}$	7.12	0.72
BPSK uncoded	500	$6 \cdot 10^{-3}$	5.57	0.57
QPSK uncoded	500	$1.5 \cdot 10^{-4}$	8.15	0.23
QPSK convolutional	1000	$7.8 \cdot 10^{-4}$	5.1	0.40
QPSK convolutional	1000	$1 \cdot 10^{-4}$	6.0	0.61
SP-L uncoded	4	$2 \cdot 10^{-4}$	7.97	0.46
SP-L uncoded	4	$3.15 \cdot 10^{-4}$	6.67	0.37
SP-L uncoded	250	$1.8 \cdot 10^{-4}$	8.03	0.36
SP-L uncoded	256	$7 \cdot 10^{-4}$	7.07	1.02 (note 1)
SP-L uncoded	1200	$2.4 \cdot 10^{-4}$	7.85	0.38

Note 1: the main cause of degradation in this case was the symbol rate, which was not correctly achieved. A correction of this issue is planned.

Figure 6 and Figure 7 show examples of the measured SP-L test case using 250ksps and QPSK ½ rate convolutionally encoded 500kbit/s.

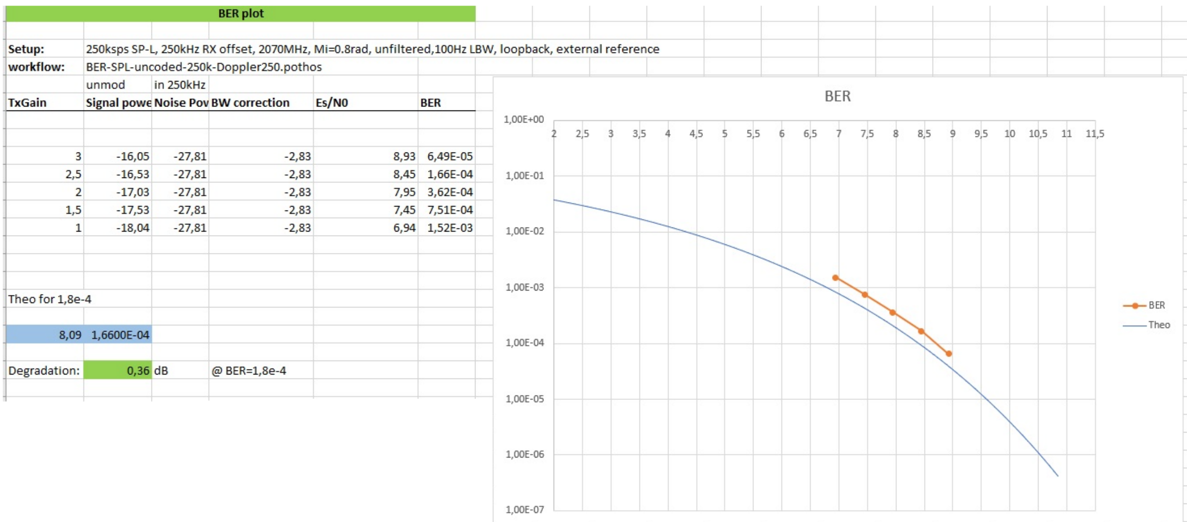
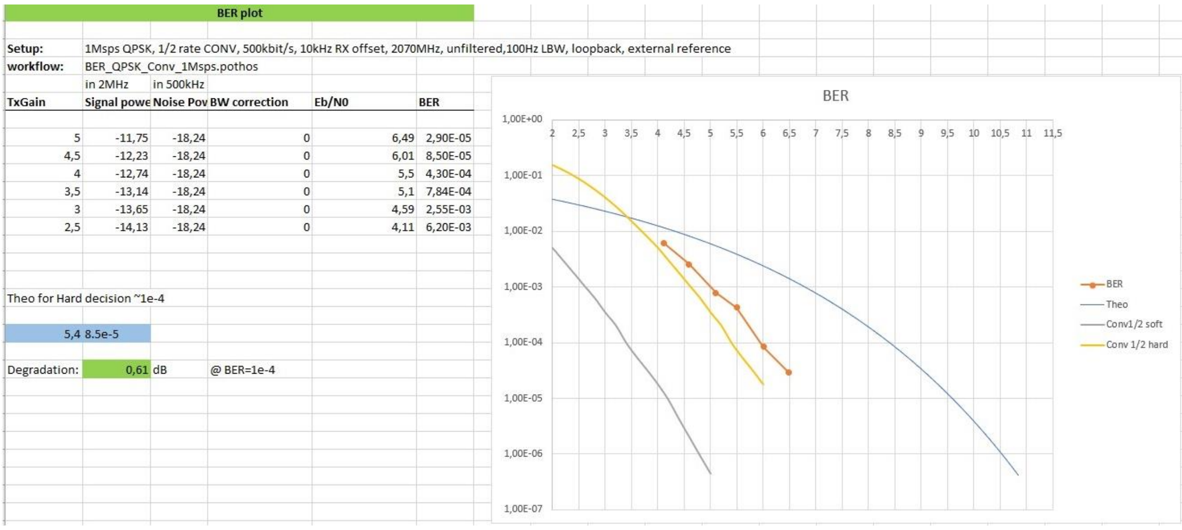


Figure 6: BER curve SP-L 250ksps, 250kHz offset



BER plot

Setup: 1Msps QPSK, 1/2 rate CONV, 500kbit/s, 10kHz RX offset, 2070MHz, unfiltered,100Hz LBW, loopback, external reference
workflow: BER_QPSK_Conv_1Msps.pothos

TxGain	Signal powe (in 2MHz)	Noise Pov (in 500kHz)	BW correction	Eb/N0	BER
5	-11,75	-18,24	0	6,49	2,90E-05
4,5	-12,23	-18,24	0	6,01	8,50E-05
4	-12,74	-18,24	0	5,5	4,30E-04
3,5	-13,14	-18,24	0	5,1	7,84E-04
3	-13,65	-18,24	0	4,59	2,55E-03
2,5	-14,13	-18,24	0	4,11	6,20E-03

Theo for Hard decision ~1e-4

5,4 8.5e-5

Degradation: 0,61 dB @ BER=1e-4

Figure 7: BER curve QPSK 500kbit/s, 1/2 rate CONV

1.4 Achievements

A modem prototype capable of transmitting and receiving TM/TC was developed based on Software defined Radio (SDR). The SDR Modem prototype provides BPSK, QPSK and SPL-PM modulations, Reed-Solomon encoding/decoding, scrambler/descrambler, convolutional encoder, Viterbi decoder, CADU and CLTU assembler and data synchronization, as well as PRBS generators and BER counter.

The SDR modem prototype was pre-developed and pre-tested on a component and model level, verifying on the one hand the BER performance in loopback mode, CADU and CLTU loopback transmission, as well as communication with a certified modem (a Cortex CRT-Q), uncoded and with coding enabled. The obtained BER performance showed good results with low/moderate degradation from the theoretical curves, approximately 1dB or lower, typically between 0.3 and 0.7 dB.

All three available modulation schemes (BPSK, QPSK, SP-L) were performance tested using a closed loop BER test with added noise.

Bitrates up to 1 Mbit/s were successfully used

Doppler related frequency offsets could be compensated (~250kHz).

BER tests with RS and/or convolutionally encoded information were successfully run (hard decision convolutional decoding and Reed-Solomon)

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