MODELLING AND SIMULATION OF S-BAND
TELEMETRY DATA DECODING FOR LOW
EARTH OBSERVATION SATELLITE

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ABSTRACT
In this paper, overall architecture of S-band Telemetry communications for Low
Earth Observation system is described. Then its components with proper parameters
is modelled and simulated using MATLAB/Simulink is performed. Bit Error rate
(BER) is the output of the proposed model and shows close correlation with practical
ground-satellite link performance.

Key words: S band Telemetry, S-band communication, Low Earth Observation satellite

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1. INTRODUCTION
During operation, a satellite sends telemetry data streams to its ground station. The telemetry
(TM) data from the spacecraft to ground can be divided into two main classes: Housekeeping
Telemetry and Science Telemetry. The first one represents the health status of the satellite,
and the second one gathers the real observed data. The housekeeping data analysis is aimed at
understanding if the on-board instruments and devices are working correctly. For Low Earth
Observation satellites, housekeeping telemetry is transmitted in S-band. A simulation of S
band Telemetry communication provide understanding about how telemetry data is
transmitted from satellite to ground station.

2. SYSTEM ARCHITECTURE
S-band Telemetry link for Low Earth Observation satellite as well as a typical communication
link includes three key elements: a transmitter, a channel, and a receiver. The transmitter and
receiver elements are then further divided into sub-systems. These include a data source, data
encoders (Reed-Solomon encoder and Convolutional encoder), a modulator, a demodulator, data decoders (Reed-Solomon decoder and Viterbi decoder), and a signal sink. The overall of the S-band TM link is illustrated in the following figure.

![S-band TM link diagram]

**Figure 1** Overall architecture of a TM S-band link for Low Earth observation system.

The data source generates the information signal that is intended to be sent to a particular receiver. This signal is a binary data sequence.

An encoder can also be used to add redundancy to a digital data stream, in the form of additional data bits, in a way that provides an error correction capability at the receiver. This overall process is referred to as Forward Error Correction (FEC). The most popular FEC schemes are convolutional coding, block coding and trellis coding. For Telemetry link, Reed-Solomon encoder and Convolution encoder are used.

Depending on the type of information signal and the particular transmission medium, different modulation techniques are employed. Modulation refers to the specific technique used to represent the information signal as it is physically transmitted to the receiver. Once the signal is modulated, it is sent through a transmission medium, also known as a channel, to reach the intended receiver. A commonly used channel model is the Additive White Gaussian Noise (AWGN) channel. In this channel, noise with uniform power spectral density is assumed to be added to the information signal.

When the transmitted signal reaches the intended receiver, it undergoes a demodulation process. This step is the opposite of modulation and refers to the process required to extract the original information signal from the modulated signal.

When data encoding is included at the transmitter, a data-decoding step must be performed prior to recovering the original data signal. A Viterbi decoder is used to decode convolutionally encoded data.

Finally, an estimate of the original signal is produced at the output of the receiver. The receiver’s output port is referred to as the signal sink. We are usually interested in knowing how well the source information was recreated at the receiver’s output. Several metrics are used by evaluating the success of the data transmission. The most common metric, in the case of digital signals, is the received Bit Error Rate (BER).

### 3. MODELLING IN MATLAB

#### 3.1. Software Tool

This simulation including system and blocks is designed by MATLAB/Simulink. Simulink is a software package for modeling, simulating, and analyzing dynamical systems. For modeling, Simulink provides a graphical user interface for building models as block diagrams, using click-and-drag mouse operations. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. We can also customize and create our own blocks if there is no what we want in the library.
Models are hierarchical, they can be built by using both top-down and bottom-up approaches. This approach provides insight into how a model is organized and how its parts interact. After defining a model, simulation can be start. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens. The simulation results can be put in the MATLAB workspace for postprocessing and visualization.

3.2. Building Block Model

Signal Source

A Bernoulli Binary Generator block generates random binary numbers using a Bernoulli distribution. This block produces zeros with Probability of a zero parameter (set to 0.5).

Others parameters of this block, such as: Source of initial seed, Sample time, Samples per frame, and Output data type are specified in dialog below:

![Source Block Parameters: Bernoulli Binary Generator](image)

**Figure 2** Source Block Parameters: Bernoulli Binary Generator

**Integer-Input RS encoder / Integer-Output RS Decoder**

The Integer-Input RS Encoder block creates a Reed-Solomon code with message length 223 and codeword length 255. These parameters are specified directly in the block mask.

![Function Block Parameters: Integer-Input RS Encoder](image)

**Figure 3** Function Block Parameters: Integer-Input RS Encoder.
The input and output are integer-valued signals that represent messages and codewords, respectively. The output is a frame-based column vector whose length is the same integer multiple of 255. The input must be a frame-based column vector whose length is an integer multiple of 223. However, output of signal source is binary signals. Therefore, we need map these bits to integers using a Bit to Integer Converter block.

![Function Block Parameters: Integer-Output RS Decoder](image)

**Figure 4** Function Block Parameters: Integer-Output RS Decoder.

In the receiver side, the Integer-Output RS Decoder block recovers an integer message vector from an integer Reed-Solomon codeword vector. For proper decoding, the parameter values in this block should match those in the corresponding Integer-Input RS Encoder block.

**Convolutional Encoder / Viterbi Decoder**

The Convolutional Encoder block encodes a sequence of binary input vectors to produce a sequence of binary output vectors. This block can process multiple symbols at a time.

For both its inputs and outputs for the dataports, the block supports double, single, boolean, int8, uint8, int16, uint16, int32, uint32 and ufix1. The port data types are inherited from the signals that drive the block.

![Function Block Parameters: Convolutional Encoder](image)

**Figure 5** Function Block Parameters: Convolutional Encoder.
In this simulation, we use the encoder with rate $1/2$; the constraint length vector is 7, code generator polynomials of 171 and 133. Operation mode is set to Continuous, means the block retains the encoder states at the end of each input, for use with the next frame.

On the opposite side, Viterbi decoder is used to decode convolutionally encoded data. The Operation mode parameter is also set to Continuous to match with Convolution encoder. The Traceback depth parameter influences the decoding delay. As a general estimate, the Traceback depth value is approximately two to three times $(k - 1)/(1 - r)$, where $k$ is the constraint length of the code and $r$ is the code rate. Because Convolution encoder has $k = 7$ and $r = 1/2$, Viterbi decoder has a Traceback depth of 30.

**Figure 6 Function Block Parameters: Viterbi Decoder.**

**DQPSK Modulator / Demodulator**

The DQPSK Modulator Baseband block modulates using the differential quadrature phase shift keying method. We set the Input type parameter to Bit, means the input contains pairs of binary values. The output is a baseband representation of the modulated signal.

**Figure 7 Function Block Parameters: DQPSK Modulator Baseband.**

On the contrary, the DQPSK Demodulator Baseband block demodulates a signal that was modulated using the differential quadrature phase shift keying method. The input is a baseband representation of the modulated signal. The output depends on the phase difference between the current symbol and the previous symbol. The first binary pair at the block output is the initial condition of zero because there is no previous symbol.
AWGN Channel
The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sample time from the input signal.

This block accepts a scalar-valued, vector, or matrix input signal with a data type of type single or double. The output signal inherits port data types from the signals that drive the block.

Signal Sink Model
We use the Error Rate Calculation block and the Display block to construct the signal sink model.

The Error Rate Calculation block compares data from the transmitter with data from the receiver. It calculates the error rate as a running statistic, by dividing the total number of unequal pairs of data elements by the total number of input data elements from one source. The Receive delay parameter specifies which elements of its input signals to compare when checking for errors. This parameter is nonzero because a given message bit and its corresponding recovered bit are separated in time by a nonzero amount of simulation time. In this case, the Receive delay value is 3619 samples.

Figure 8 Function Block Parameters: DQPSK Demodulator Baseband.

Figure 9 Function Block Parameters: Error Rate Calculation.
The Display block shows the value of its input. We use Display block to display the final results of the bit error rate.

In summary, the complete model of S-band Telemetry communications for Low Earth Observation is shown below.

![Model of S-band Telemetry communications for Low Earth Observation system.](image)

### 4. SIMULATION AND RESULTS

We use BERTool to analyze the bit error rate (BER) performance of the S-band Telemetry link. BERTool computes the BER as a function of signal-to-noise ratio. To do this, a To Workspace block, with $BER$ as Variable name, is connected to the output of Error Rate Calculation block. In addition, we set SNR parameter of AWGN Channel block to $E_b/N_0$. This value is specified as $[0:0.1:10]$ in Monte Carlo tab of BERTool. The result is shown below. When $SNR > 8$, $BER = 0$.

![BER output](image)
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For S-Band Telemetry link of Observation Satellite, $BER \leq 10^{-4}$ is required. So this model works functionally if $SNR > 8$ dB.

5. CONCLUSIONS
Model of a S-band Telemetry link for Low Earth Observation satellite has been built and simulated using MATLAB/Simulink and practical input parameters which can be tuned to fit with user requirements and design. This model can be used for design and verification of decoding hardware in reality.

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REFERENCES


