The Consultative Committee for Space Data Systems

INDEPENDENT IMPLEMENTATIONS OF TELEMETRY RANGING

DRAFT CCSDS RECORD

CCSDS 401.0-Y.30.0

YELLOW BOOK

April 2019

FOREWORD

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– Swedish Space Corporation (SSC)/Sweden.
– Swiss Space Office (SSO)/Switzerland.

– United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 401.0-Y-30.0	Independent Implementations of Telemetry Ranging, CCSDS Record, Issue 1	April 2019	Current draft

CONTENTS

1 INTRODUCTION

1.1 PURPOSE

This document is a record of two independent implementations of a telemetry ranging capability being developed as part of a new Recommended Standard CCSDS 401.0-B-30- by the CCSDS Radio Frequency and Modulation Systems working group.

Issue 29 of CCSDS-401.0-B was published in March 2019 [1]. Proposed for Issue 30 is a new section 2.4.24, recommending that a new ranging method called telemetry ranging be used for space-to-Earth transmissions under certain circumstances. Currently as of April 2019, Pink Sheets [2] have been delivered to CCSDS RF Modulation Working Group, and consensus has been achieved regarding the acceptance and wording of the new specification. The RFM Working Group resolved to publish the telemetry ranging specification in 401.0-B when this Yellow Book is complete. The two telemetry ranging implementations described in this document are based on the telemetry ranging specification in reference [2].

In order to complete the conversion into a CCSDS recommended standard, CCSDS requires [3] "that at least two independent and interoperable prototypes or implementations must have been developed and demonstrated […] The WG Chair is responsible for documenting the specific implementations that qualify the specification for CCSDS Recommended Standard status, along with reports relevant to their testing." This document serves that purpose.

Document CCSDS A02.1-Y-2 also requires, "If patented or otherwise controlled technology is required for the separate implementations, they each must also have resulted from separate exercise of the licensing process." No patents of concern have been identified.

1.2 SCOPE

This document is not part of any CCSDS Recommended Standard.

1.3 DOCUMENT STRUCTURE

This document is divided into five parts. Section 1 (this section) presents the purpose and organization of the document. Section 2 describes the independent implementations of telemetry ranging. Section 3 contains a note about patented technology. Section 4 contains references.

2 INDEPENDENT IMPLEMENTATIONS OF TELEMETRY RANGING

2.1 OVERVIEW

Two software implementations of the draft Recommended Standard have been independently developed. Section 2.2 provides a brief overview of each.

2.2 IMPLEMENTATIONS

2.2.1 NASA/JPL

The NASA Jet Propulsion Laboratory has implemented telemetry ranging as defined in [2], in software. This software simulates both the ground and spacecraft components of the ranging system. In particular, the normative statements in [2] were validated, including the tracking of an uplink PN signal generated in accordance with CCSDS 414.1-B-2, the recording of the range code phase in a 40-bit number, the subsequent transmission of the range code phase in downlink telemetry, and the establishment of Earth receive time of downlink telemetry frames, and the use of this without punctured convolutional codes.

The implementation is described in more detail here. For additional details, see [4], [5], [6].

For the ground system, the software begins by generating of blocks of samples of an uplink PN ranging waveform as described in CCSDS 414.1-B-2, including a PN signal, pulse-shaping, and phase-modulation of the signal onto an uplink carrier, as shown in Figure 1.

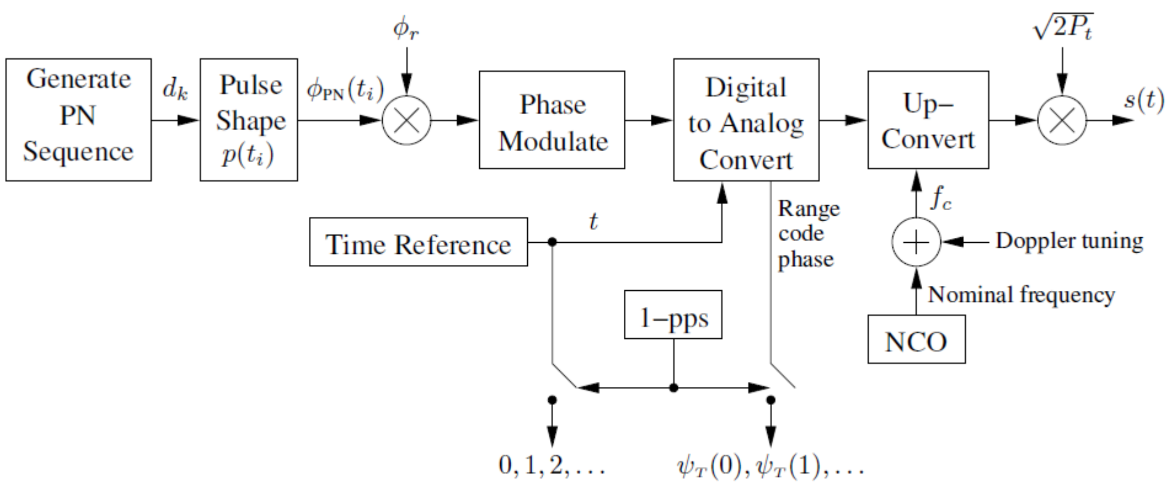

Figure 1: Generation of uplink signal.

Additional software modules simulate channel effects, including noise, Doppler, and delay.

On the spacecraft side, the simulated samples are received and processed with a software receiver, as shown in Figure 2. A digital phase-locked loop (DPLL) is used to acquire and track the uplink carrier. Chip timing from the PN sequence is recovered with another DPLL – this determines the fractional chip offset. The integer chip offset is determined algorithmically using the Chinese remainder theorem. The range code phase, i.e., the integer and fractional offset is then recorded for subsequent use.

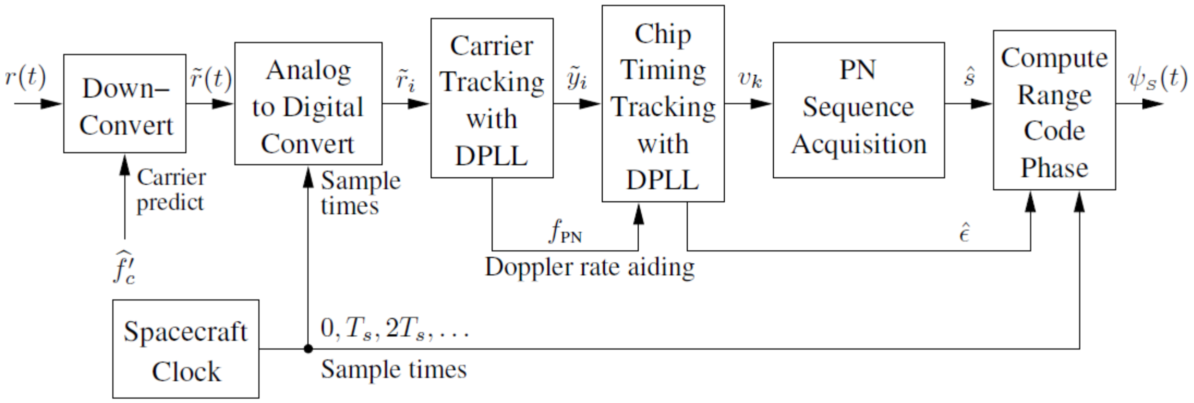

Figure 2: Uplink receiver processing

Next, the spacecraft downlink telemetry transmission is simulated. In this process, dummy (random data) telemetry is simulated, along with the transmission of the range code phase, as shown in Figure 3. The range code phase is stored as described in the telemetry ranging specification [2].

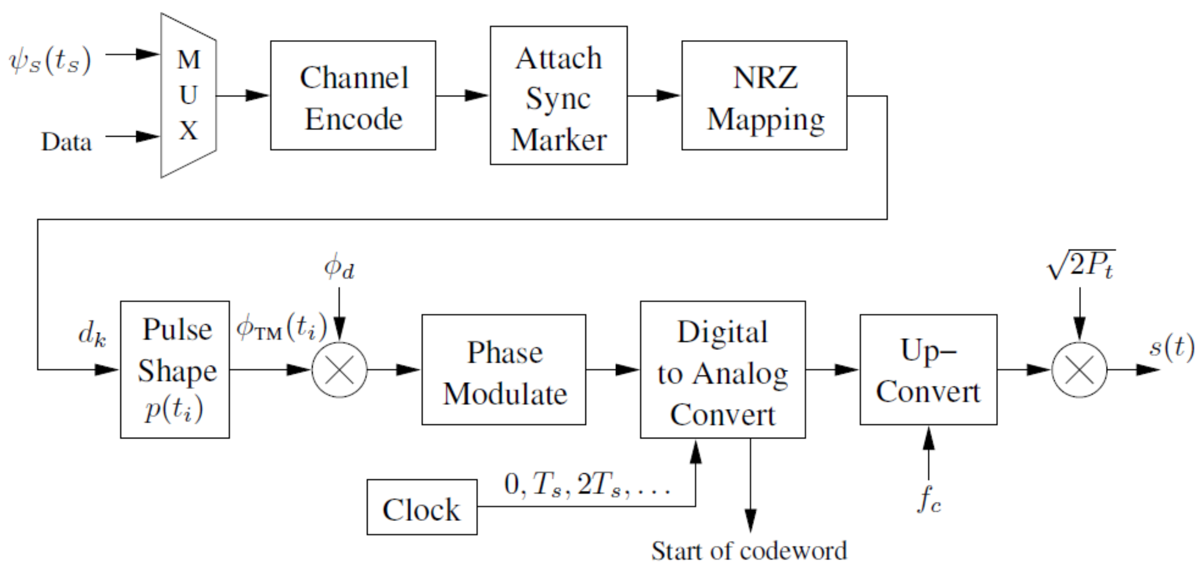

Figure 3: Generation of downlink telemetry signal

Finally, the ground receiver is implemented, using standard techniques to track the carrier, track the symbol timing, and decode. This implementation assumes the availability of an accurate 1-pulse-per-second (1-PPS) time reference at the ground station, as is available in

NASA's DSN ground stations. Using the 1-PPS time reference, along with an open loop recording, an accurate time tag of each received sample can be made.

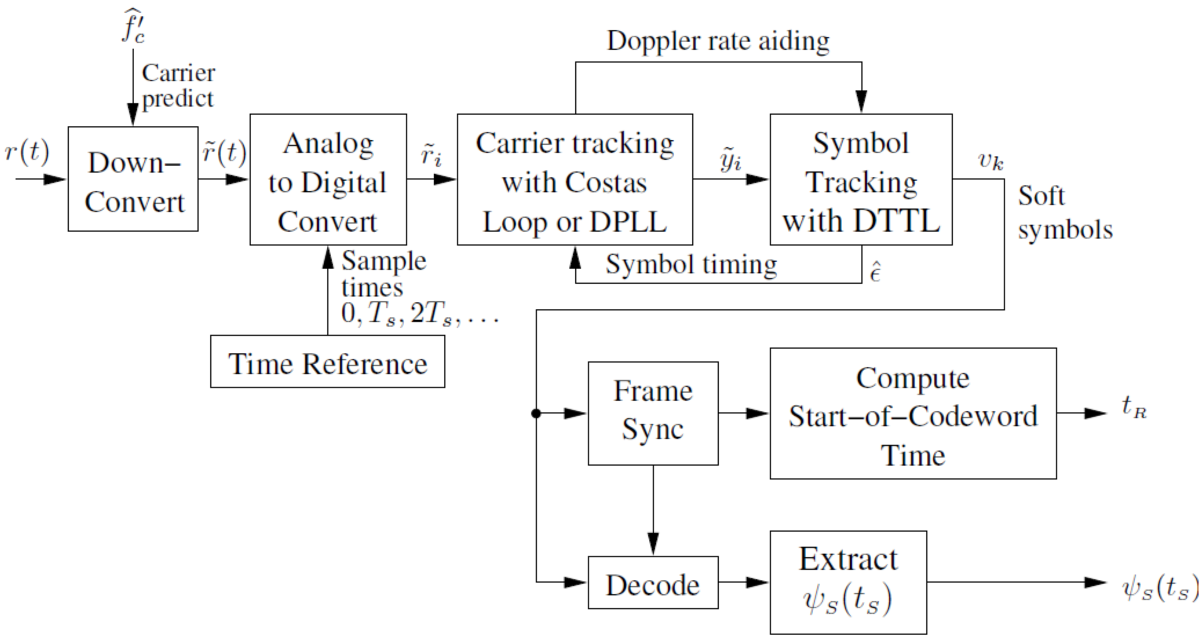

Figure 4: Downlink receiver

JPL has tested its software in a stand-alone mode and confirms that the performance of the uplink receiver and the downlink receiver are as expected [5], [6].

2.2.2 JOHNS HOPKINS UNIVERSITY/APPLIED PHYSICS LAB

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has implemented the telemetry ranging recommendation, in support of its own technology development of its Frontier Radio. The Frontier Radio is described in [7]. APL implemented a testbed which includes their Frontier Radio as a component, as shown in Figure 5.

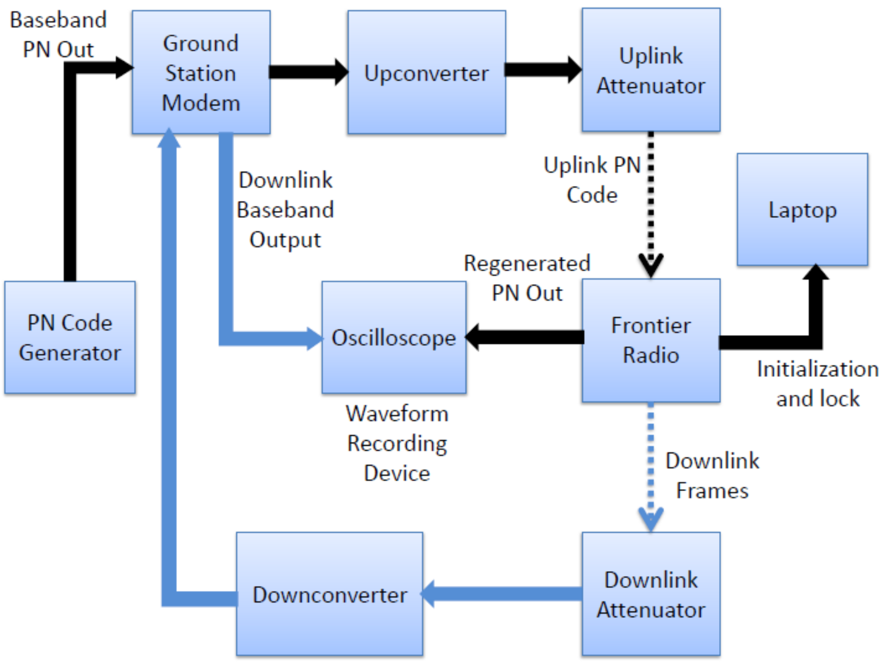

Figure 5: APL implementation of telemetry ranging.

The other components included a ground station modem implemented on RT Logic equipment, an up converter to convert from an IF to X-band and vice versa, an attenuator, a laptop to configure an monitor the Frontier Radio, an oscilloscope to monitor the uplink PN sequence, and a trigger source to measure performance relative to ground truth. This is shown in Figure 6.

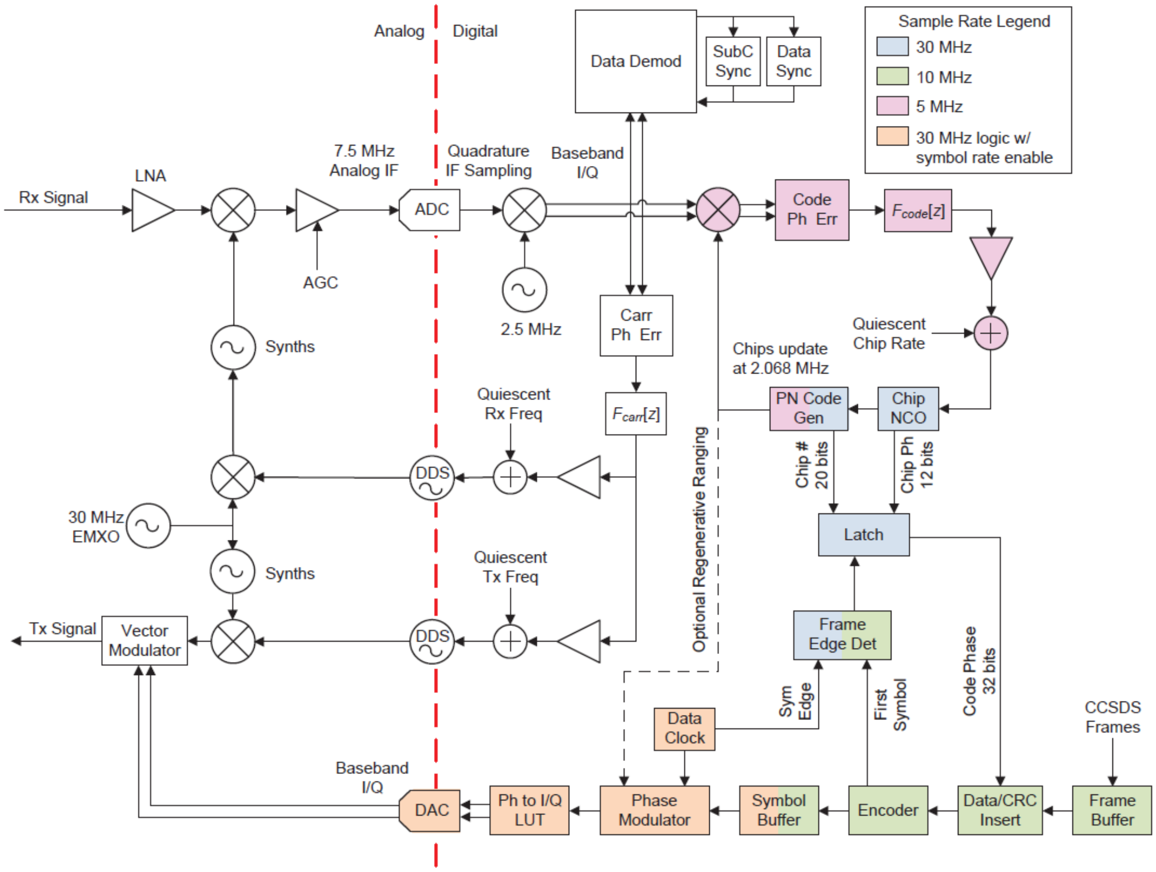

Figure 6: Telemetry Ranging implemented in the Frontier Radio

Performance of the APL system also performed as expected. A representative result is shown in Figure 7, which describes the accuracy of timing measurements that are possible in the Frontier Radio, as a function of integration time.

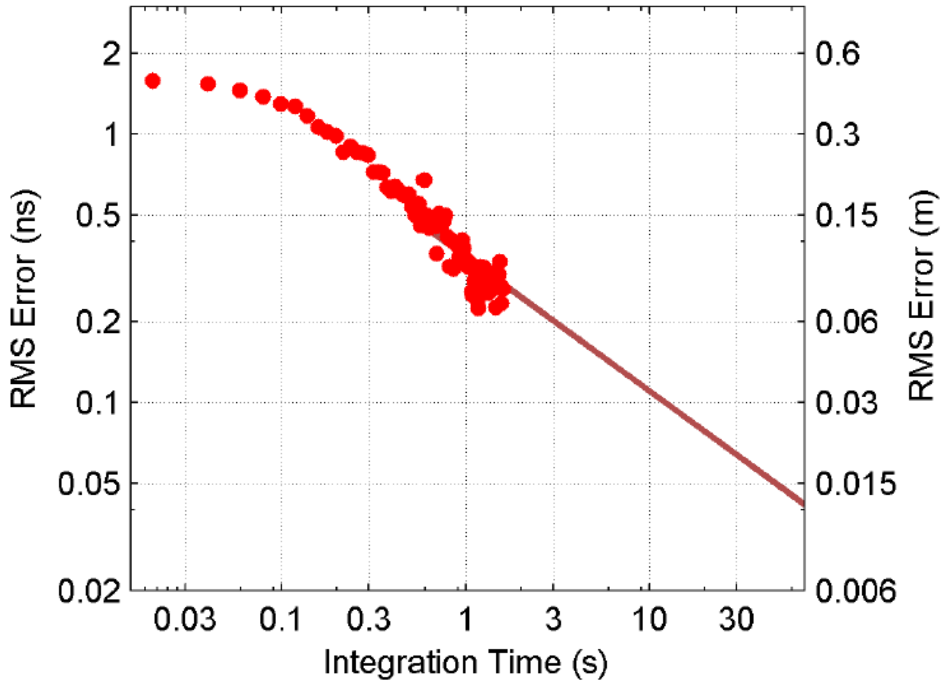

Figure 7: Measured range code phase error in the Frontier Radio.

2.2.3 CROSS-COMPATIBILITY TEST

A sequence of tests were performed to verify the cross-compatibility of the two implementations. In these tests, the APL Frontier Radio was brought to Monrovia, California and tested in conjunction with NASA's equipment at the DSN Test Facility 21 (DTF-21). In this set up, NASA/JPL supplied the ground part of the telemetry ranging system, and APL supplied the flight radio part.

In the test, JPL's implementation generated a time-tagged uplink PN ranging signal, in accordance with [2], and it was received and tracked on the Frontier Radio. The range code phase was latched by the Frontier Radio in accordance with [2], inserted into the downlink X-band telemetry, and the telemetry signal was recorded using an open-loop recorder in the ground station. JPL's software implementation of the telemetry ranging receiver correctly processed the downlink signal, extracted the flight-radio range code phase and successfully made simulated range computations. This validated the cross-compatibility of the two implementations of telemetry ranging.

3 PATENT CONSIDERATIONS

JPL has not filed any patents specific to the proposed telemetry ranging technology, and is not aware of any patents that apply to this technology. However, implementers are cautioned that there are many patents filed on the general topics of communications, transmission schemes, reception schemes, and ranging.

4 REFERENCES

The following publications are referenced in this document. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the publications indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS publications.

[1] *Radio Frequency and Modulation Systems – Part 1 Earth Stations and Spacecraft*. Recommended Standards CCSDS 123.0-B-29. Blue Book. Issue 29. Washington, D.C.: CCSDS, March 2019.

[2] *Telemetry Ranging for Space Research 8.40 – 8.50 GHz Band, Space-to-Earth, Categories A and B, and 31.8 – 32.3 GHz Band, Space-to-Earth, Category B*. Section 2.4.24 of Draft Red Book for Space Data System Standards, CCSDS 401.0 (2.4.24) R-1. Red Book draft of October 25, 2018.

[3] *Restructured Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-4. Yellow Book. Washington, D.C.: CCSDS, April 2014.

[4] Jon Hamkins, Peter Kinman, Hua Xie, Victor Vilnrotter, and Sam Dolinar. Telemetry Ranging: Concepts. The Interplanetary Network Progress Report, Volume 42-203, November 15, 2015. https://ipnpr.jpl.nasa.gov/progress_report/42-203/203C.pdf.

[5] Jon Hamkins, Peter Kinman, Hua Xie, Victor Vilnrotter, and Sam Dolinar. Telemetry Ranging: Signal Processing. The Interplanetary Network Progress Report, Volume 42-204, February 15, 2016. https://ipnpr.jpl.nasa.gov/progress_report/42-204/204D.pdf.

[6] Jon Hamkins, Peter Kinman, Hua Xie, Victor Vilnrotter, Sam Dolinar, Norman Adams, Erika Sanchez, and Wesley Millard. Telemetry Ranging: Laboratory Validation Tests and End-to-End Performance. The Interplanetary Network Progress Report, Volume 42-206, August 15, 2016. https://ipnpr.jpl.nasa.gov/progress_report/42-206/206D.pdf.

[7] C.B. Haskins and W.P. Millard, "Multi-band software defined radio for spaceborne communications, navigation, radio science, and sensors," Proceedings of the IEEE Aerospace Conference, Big Sky, MT, pp. 1–9, March 2010.

[8] J. Hennawy, N. Adams, E. Sanchez, D. Srinivasan, J. Hamkins, V. Vilnrotter, Hua Xie, and P. Kinman, "Telemetry ranging using software-defined radios," Proceedings of the IEEE Aerospace Conference, Big Sky, MT, pp. 1–14, March 2015.