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A Space Link Channel emulator based on off-the-shelf software defined radio peripherals.

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Abstract

To be able to ensure the ground stations will succeed to communicate with spacecraft, ahead of its launch, a radio frequency compatibility test (RFCT) is carried out. The RFCT is most often performed under laboratory conditions and the most important effects on the space link are simulated by devices like attenuators and noise sources.

We propose to re-purpose off-the-shelf software defined radios (SDR), to simulate effects more accurately like free space loss, noise, Doppler, Doppler rate and the latencies of the space link, both in-situ but also with Internet as a proxy. In our setup the SDRs are not used as modulators or demodulators, but rather as a sample-buffer-transform-and-play-back device where all the necessary transformation happens in the digital domain.

The core module includes a signal source, a USRP and a computer with the open-source software GNU-Radio. The setup is used with an IFMS (Intermediate Frequency Modem System) as a signal source, which generates a carrier at 70 MHz. Ranging measurements are performed. A time delay is introduced via a created channel delay simulator. Its task is to act on the complex envelope of the signal to simulate the dynamic effects.

All in all, we believe that for future demanding science and exploration missions, the ability to fully simulate impairments and dynamical effects of the propagation channel will increase the confidence and the adequacy of space link communication solution.

Keywords: RFCT, USRP, SDR, Spacelink, Simulator

1. Introduction

Spacecraft that are about to launch typically needs to perform a Radio Frequency Compatibility Test (RFCT) with the representative Receive and Transmit equipment used by the Ground Stations. The test is typically performed using a "RF suitcase" which consist of the engineering prototype or flight equivalent transponder together with its ground support equipment. In the case of the European Space Operations Centre (ESOC), The "RF suitcase" for Spacecraft that is to be supported by the ESTRACK Core and Augmented network, is brought to the Ground Segment Reference Facility (GSRF) in Darmstadt, Germany. In the GSRF it will interface with the ground station modems through a set up to emulate many of the physical effects of the space link.

With the maturation of commercial modems that almost exclusively operate in the digital domain and using computers for near real-time Digital Signal Processing (DSP), known as Software Defined Radios (SDR), a new opportunity for emulating the physical effects on the space links is coming about. In addition to the typical noise injection and free space attenuation of the traditional RFCTs the SDRs using large buffers of randomly accessible memory (RAM) can also be used to emulate the propagation delay together with effects like Doppler and Doppler rates using software "filters" to perform the transformations of the signal and control the recording or playback of the samples of the signal.

2. Architecture

The envisioned architecture is using an SDR with a Universal Software Radio Peripheral (USRP) as a front end and a common software like GNU Radio as a back end, one instance for each of the directions of the space link. For each direction the signal is first sampled at the output of the Transmitter using an Analogue to Digital Converter (ADC), the transformations are applied using software processing of the samples and then the resulting signal is played into the receiver through a Digital to Analogue Converter (DAC) of the USRP.
In its simplest form the set-up can be as in the figure below, this is using the Ettus Research N321:

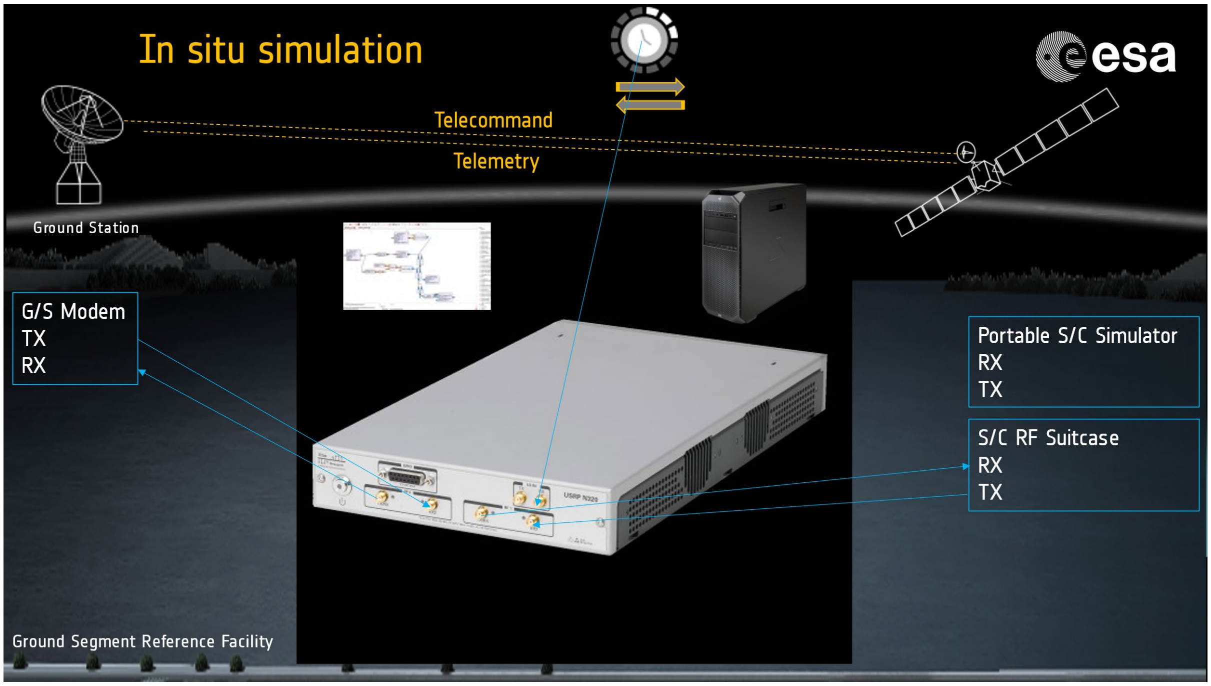

Fig. 1. Architecture for In-situ simulation

In this figure the Ground station modem is connected to the Receive and Transmit of one of the analogue to digital digital front-ends, and the spacecraft representative transponder is connected to the other. These devices can deal with missions in the frequency ranges from 1 MHz to 6 GHz without additional frequency converters.

Another set-up can be the RFCT by proxy, where the channel samples are transmitted over a network, e.g. Internet, or even by exchanging memory cards with an agreed exchange format like a CCSDS Open-Loop Recording Protocol (COLRP).

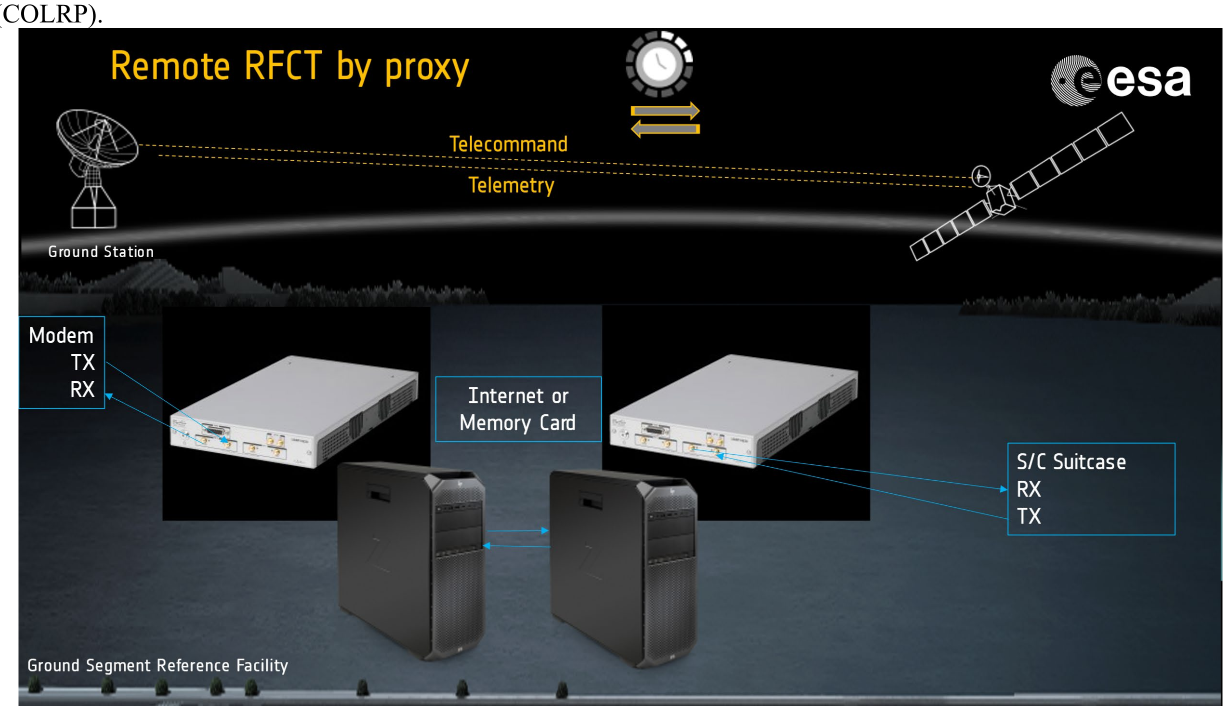

Fig. 2. Architecture a remote RFCT by proxy

If the Spacecraft transponder/RF suitcase and the GSRF cannot not be easily co-located one USRP can be used near the RF suitcase and another near the GSRF and connected through internet or by transporting the files with the sampled signal without any other penalty than non-concurrency.

3. Capabilities

Once the signal is in the digital domain in theory all the physical effects experienced by the expected space links can be emulated.
From the flight-dynamics state-vectors the attenuation, the propagation delay, Doppler and Doppler rates can be extracted, estimated and emulated by filters. From weather models various scenarios of atmospheric losses, multipath effects can be emulated. From models of planetary and solar occultations empirical noise can be mixed with the signals. Even recorded interferers can be mixed with the signal to test for Radio Frequency Interference (RFI) tolerance and effects.

4. Proof-of-concept tests

During 2022 a series of tests were carried out. The concept was tested in the ground station reference facility by performing ranging measurements. Fig. 3 shows the setup.

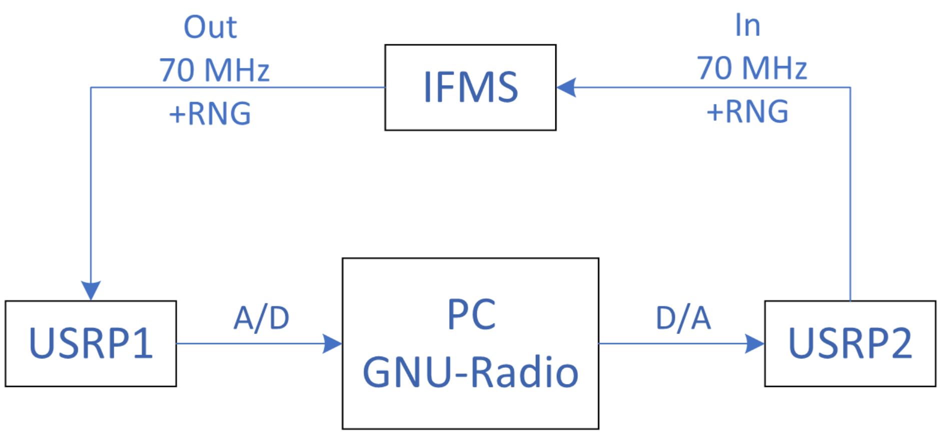

Fig. 3. Setup of intermediate frequency ground station modem in ranging configuration

A 70 MHz input signal is coming from an Intermediate Frequency and Modem System (IFMS). The ADC-unit in the USRP is converting the signal to the digital domain where signal processing is performed using GNU-Radio.
Simple filters can be used to insert a static delay. In order to introduce a first dynamic delay, a sine wave signal is linked to the delay as displayed in the GNU-Radio flow graph in Fig. 4.

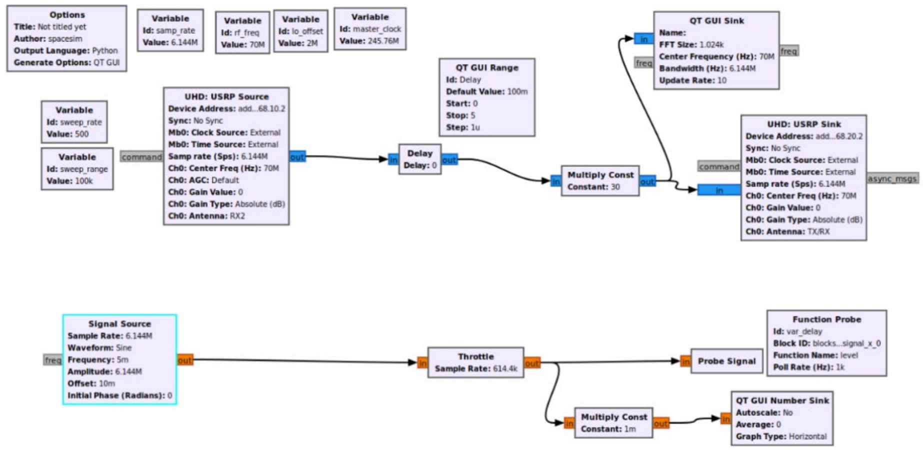

Fig. 4. Graphical blocks representing the filters applied by GNU radio

Afterwards, the processed signal is sent to USRP 2 and back to the IFMS. The results displayed in Fig. 5 shows a successful ranging measurement which reflects the sine-wave delay.

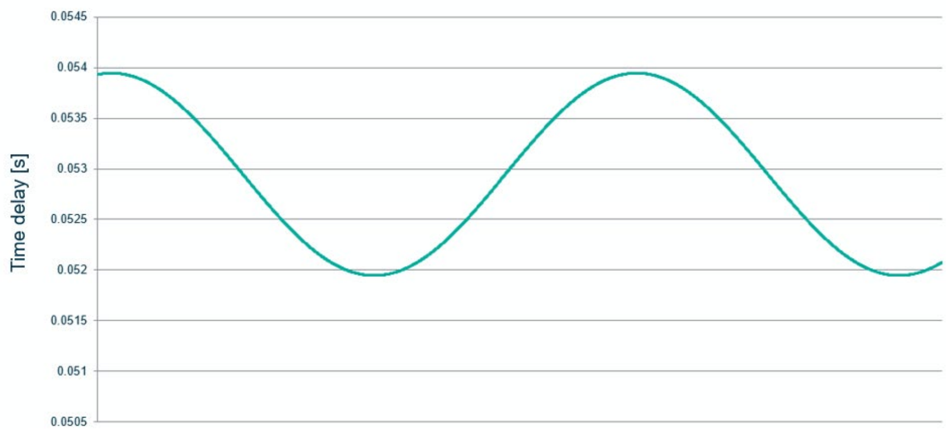

Fig. 5. Measured delay when range was simulated to change in a sinusoidal way

6. Vision and conclusion

The vision for the future is to be able to establish a standardised high fidelity sampled signal file format, covering both the Space to Ground direction and the Ground to Space direction (TM&TC), including the support for Coherent and Non-coherent operation, Radiometry and transitions cases when those services are started and stopped. That can be exchanged between agencies and industries, to investigate preliminary compatibility issues, to offer a replacement for hardware in the loop requirements by emulating the different signal conditions on the relevant recordings of the transmitters using software filters.

The actors in the field then would have similar equipment and software that can be used to make recordings of transmitted waveforms and to provide a playback at the fidelity required for the signal to be representative.

The files can be post processed, prepared, calibrated and validated to emulate scenarios like maximum Doppler and maximum Doppler rates for interplanetary probes, planetary re-entry and landing, launch vehicle plume interference and attenuations, radiation pattern and orientation anomalies, worst case weather effects and noise and interference modelling.