Compensating for Doppler effect in satellite D-STAR radiocommunications: On-board and on-the-ground solutions

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Abstract

A major issue in the design of a D-STAR radiocommunication system for a satellite is the issue of Doppler shift compensation. We describe the various constraints we faced, and the solutions we implemented on-board and on the ground for the OUFTI-1 nanosatellite system.

The main payload of the OUFTI-1 nanosatellite is a homemade D-STAR radiocommunication system. D-STAR is an amateur-radio ("ham") digital communication protocol developed by the Japanese Amateur-Radio League in 2003 that allows the simultaneous transmission of voice and data (e.g. callsigns and GPS coordinates). The analog voice is digitized and coded by the AMBE voice coder. The resulting digital data is scrambled, interleaved, and convolved in order to prevent transmission errors such as burst errors. The digital frame is then GMSK-modulated. D-STAR radio equipments work on the ham frequency bands of 145 MHz, 435 MHz, and 1.2 GHz. Over the last few years, we have developed a full understanding of the D-STAR protocol (despite many initial uncertainties) [1], and we have built, from scratch, our own D-STAR receivers and transmitters.

One of the main issue about using the D-STAR protocol for space communications is the compensation of the Doppler effect. It was shown in [2] that, for our initial mission, the Doppler shift ranges from -3 KHz to +3 KHz on the 145 MHz frequency band, and thus from -9 KHz to +9 KHz on the 435 MHz frequency band, which are respectively the downlink and uplink frequency bands chosen for OUFTI-1. Since commercial D-STAR transceivers accept frequency shifts of at most 1 kHz, the Doppler shift must be compensated for. However, commercially-available D-STAR-capable transceivers have a frequency step of 5 kHz, and are thus unable to compensate correctly for the Doppler shift. (They are not intended for satellite communications.) Therefore, we were forced to develop our own, specific compensation strategies on-board and on the ground.

The on-board solution consists in applying pre-computed Doppler frequency corrections to all received and transmitted signals for two specific geographical regions, thereby allowing any two ham operators, each located in the same of these regions or in each of these regions, to communicate via OUFTI-1 without having to worry about the Doppler shift. (They just need to dial the nominal transmit and receive frequencies). If a conventional, internet-connected D-STAR repeater is located in one of these two regions, a ham operator will be able to communicate with the rest of the world through OUFTI-1, since most D-STAR repeaters are linked via the internet. One of the two regions will typically be centered on Liège, and the second will be chosen by ham operators, on a reservation basis. Our ground station will upload to the satellite (via the AX.25 protocol) the Doppler shifts that need to be applied on-board.

Although the above solution provides the desired functionality, we decided to develop a backup strategy, in case the above compensation fails, for example as a result of errors in the uplinked corrections (especially initially). To perform the compensation on the ground, we must address two issues. First, we must build the necessary hardware to allow standard D-STAR transceivers to do the compensation, and we must communicate the construction details to technically-inclined ham radio operators so they can also build the required hardware. Second, we must build other hardware to allow a standard D-STAR repeater, in particular ours, to do the compensation.

In D-STAR equipments, the GMSK modulation is implemented via the cascade of a digital Gaussian filter followed by a customary FM modulator. Therefore, if, in a conventional, commercial transceiver, one can access, and use as independent input, the input of its FM modulator, one can feed this modulator with a digital GMSK signal, and make the transceiver D-STAR-capable. We have implemented the digital processing part of the D-STAR protocol on an electronic board of our own design, both for receive and for transmit. This board converts user's digital data into a D-STAR digital frame that is passed through a Gaussian filter before being sent to the FM stage of the commercial transceiver. It has been successfully tested on transmit and receive, using other commercial D-STAR equipments to receive or transmit signals as appropriate. Future work include the handling of the voice data on the board. (The AMBE protocol is indeed proprietary.)

D-STAR repeaters use the notion of ports, and each port works at a given frequency, e.g. 145 MHz or 435 MHz, with one transceiver module corresponding to each port. This means that any basic two-way communication goes through a given module, thus at a given frequency. (However, this does not prevent a communication from entering through one port and exiting through another.) While each D-STAR module is mono-frequency, OUFTI-1 is bi-frequency, with uplink at 435 MHz and downlink at 145 MHz. Yet, the signals up and from OUFTI-1 must appear as if they were at the same frequency. This means that we have to do a frequency conversion either on the uplink or on the downlink. We have chosen to convert the downlink 145 MHz signal to 435 MHz, and to use a standard 435 MHz repeater transceiver module fully dedicated to OUFTI-1. By building a frequency converter that can be frequency controlled, we can easily compensate the downlink signals for the Doppler effect. Of course, we must also provide the appropriate compensation to the uplink signals.

We will describe our strategies for on-board and on-the-ground Doppler compensations and the status of developments and tests.

References

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