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Data Format and Observational Modes for the RadioAstron Interferometer

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Abstract—To transmit radio-astronomy and auxiliary data from a space radio telescope to a ground tracking station (and then to a correlator) via radio link it is necessary to use a special data format and coding and decoding procedures. Here, the format developed and successfully implemented in the RadioAstron ground–space radio interferometer is considered in detail. The goal of the paper is to present the characteristics necessary for astronomers, observers, designers of tracking stations, and management and planning workgroups, as well as for testing for compatibility of the space radio telescope and tracking stations.

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INTRODUCTION

The output data of the Space Radio Telescope (SRT) are transmitted to the tracking station by two streams simultaneously via radio link in the *Q*-band (15 GHz) using a special data format and QPSK (double relative phase manipulation, DRPM) transmitter modulation. Before modulating, both formatted and "packed" data stream are additionally differentially coded in order to separate streams in phase. Each stream is divided into frames and contains radio astronomical data obtained after clipping and 1-bit quantization (in sign of a signal). At the beginning of each frame a header is introduced, which contains a synchronized code and the technical parameters of SRT and the service module. The rate of transmission streams is equal to 2 × 72 or 2 × 18 Mbit/s depending on the video band width and the number of bands used simultaneously, i.e., on the chosen observational mode. Indicated operations in SRT are performed by the Formatter device. Formatter flight models are manufactured in SINP MSU and SKB IRE (Fryazino). The tracking station (TS) receives, demodulates, and removes the differential coding in the signals from SRT. Then, streams on TS are "unpacked," i.e., frame headers are distinguished, and the astronomical data are transformed into several parallel streams compatible with the data of the ground-based radio telescopes (GRT). Figure 1 illustrates these procedures. During flight tests only TS in Pushchino was used, later TS in USA (Green Bank) was put into operation.

OBSERVATIONAL MODES

RadioAstron can provide for observations 2 or 4 video signals with a band width of 4 or 16 MHz and 1-bit quantization (in sign of a signal). Two input signals come either from two SRT different receivers, but with a single polarization, or from one receiver, but with two circular polarizations. Figure 2 shows the mutual position of the SRT operating frequencies and spectra, which can be processed for each polarization. Here, lines of deuterium D, hydroxyl OH, formaldehyde H_2CO, and water H_2O are marked by an asterisk to select the narrow-band observations.

The mode is indicated by four parameters: the used frequencies of the second heterodyne for video converters ($F_1 \ldots F_4$ for two intermediate-frequency signals); a width of one (lateral) video band, MHz; the total used band, MHz; the transmission rate of the binary data to the Earth, Mbit/s. For example, the mode F_2F_2 –16–32–72 means: F_2 = 508 MHz for both channels, video band is 16 MHz, full band is 16 × 2 = 32 MHz, the transmission rate is (32 × 2) × (9/8) = 72 Mbit/s for both channels simultaneously.

We provide a choice of 9 combinations of 2 heterodynes: F_2 F_2, F_3 F_3 for video bands of 16 MHz (see Table 1), as well as F_1F_2, F_2F_3, F_3F_4 and any pair of identical heterodynes for 4-MHz bands (see Table 2). During flight tests of the RadioAstron SRTVLB for simplicity's sake only part of the modes was used, mainly that with a video band of 16 MHz. In further observations, modes with video band of 16 MHz were thus also successfully implemented.

THE SRT DATA FORMAT

By applying the QPSK modulation of the 15-GHz transmitter the data stream 1 and the data stream 2 can be transmitted simultaneously. In this case, the order of the device connection in SRT (from the *L* and *R* antenna polarizers) is as follows:

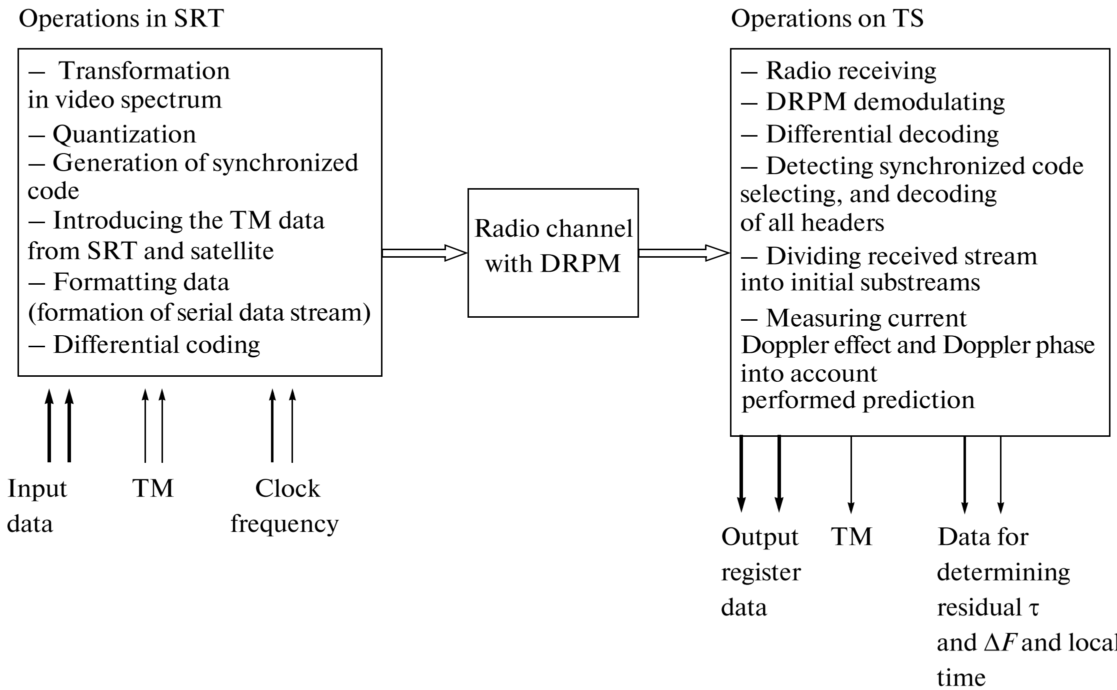

Fig. 1. Basic operations for forming, transmitting, and allocating data from SRT.

L – the first receiver channel – the first Formatter channel – the *I* input of the QPSK modulator;

R – the second receiver channel – the second Formatter channel–the *Q* input the QPSK modulator.

Figure 3 illustrates the structure of frames and their headers for both packed streams.

Each frame in the streams contains 20000 bytes: 30 bytes for the header and 19970 bytes for the radio astronomy data. Each frame is numbered from 1 to 400 (the number is placed in the header); 400 frames occupy a time of 1 or 4 seconds depending on the selected observational mode (the data transmission rate). To distinguish streams 1 and 2 the position of synchronized codes in the headers are shifted by 8 bits. Each byte in the frames contains 9 bits; the 9th bit is a parity bit (always in synchronized code, each byte always contains an even number of "1" bits). This measure reduces the number of mistaken bytes (due to noise of the radio channel) and avoids failures or, which is the most dangerous, the formation of falsely synchronized code.

The structure of the astronomical data. The position of bits in bytes depends on byte packing. When observing sources with a wide spectrum, both lateral video bands can be used: the bottom (BLB) and the upper (ULB) in each channel. In this case, this byte packing takes the form:

Astronomical byte

Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Bit 9
ULB	BLB	ULB	BLB	ULB	BLB	ULB	BLB	Parity

This feature should be taken into account before correlation with the GRT data in order to use identical video bands. When a source with a narrow spectrum (for example, 4 MHz in ULB) is observed, the other output of the converter (BLB) will be filled with useless data (receiver noise). To check SRT and TS without observing the source, there are two test modes: Test 1, when Formatter continuously repeats synchronized code without the header, and Test 2, when the binary sequence 0101010101… is generated instead of astronomical data. The rule of differential coding of streams before transmitter modulation is shown in Table 3.

Table 1

Band		Possible mode
327 MHz		F_4 – 4–8–18, F_3F_3 – 16–32–72
1665 MHz 4830 MHz 22235 MHz	For both polarizations simultaneously	F_2F_2 – 16–32–72 F_3F_3 – 16–32–72 F_1F_2 – 4–16–18 F_2F_3 – 4–16–18 F_3F_4 – 4–16–18 F_iF_i – 4–16–18

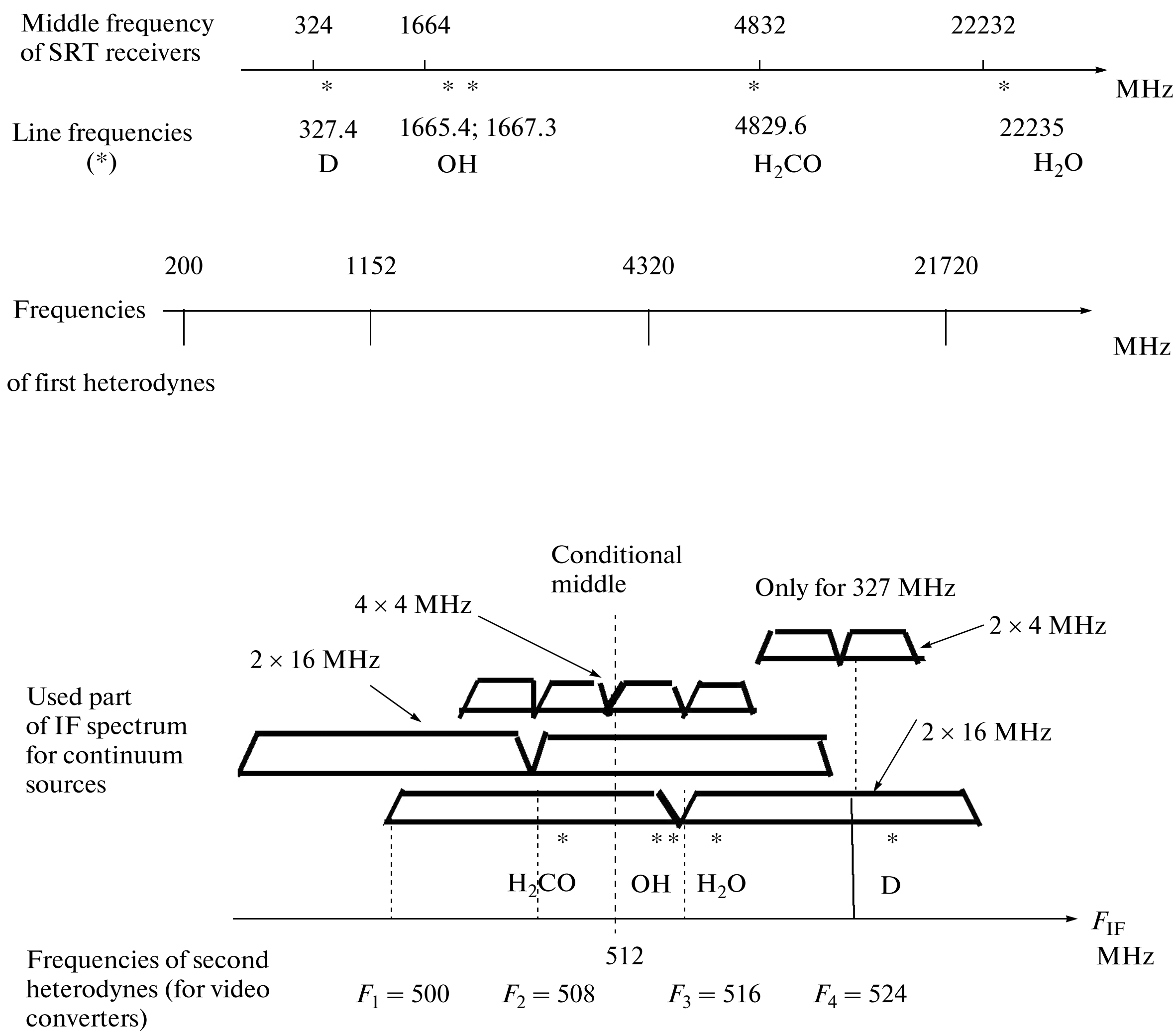

Fig. 2. Relative position of the SRT working ranges and bands.

Detailed structure of the header. Bytes 1–10 contain technical telemetry from the TM satellite system.

Bytes 11–12 contain data on the output power level (8-bit ADC) of video channels 1 and 2, including noise calibration with the period of second frame (even–odd).

Byte 13 is reserve (000000001).

Table 2

Band	Possible mode	
327 MHz	F_4 – 4–8–18, F_3 –16–32–72	
1665 MHz	F_3 – 4–8–18	
4830 MHz	F_2 – 4–8–18	
22235 MHz	F_1 – 16–32–72 F_2 – 16–32–72 F_3 – 16–32–72 F_4 – 16–32–72	Selected depending on predicted source velocity (up to 1500 km/s)

Byte 14 shows the receiver mode.

Byte 15 shows the Formatter mode.

Bytes 16–22 for stream 1 and 17–23 for stream 2 are anti-interference synchronized code representing pseudonoise 63-bit sequence with an even number of units in bytes:

111011001 111000001 000011000 101001111 010001110 010010110.

Byte 23 in the stream 1 and byte 16 in stream 2 are reserve.

Byte 24 is the same as byte 14.

Byte 25 is the receiver and Formatter modes.

Bytes 26–27 are the frame number (1–400) in 9-bit binary code.

Bytes 28–30 are reserve in both streams.

Table 3

Current bits of streams 1 and 2 \ Previous bits of streams 1 and 2	00	01	10	11
00	00	01	10	11
01	01	11	00	10
10	10	00	11	01
11	11	10	01	00

THE RESULTS

For observations of celestial sources with different spectral widths in different bands recommended observational modes are composed. The necessity to transfer the data from SRT to the Earth requires the conversion of the received SRT data into a form compatible with the capabilities of the radio link of the SRT–TS communication. For this, in the case of RadioAstron, a particular format is selected. All this requires the restoration on TS of the data form from SRT and the reliability of their compatibility when correlating with the GRT data. The transmission in the scientific data stream of a part of technical information eliminates the loss of the most important service telemetry during scientific sessions. The knowledge of observational modes and the SRT data format after decoding on TS allow to users of this radio interferometer to ensure the identity with the GRT data format.

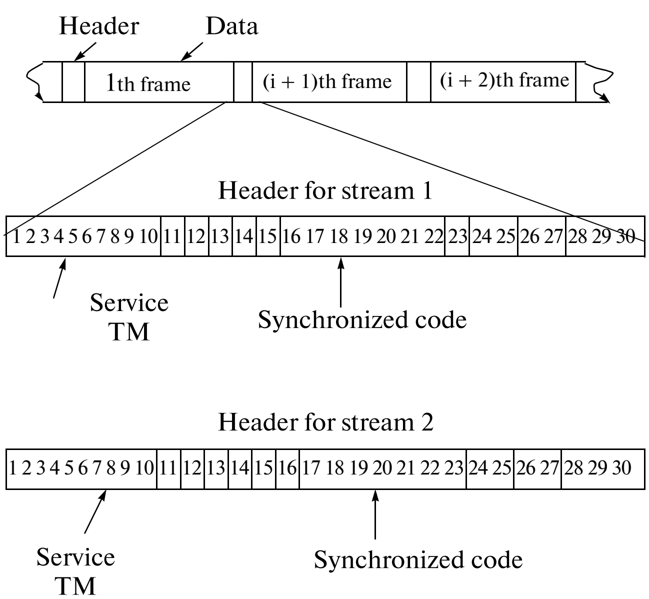

Fig. 3. Structure of frame and its header.

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