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On the Possibilities of Digital Method Applications in Probe Space Experiments

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Recently the digital methods of information transmission find greater application in radiotelemetry, replacing the analog ones. That is due to the successful development of the pulse-digital technique and to some advantages of the digital systems compared to analog ones. The information signals from the ionospheric scientific experiments are analog in their majority. In order to be transmitted by the digital telemetric channels, it is necessary for the dynamic range of the analog process to be divided into a finite number of subregions, i. e. to be quantized by level. When the value of the measured quantity falls in some of the subregions, a value approximated to the closest higher or lowest level value is transmitted. If instead of this approximated value the number of the subregions is transmitted, then this method of transmission is called digital. A reestablishment of the quantized instantaneous signal value is performed in the receiving part through various methods of interpolation. The basic advantages of the digital methods, justifying them as a real and promising way to transmit information are: possibility of increase without informational losses, easy transfer and storage by one memory device into another, direct introduction into a digital computer, and possibility to increase the noise resistance of the system while introducing coding of informational excess.

The objective of this work is to evaluate the application possibilities of the principal digital methods in analog-digital informational transmission from direct probe space experiments.

We discuss and compare methods for: (a) pulse-code presentation with uniform quantization; (b) relative (difference) presentation; (c) delta-presentation.

Two determined probe signals are processed under linear and step interpolation.

We should note that the paper deliberately avoids the analysis of the adaptive informational presentation methods. The reason being: the relative complexity of equipment in the receiving and emitting part when using these methods; the variety and the relatively great possibilities of these methods is subject to a separate analysis which could be further developed in another work.

The first analysed signal is the classical volt-ampere charactetistic of the Langmuir probe. The curve in Fig. 1 is a typical characteristic obtained dur-

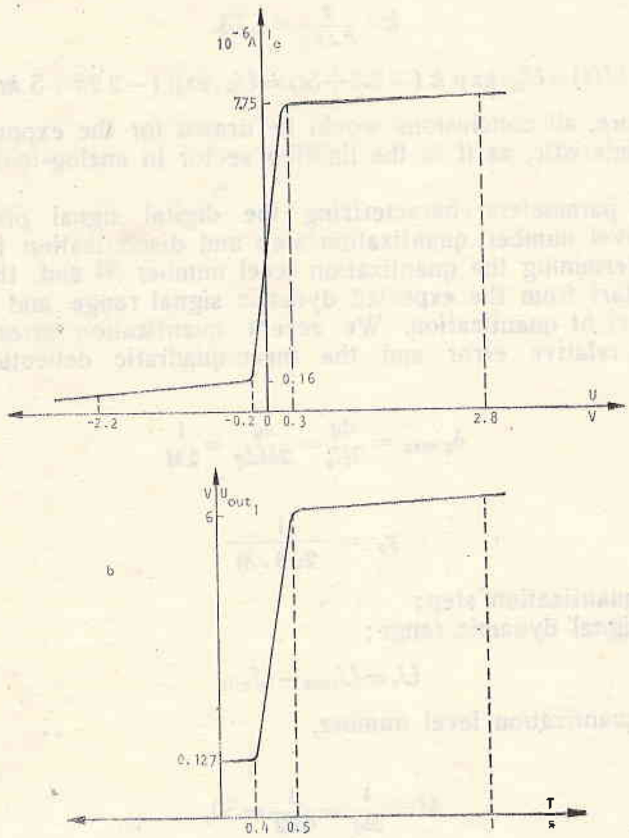

Fig. 1
a — Typical characteristics obtained during the operation of the Bulgarian probe equipment mounted onboard the Vertical-6 rocket (1977); *b* — The transformed characteristics of Fig. 1a

ing the operation of the Bulgarian probe equipment onboard the Vertical-6 rocket (1977).

Figure 1b shows the transformed characteristic of Fig. 1a taking into account that the sweep is linear and with period of 1 s.

The analysis and conclusions from the characteristic shown are valuable for the digital transmission of volt-ampere characteristics in general.

The minimal and maximal electron probe currents are, respectively, $I_{e\,min}=0.16\times10^{-6}$ A and $I_{e\,max}=7.75\times10^{-6}$ A. The maximal input level of the telemetric system $U_{in\,max}=6$ V and the minimal $U_{in\,min}=U_0=I_{e\,min}\cdot\frac{U_{in}}{I_{e\,max}}=0.127$ V. The sweep voltage at values shown in Fig. 1*a* would be described by the expression $V_{SW}=-2.2+5t$ (t changing from 0 to T), and the exponential sector of the V-A characteristic can be presented analytically by the expression

(1) $$U(t)=U_0 \cdot \exp\left(\frac{eU_{SW}}{k \cdot T_e}\right)=U_0 \cdot e^{k \cdot U_{SW}},$$

where $$k=\frac{e}{k \cdot T_e}=7.73.$$

(2) $$U(t)=U_0 \cdot \exp k\,(-2.2+5t)=U_0 \cdot \exp\,(-2.2k+5\,kt).$$

Furthermore, all conclusions would be drawn for the exponential part of the V-A characteristic, as it is the limiting sector in analog-to-digital transformations.

The main parameters characterizing the digital signal presentation are: quantization level number, quantization step and discretization frequency.

When determining the quantization level number M and the quantization step dk, we start from the expected dynamic signal range and the necessary accuracy (error) of quantization. We accept quantization error = 1 per cent. The maximum relative error and the mean-quadratic deflection are, respectively

(3) $$\delta_{q\,\max}=\frac{dq}{2U_s}=\frac{dq}{2Mdq}=\frac{1}{2M}$$

and

(4) $$\gamma_q=\frac{1}{2\sqrt{3} \cdot M},$$

where dq — quantization step;

U_s — signal dynamic range;

$$U_s=U_{\max}-U_{\min}$$

M — quantization level number,

hence

(5) $$M=\frac{1}{2\delta q}=\frac{1}{0.02}=50,$$

but $M=2^m$, therefore we chose the closest multiple to the 2^m number — $M=64$. At 64 levels the mean-quadratic error from quantization would be $\gamma q=0.46$ per cent.

The quantization step is equal to

(6) $$dq=\frac{U_s}{M}=95\times 10^{-8}\,\mathrm{V}.$$

At uniform quantization, the quantization level is placed in the middle of the quantization interval. The absolute error obtained in identifying the instantaneous value with the quantization level is

(7) $$\varepsilon_q=\lambda_q-\lambda,$$

λ_q — quantization level;

λ — counted instantaneous value.

And the maximal absolute quantization error would be

(8) $$|\varepsilon_q|_{\max}=\frac{dq}{2}.$$

The discretization frequency of the signal described in (2) is determined by its correlative function. This frequency should be within the limits 1.5 to 6 of the discretization frequency defined by Kotelnikov's theorem

(9) $$F_0=(1.5\div 6)2\Delta f_{eff}.$$

The amplitude-frequency spectrum width is obtained from the spectral density, calculated from the formulae in (1), in our case $\Delta f_{eff}=30$ Hz.

We should underline that the discretization frequency can be determined more accurately by the relationship between the interpretation error and the signal correlative function.

When interpolating the examined signal with a polynomial of first power (step function), we obtain:

discretization period $T_0=0.004$ s,

discretization frequency $F_0=250$ Hz,

informational transmission rate $I=F_0 . m=1{,}500$ bit/s.

At interpolation of the informational signal with the Lagrange polynomial of second power we obtain $T_0=0.0078$ s; $F_0=130$ Hz and $I=780$ bit/s.

In differential methods of informational presentation the difference between two instantaneous values sampled in two subsequent discretization instants is quantized. These methods are valid only when there is a considerable decrease of the emitted informational quantity. It is obvious that the uniform difference representation could be valid when the signal fluctuates fast with small amplitudes and slowly changes within the limits of the full scale.

Therefore, the differential presentation is valid if an informational compression is obtained, i. e. if the difference between coordinates is encoded with less symbols than the discrete instantaneous value

(10) $$m_d=m-\Delta m_d,$$

where m_d is symbols number in the difference coordinate,
m — symbols number with which the discrete instantaneous value is transmitted.
$\Delta m_d=E$ — where E is a full number minimal in the discretization range.

(11) $$\Delta m_d=E\left\{\frac{1}{2}\log_2\frac{1}{2[1-\hat{k}_i(T_0)]}\right\},$$

where $\hat{k}_i(T_0)$ is the reduced signal correlative function.

For the case (Fig. 1b) we obtain $\hat{k}_i(T_0)=0.85$ at step function of interpolation and at the above-obtained values of T_0 and F_0. Hence $\Delta m=0.85$ 1. Therefore, at difference presentation the number of binary symbols is the same one with which the instantaneous discrete value is given at pulse-code modulation with uniform quantization.

Upon linear interpolation and difference presentation we obtain $T_0=0.0078$ s; $\hat{k}_l(T_0)=0.55$ and $\Delta m_a<1$.

We see that the difference presentation of the symbol examined is not effective (at both ways of signal interpretation from Fig. 1), because of lack of information compression.

Upon delta-presentation of the signal the discretization frequency has to be selected in such a way that the function change per unit of discretization period would be less than the quantization step.

For interpolation with polynomial of first power, the quantization step is selected by the dependence

$$\varepsilon_{max} \le 2\,dq = 0.06 \text{ V},$$

$$dq \le 0.03,$$

$$dq = 0.03 \text{ V},$$

for the discretization frequency we obtain

$$[U(t+T_0) - U(t)] \le dq \quad F_0 = 1500 \text{ Hz},$$

for the interpolation with polynomial from second power

$$\varepsilon_{max} \le dq = 0.06 \text{ V}$$

$$dq = 0.06 \text{ V}$$

$$F_0 = 720 \text{ Hz}.$$

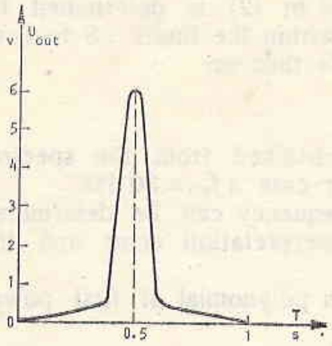

Fig. 2. A signal shape from an electron temperature study experiment with double modulation probe

The transmission rate of information quantity in both cases of interpolation is approximately equal to the rate in PCM, but this is achieved with much higher discretization frequency and the accuracy of this presentation method is much smaller because of the summing error effect from the different coordinates. For this signal type the classical PCM method appears to suit best in analog-digital presentation.

In many cases the information from V-A characteristic can be obtained with greater accuracy by their derivatives. Series of experiments prove that in practice [2, 3]. The signal shape from an electron temperature study experiment with double-modulation probe is shown in Fig. 2 and can be described analytically by the expression

$$U(t) = A \,.\, \exp\left[-\frac{(t-t_m)^2}{2a^2}\right]$$

$$t_m = 0.5 \text{ s},$$

where

$A = 6$ V — signal amplitude,

$a = 30 \times 10^{-6}$ is determined by the condition $t - t_m = a$

$$U(a) = A \exp(0.5).$$

The processing results of this signal from the three digital methods with the described techniques are given in Table 1.

As is seen from the Table, it is more reasonable for this signal also to use classical pulse-code presentation of the signal at linear interpolation. The relative presentation of this signal type has small coefficients of information compression (1.5) and upon delta-presentation in transmitting the same information much greater discretization frequency is necessary.

In conclusion, we can say that the digital methods application (namely, the classical pulse-code presentation) in probe methods is very effective when accompanied by prior processing of the V-A characteristic onboard the spacecraft. This processing should include the determination of the first and second signal derivatives. On the one hand, the differentiation decreases the dynamic range of the transmitted information, while on the other, it increases the ac-

Table 1

Type interpolation	Method of digital presentation	Level No. of quant. M	Quant. step d_k [v]	Discr. frequency [Hz]	Inf. trans. rate [bit/s]	Compr. coeff
Step interpolation	Classical pulse-code presentation	64	95×10^{-3}	110	660	—
	Relative (differ.) presentation	64	95×10^{-3}	100	500	1.5
	Delta-presentation	200	30×10^{-3}	2260	2260	—
Linear interpolation	Classical pulse-code presentation	64	95×10^{-3}	54	324	—
	Relative (differ.) presentation	64	95×10^{-3}	54	270	—
	Delta-presentation	200	60×10^{-3}	1670	1670	—

curacy of the measured parameters (electron density and temperature) and faciliates the ground-based computing of the telemetric information.

Such are in fact the development trends of the probe methods at the Central Laboratory for Space Research of the Bulgarian Academy of Sciences.

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О возможностях применения цифровых методов в зондовых космических экспериментах

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(Резюме)

Рассмотрены возможности применения основных существующих методов аналого-цифрового преобразования для двух конкретных сигналов. В качестве конкретных примеров восприняты классическая вольтамперная характеристика, получаемая при применении зонда Ленгмюра, и характеристика,

получаемая при использовании двойного модуляционного зонда (для определения плазменной электронной температуры).

Частота дискретизации, число уровней и шаг квантования при заданной ошибке являлись основными параметрами для сравнения применимости различных цифровых методов.

Исследования двух конкретных примеров показали, что классическое код-импульсное представление обладает определенными преимуществами как по сравнению с разностным представлением (из-за отсутствия компрессии данных в последнем), так и по сравнению с дельта-представлением (из-за увеличения частоты дискретизации и ухудшения точности при дельта-представлении).