Single-Channel Measuring Information System: Metrological Description and Normalization

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Abstract — Measuring information systems with only one input channel are considered. Those systems characteristic feature is that information part is integrated into a heart of measuring transformation chain. And so output measurand estimates are the result of joint action of measuring and information elements. The problem of the system description and normalization is discussed.

***Keywords*:** System, channel, measurement, description, normalization.

I. Introduction

Traditionally, by a measuring information system (MIS) we mean the collection of measuring channels and the information part. Signals output by the channels contain measuring information (estimates of magnitudes presenting the properties of the test subject), and information part generates non-measuring (usually, classification) information on the object based on this signals. MIS generalized structure is shown in Fig. 1 [1].

Metrological assurance of such MIS is not a problem because its object is the measuring part of MIS, which is a usual measuring system, as a rule, multi-channel one.

Along with the described multichannel MIS there exist single-channel systems (SCS) exemplified by radar station or a radar navigator.

SCS perceives object patterns $\mathbf{x}_1, \ldots, \mathbf{x}_m$ carrying information on objects properties under interest. Those properties are presented as a rule by such characteristics as amplitude, frequency, time interval between pulses, faze shift between continuous signals, modulation parameters (amplitude, percentage, frequency, faze), polarization characteristics, space parameters (bearing, angular size, distance, motion rate projection onto established axes). Most important feature of SCS is that all object patterns $\mathbf{x}_1, \ldots, \mathbf{x}_m$ are fed (enter the system) to common primary measuring transducer (**PMT**) input. At the same time, data burst is formed at the SCS output which is the output of data processing hardware. Each data burst contains goals estimates for definite object. So SCS can be considered as physical system with one input and one output but its functional structure is characterized by presence of channels of uncertain quantity. The latter is determined by the quantity of objects under observation at the same time.

This work is aimed to inclusion of SCS as special kind of measuring device into traditional system of metrological traceability. For the aim achievement, functional structure of SCS has been analyzed, metrological models of special (uncharacteristic for traditional measuring instrument)) signal transductions including measurement formation on virtual measuring channel output are proposed and discussed.

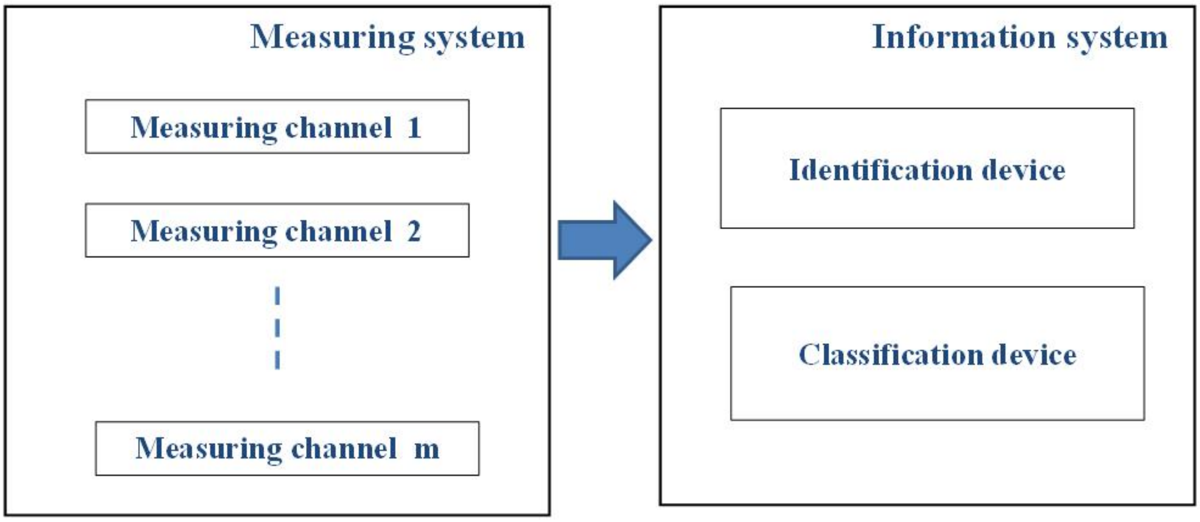

Fig. 1. Generalized structure of traditional MIS.

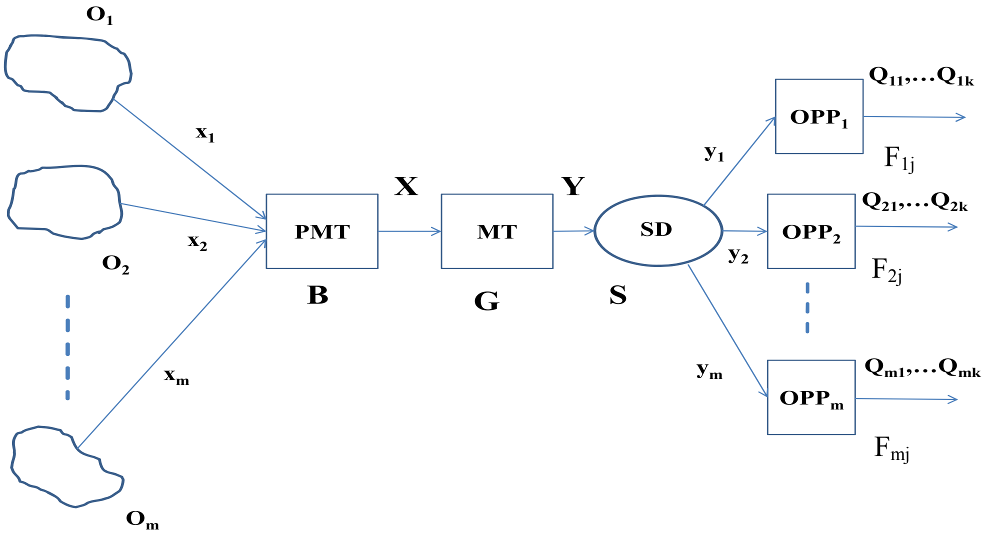

Fig. 2. Generalized structure of single-channel MIS.
O_1, …, O_k – objects of radar observation; B, G, S, F_{ij} and X, Y, y_i, Q_{ij} – transformation operators and output signals of PMT, MT, SD, OPP_i.
F_{ij} – operator of signal transformation by OPP_i.

II. SCS Functional Structure

The generalized structure of SCS as a single-channel MIS is presented in Fig. 2.

Objects patterns . $\mathbf{x_1}, \ldots, \mathbf{x_m}$ come to common input of **PMT**. After conversion by the measuring transducer (**MT**) the signals are separated in the selecting device (**SD**) into the patterns referring to one of the observed/studied objects. The patterns are processed by object pattern processors (**OPP**) to receive the estimates of magnitudes $\mathbf{Q_{ij}}$, i=1…m, j=1…k, characteristic for objects $\mathbf{O_i}$. For simplification we assume that each object is characterized by one magnitude, and the quantity of realizations of different magnitudes is the same and equal to **k**. Further discussions are valid only for the case if index **j** denotes various magnitudes characterizing the object $\mathbf{O_i}$ rather than realizations of one magnitude $\mathbf{Q_i}$.

An attempt to separate *measuring channels* in such SCS gives the following results (see Fig. 3).

In Fig. 3, there is a formal reflection of an affect, on any channel, not only "nominal" (inherent in just that channel) but all other patterns as well.

III. Models of Signal Transformations in SCS

Generalized metrological model of MIS which answers the fig. 2, can be represented by the following symbolic equation:

$$\mathbf{X} \cdot \mathbf{A}^T = \mathbf{Q}, \qquad (1)$$

where

$$\mathbf{X} = [x_1 \quad x_2 \quad \ldots \quad x_{1m}]; \qquad (2)$$

$$\mathbf{A} = [A_1 \quad A_2 \quad \ldots \quad A_{1k}], \; A_j = \mathbf{B} \cdot \mathbf{G} \cdot \mathbf{S} \cdot \mathbf{F}_j; \qquad (3)$$

$$Q = \begin{bmatrix} Q_{11} & \cdots & Q_{m1} \\ \vdots & \ddots & \vdots \\ Q_{1k} & \cdots & Q_{mk} \end{bmatrix}. \qquad (4)$$

The block diagram shown in Fig. 3 provides a basis for metrological description of a single-channel MIS since it reduces it to a traditional representation of multichannel system. The channels are identical in structure and elements with the exception for different *tuning* of selecting device **SD** and object pattern processors each assigned to a specific object. Conversion components of the channel **PMT** and **MT** should be described by their metrological characteristics (generally, operators **B** and **G**). As for selecting device **SD**, the SCS presentation in Fig. 3 has to be specified in following manner (see fig. 4) to reveal SD role. Evidently, SCS function is assigning the pattern $\mathbf{x_i}$ from object $\mathbf{O_i}$ to this object[1]. Therefore, **SD** can be characterized in the first approximation[2] by the probability of correct performance of the noted function. Depending on **SD** operating principle (structure) its function can be performed differently. In the first method, in population **X** of all patterns $\mathbf{x_i}$ each signal is identified as a signal belonging to the pattern with a certain number $\mathbf{i = l}$. Identification operation can be characterized by probability $\mathbf{P_i}$ of assigning an arbitrary signal from population **X** to pattern $\mathbf{x_i}$. Then the probability of the fact that pattern $\mathbf{\tilde{u}_i}$, generated/restored from population **X** and associated with object $\mathbf{O_i}$, coincides with true pattern $\mathbf{x_i}$ (with **k** signals) is

$$\mathbf{P}_1\{\mathbf{\tilde{u}_i} \equiv \mathbf{x_i}\} = (\mathbf{P_i})^{\mathbf{k}}. \qquad (5)$$

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[1] This function is realized indirectly by processing signals $\mathbf{y_i}$ coming to the input **SD**.

[2] **SD** can be characterized in more detail by the probabilities of correct solutions (and therefore, errors) of types I and II.

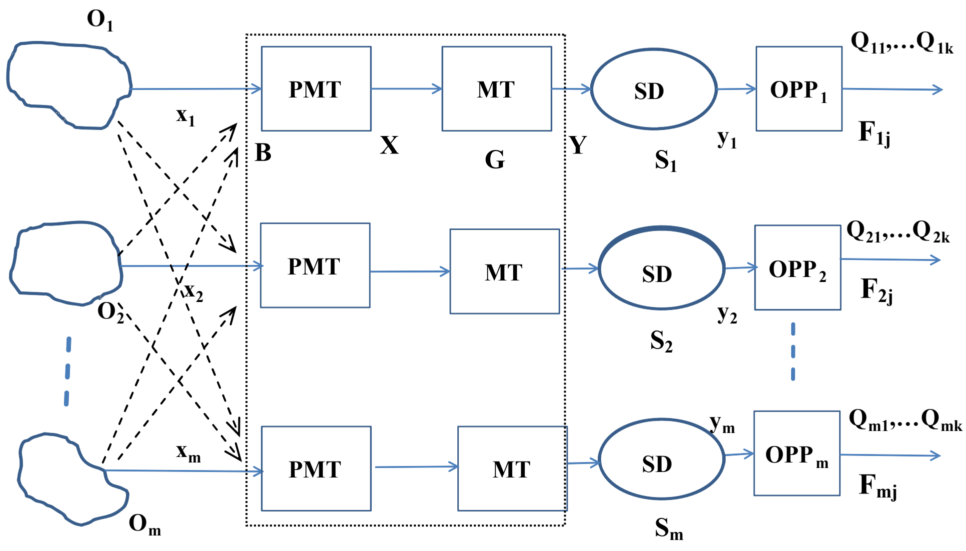

Fig. 3. Measuring channels of single-channel MIS.

In the second method, at first the signals **X** are grouped, that is, their belonging to one pattern is established, and then each pattern is associated/identified with a certain object. In other words, at the first processing stage the signals are compared with each other and their identity is established with the probability of correct assignment $\mathbf{P_{1i}}$. At the second stage, each generated group is assigned to a certain object with the probability of correct assignment $\mathbf{P_{2i}}$. Thus, the probability of correct identification of the generated pattern $\tilde{\mathbf{u}}_i$ is given by

$$\mathbf{P_2\{\tilde{u}_i \equiv x_i\} = (P_{1i})^{mk}(P_{2i})^m}. \qquad (6)$$

Incorrect identification of the generated pattern, the probabilities of which are $\mathbf{1\text{-}P_1\{\tilde{u}_i \equiv x_i\}}$ and $\mathbf{1\text{-}P_2\{\tilde{u}_i \equiv x_i\}}$ for the considered methods, means that pattern $\tilde{\mathbf{u}}_i$ contains the signals from other patterns along with signals from $\mathbf{x_i}$. These foreign signals will affect the errors of the received estimates $\mathbf{Q_{i1}, Q_{i2}, \dots, Q_{ik}}$. To determine the degree of this effect, we need to know what exactly foreign signals are meant. This information can be only of probabilistic nature only.

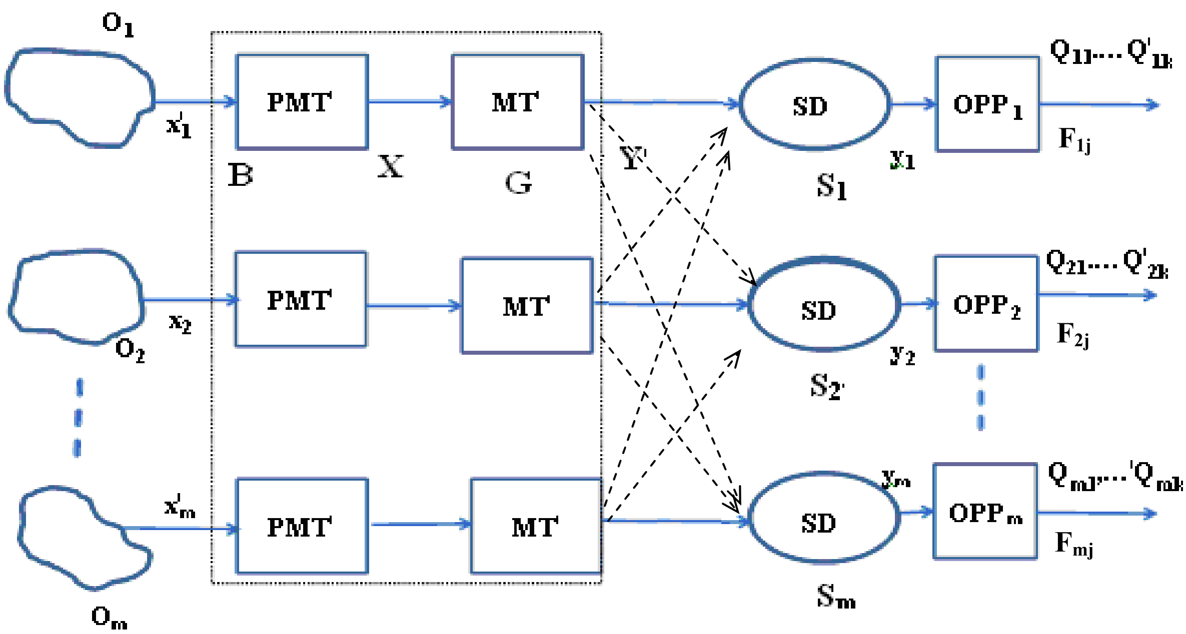

Fig. 4. Specified block diagram of SCS.

Clearly, the probability that signal $\mathbf{x_{ij}} \in \mathbf{x_i}$ gets in a different pattern, or, which is the same, some other pattern except $\mathbf{x_i}$ contains $\mathbf{x_n}$ (n≠i)>, is equal to $\mathbf{1-P_i}$ in the first method. However, the probability that $\mathbf{x_{ij}} \in \mathbf{x_i}$ gets in a certain pattern is much lower and in the first approximation can be estimated as $(\mathbf{1-P_i})/(\mathbf{m-1})$. These considerations can serve as a reference to develop the procedures to estimate the errors of estimates $\mathbf{Q_{i1}}$, $\mathbf{Q_{i2}}, \ldots, \mathbf{Q_{ik}}$, if reasonable limitations on the number of foreign signals in the considered pattern are introduced. These limitations can be based on the ratios between probabilities $\mathbf{P_i}$ and $\mathbf{1-P_i}$ for each object. The logic similar to the one used above can be formed for the second method as well.

As to the general representation of the result at the output of the **i**-th channel, probabilistic meaning should be assigned to the group of estimates $\mathbf{Q_{ij}}$, j=1…k,: the group refers to object $\mathbf{O_i}$ with probability $\mathbf{P_1}$ in the first method or $\mathbf{P_2}$ for the other. In other words, unlike the traditional multichannel MIS, the measurement result obtained at the **i**-th output should be provided with probabilistic estimate $\mathbf{P_1}$ or $\mathbf{P_2}$. Therefore, the quality of estimating any measured magnitude (object characteristic) is expressed not by a scalar (error estimate) but by a vector: set of error estimate and probability of assigning the magnitude estimate (or magnitude itself) to a certain object. Formally, this can be expressed by the following notation of the **i**-th result $\mathbf{R_i}$:

$$\mathbf{R_i} = \{[\mathbf{M_i}, \mathbf{T_i}(\mathbf{Q_{ij}}), \boldsymbol{\delta_i}]; \mathbf{P}[\Re_i(\mathbf{Q})]\}, \quad (7)$$

where $\mathbf{M_i}$ is the model of object $\mathbf{O_i}$; $\mathbf{T_i(Q_{ij})}$ is the statistic determining the estimate of the **i**-th measured magnitude $\mathbf{Q}$; $\boldsymbol{\delta_i}$ is the estimate of the established characteristic of error; $\Re_i(\mathbf{Q})$ is a one-place predicate [2] expressing that magnitude $\mathbf{Q}$ belongs to object $\mathbf{O_i}$, $\Re_i(\mathbf{Q}) = \Re(\mathbf{Q}, \mathbf{O_i})$; $\Re$ is a two-place predicate expressing the belonging.

Considerations given above make it possible to present both metrological and informational (logical) features of SCS. Each of distinguished channels (see Fig. 3) can be characterized by traditional metrological characteristics. For static mode, it is a set of function of transformation of measuring signal and functions of disturbing factor effects. For dynamic mode, it is a form of transformation operator (total dynamic characteristic [3]). Again, transformation function and total dynamic characteristic are determined using the relevant characteristics of all components (members) of the channel. The only feature of this representation is that metrological characteristic of **SD** should be introduced, which is considered to be a measuring transducer. In other words, **SD** properties determining distortions of any signal as information carrier have to be revealed and represented in addition to the properties expressing its ability to separate patterns (or, that is the same, to form homogeneous patterns by selecting proper signals from mixture of heterogeneous patterns. As to selecting properties of **SD,** they should be presented by probabilistic characteristics as shown above.

IV. Conclusions

The analysis realized above has showed that basic problem accompanying the process of SCS inclusion in traditional metrological traceability system is determined by a presence of transduction of special kind in the SCS - namely selection of measuring signal patterns. SCS element performing that transduction, namely **SD**, can not be attributed to any known kind of measuring instruments, in particular, measuring transducers. **SD** realizes two kinds of signal transformation - non-measuring one (selection) and measuring one (generally aggregate of inertialess and inertial ones. The first one corresponds to basic functional destination, and the second one is as "parasitic" one. In accordance with above SD model has to include two complexes of characteristics - traditional metrological characteristics and special logic-probabilistic characteristics.

Thus, as is shown above, the measuring information system with only one input channel differs fundamentally from traditional multichannel MIS. The one-channel system includes information part as an inner link of measuring transformation chain. Because of that a new metrological approach to the system description is “a must”. So the output result of the system has to be represented more widely than usual measurement result.

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