CATV systems - Volterra Kernels Identification

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***Abstract* – Nowadays, the most popular identification methods are those that allow the achievement of satisfactory results for the system with a minimum quantity of preliminary information or without any information about it. This is related to a certain universality of the models used. This universality allows the solution of many applicable tasks through these methods.**

***Keywords* – CATV, identification, Volterra kernel, CSO, CTB.**

I. INTRODUCTION

In the analysis of nonlinear systems whose model is described by Volterra series [1], [2], the basic problem consists in the possibility of identification of the non-linear operator $H_k(\omega)$ [3], [4]. In order to solve the task of identification, one needs to define the format of the mathematical system description (structural model). Then, the types of signals necessary for the identification have to be defined and an algorithm for restoring the model parameters according to the test results has to be developed. The identification success depends very much on the right choice of the model structure. There are two basic requirements to the model:

- The model should possess the sufficient precision to reflect the system properties for quite a wide range of signals compared to those used in the testing;
- The model form should not create great theoretical and calculative difficulties in the process of defining the system parameters.

The first requirement is usually hard to meet, because there is no sufficient preliminary information about the system. As a rule, we have to be content with the chosen model and its adequacy (correspondence) to the system [2]. After building the model, we test it by signals different from those used while building it. The system that is being examined is tested by the same signals (Fig.1), and then, the level of correspondence between the reactions of the system and the model is assessed.

Nowadays, the most popular identification methods are those that allow the achievement of satisfactory results for the system with a minimum quantity of preliminary information or without any information about it. This is related to a certain universality of the models used. This universality allows the solution of many applicable tasks through these methods [5], [6].

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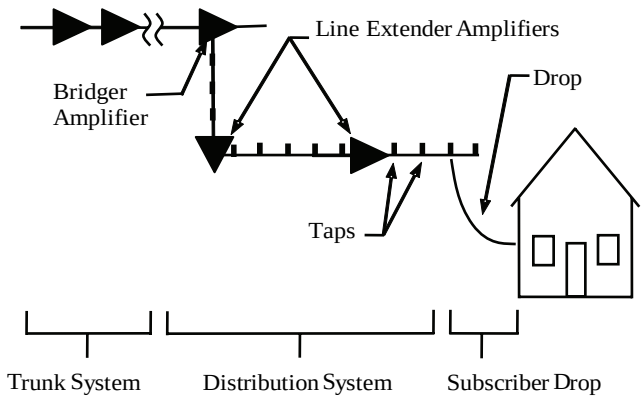

Fig.1. Scheme of the CATV system that is being examined

The problems of operator identification become more and more topical, due to the complication of the modern systems and the appearance of new technologies. Besides, the identification is also complicated by the existence of noise during the measurements. The noise causes some distortion of the useful signal. Therefore, in order to increase the precision of identification, we need to provide suppression of the noises and correction of the mistakes related to the distortion of the input signal.

II. IDENTIFICATION OF THE VOLTERRA KERNELS IN THE PRESENCE OF COMPOSITE INTERMODULATION PRODUCTS

Depending on the dynamic conditions of the active devices from the transmission medium, and even those from the high-frequency part of the subscriber equipment and the Head End, the Volterra kernels are analyzed in weak-signal regime. It is characteristic of these conditions that, due to many specific features, the non-linear distortions in the output reach the admissible norm with a very weak input signal (under 80 dBμV), long before the non-linearity of the output characteristics starts taking effect [3], [5], [7].

Of the greatest interest to us, when calculating and measuring the amplitudes of the nonlinear products of intermodulation, are the Volterra kernels of second and third order. For initial data when defining the values of normal and normalized kernels, we will use the relationships between the composite distortion coefficients of the respective order and the signal transmission amplitudes, the system (amplifier) transfer coefficients and the Volterra kernels.

For the derivation of the expressions for the normal and the normalized kernels of second and third order, we will use the

composite distortion formulae (CSO, CTB), which are derived in [8]. Below, you can see the expressions for the normal H_x and the normalized H_{xG} Volterra kernels after the anti-logarithm calculations and some other necessary mathematical operations related to them. During the derivation of the formulae, the following are taken into account: the data about the levels of the input A_{in} and the output A_{out} signals, the transfer coefficient G of the CATV system (amplifier) and the value of the composite distortions (CSO, CTB).

A. Second order Volterra kernels

$$H_2(f_i \pm f_j) = \frac{G^2}{A_{out}} \times 10^{-\frac{CSO}{20}} \quad (1)$$

$$H_{2G}(f_i \pm f_j) = \frac{G}{A_{out}} \times 10^{-\frac{CSO}{20}} \quad (2)$$

B. Third order Volterra kernels (three-component beat)

$$H_3(f_i \pm f_j \pm f_k) = \frac{2}{3} \times \frac{G^3}{A_{out}^2} \times 10^{-\frac{CTB}{20}}; \quad (3)$$

$$H_{3G}(f_i \pm f_j \pm f_k) = \frac{2}{3} \times \frac{G^2}{A_{out}^2} \times 10^{-\frac{CTB}{20}} \quad (4)$$

C. Third order Volterra kernels (two-component beat)

$$H_3(2f_i \pm f_j) = \frac{4}{3} \times \frac{G^3}{A_{out}^2} \times 10^{-\frac{CTB}{20}} \quad (5)$$

$$H_{3G}(2f_i \pm f_j) = \frac{4}{3} \times \frac{G^2}{A_{out}^2} \times 10^{-\frac{CTB}{20}} \quad (6)$$

In all the above-mentioned formulas $i \neq j \neq k = 1, 2, 3\ldots$; $A_{out} = A_{in} * G$ and f_i, f_j, f_k are the carrying frequencies of the image of the respective television channel from the CATV system.

III. Relation between third Volterra kernels with two-component or three-component beat

When we compare (3), (4), and (5), (6), we can write down the following general formulae for Volterra kernels:

$$H_3(\omega_b) = \frac{2}{3} q \times \frac{G^3}{A_{out}^2} \times 10^{-\frac{CTB}{20}}; \quad (7)$$

$$H_{3G}(\omega_b) = \frac{2}{3} q \times \frac{G^2}{A_{out}^2} \times 10^{-\frac{CTB}{20}}, \quad (8)$$

where ω_b takes the values $2\pi(2f_i \pm f_j)$ or $2\pi(f_i \pm f_j \pm f_k)$.

The parameter q takes values according to Table 1, and the relation between the Volterra kernels with two-component and three-component beat is displayed by the expressions:

$$H_3(2f_i \pm f_j) = 2H_3(f_i \pm f_j \pm f_k); \quad (9)$$

$$H_{3G}(2f_i \pm f_j) = 2H_{3G}(f_i \pm f_j \pm f_k). \quad (10)$$

TABLE 1

Third order beat	q
$2f_i \pm f_j$	2
$f_i \pm f_j \pm f_k$	1

IV. Calculating Volterra kernels for linear (subtrunk) amplifier in the presence of intermodulation

Here are the results of the theoretical identification Volterra kernels of the second and third order, characteristic of linear amplifier VX23A, produced by the German company WISI [9]. The drawing from Fig.2 is used for the definition of the composite distortion values. The derived data are written in Table 2, and the carrying frequencies of the image are chosen according to Appendix C of the European Standard CENELEC EN 50083-3. The frequency spectrum of the examined cable television system is from 49.75 MHz to 511.25 MHz, with the total number of the channels being 50.

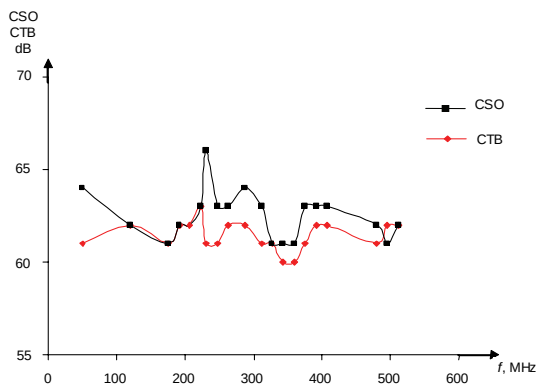

Fig.2. Graphic interdependency of the intermodulation composite distortions of the linear amplifier VX23A

TABLE 2

Frequency MHz	CTB dB	CSO dB
49.75	61	64
119.25	62	62
175.25	61	61
191.25	62	62
207.25	62	62
223.25	63	63
231.25	61	66
247.25	61	63
263.25	62	63
287.25	62	64
311.25	61	63
327.25	61	61
343.25	60	61
359.25	60	61
375.25	61	63
391.25	62	63
407.25	62	63
479.25	61	62
495.25	62	61
511.25	62	62

In Table3, the theoretical results about the Volterra kernels for a particular cable amplifier VX23A are presented. Their graphic interpretation is displayed on Fig.4 (normal kernels) and Fig.5 (normalized kernels).

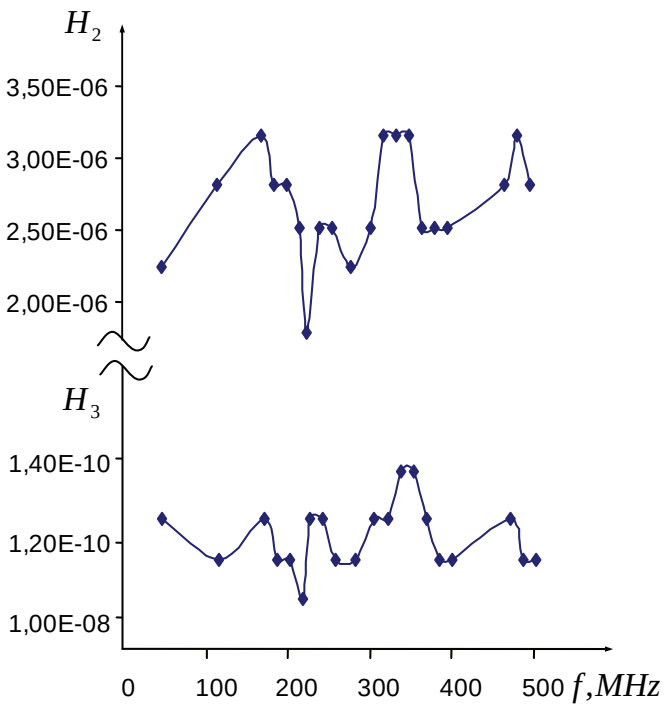

Fig.4. Normal Volterra kernels

TABLE 3

Volterra kernels / f MHz	Intermodulation			
	Second order		Third order	
	H_2	H_{2G}	H_3	H_{3G}
49,75	2,24E-06	3,98E-08	1,33E-10	2,37E-12
119,25	2,82E-06	5,01E-08	1,19E-10	2,11E-12
175,25	3,16E-06	5,62E-08	1,33E-10	2,37E-12
191,25	2,82E-06	5,01E-08	1,19E-10	2,11E-12
207,25	2,82E-06	5,01E-08	1,19E-10	2,11E-12
223,25	2,51E-06	4,47E-08	1,06E-10	1,88E-12
231,25	1,78E-06	3,16E-08	1,33E-10	2,37E-12
247,25	2,51E-06	4,47E-08	1,33E-10	2,37E-12
263,25	2,51E-06	4,47E-08	1,19E-10	2,11E-12
287,25	2,24E-06	3,98E-08	1,19E-10	2,11E-12
311.25	2,51E-06	4,47E-08	1,33E-10	2,37E-12
327.25	3,16E-06	5,62E-08	1,33E-10	2,37E-12
343.25	3,16E-06	5,62E-08	1,49E-10	2,65E-12
359.25	3,16E-06	5,62E-08	1,49E-10	2,65E-12
375.25	2,51E-06	4,47E-08	1,33E-10	2,37E-12
391.25	2,51E-06	4,47E-08	1,19E-10	2,11E-12
407.25	2,51E-06	4,47E-08	1,19E-10	2,11E-12
479.25	2,82E-06	5,01E-08	1,33E-10	2,37E-12
495.25	3,16E-06	5,62E-08	1,19E-10	2,11E-12
511.25	2,82E-06	5,01E-08	1,19E-10	2,11E-12

V. CONCLUSION

The Volterra kernels can be derived by passing several successive signals to the input of the system (amplifier) and defining the reactions to them. The more test signals there are, the more precise the identification is, but the operations are more complex and longer. It is possible that the same non-linear system reactions occur with different input signals. The type and amplitude of the test signals is of a great importance to the precision of the identification and the convergence of the Volterra series.

The identification of kernels by this method is possible, if the power of the polynomial describing the system is known. Otherwise, it is necessary that an experiment for its definition be made. If the system is stationary, a sinusoidal signal with

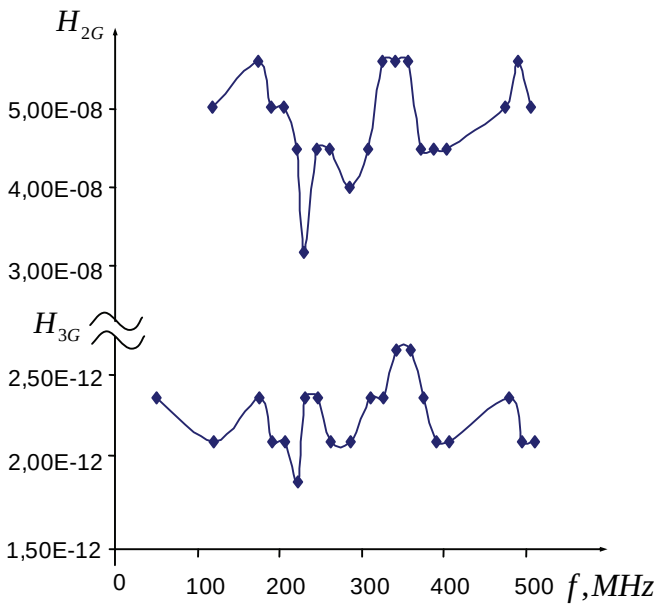

Fig.5. Normalized Volterra kernels

frequency ω is passed through its input, and then, a spectrum analysis of the output signal is done. The power of the polynomial is defined by the maximum multiple frequency present in the output signal.

In the theoretical research made, the Volterra kernels for a particular linear amplifier VX23A were identified. The derived results can be successfully used for the prediction, simulation and calculation of the nonlinear products in its output in whichever point of the cable distribution network, with the output/input signal being known.

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