

MACRO-MODELLING OF NONLINEAR EFFECTS IN THE REVERBERATION CHAMBER UNDER HIGH-FREQUENCY EXCITATION

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Abstract. The method of construction of nonlinear model of stirred chamber with nonlinear object is considered. The nonlinear model is a polynomial of split signals. This model can be used for compensation of distortions of characteristics of an electromagnetic field in the chamber. A source of these distortions is nonlinear processes. The example of modeling of the stirred chamber with nonlinear loop is described. The accuracy of modeling is estimated.

The analysis of the interaction between high-frequency electromagnetic fields and nonlinear systems forms an important part in the High-Power Electromagnetic field interaction with modern electronic equipment [1]. It is often that the non-linear electronic systems, as cables with non-linear loads, printed circuits, chips, etc., are enclosed in a resonator-like object (as, for example, in a computer housing), which have their own resonance frequencies. The coupling to internal electronic devices, which can be considered as scatterers, yields non-trivial results (changing of cavity resonances, changing of the response function in comparison with free space) even in the case of linear loads [2–4]. For the nonlinearly loaded scatterers the picture of interaction becomes much more complicated.

In [5] we experimentally investigated a simple configuration – the mode stirred chamber (without stirrers) of the University of Magdeburg which was excited by a dipole antenna fed by a rectangularly modulated Gigahertz pulse. It was observed that, even for the empty chamber when the resonance frequency of the chamber (31 MHz) was approximately a multiple of the modulation frequencies, the electric field in the chamber increases approximately by 30 dB (depending on the number of resonance) if compared to the non-resonant case. This can be explained quantitatively in time and frequency domains (because the modulating pulse yields low frequency components in the spectrum of the exciting signal) [5]. However, when we placed a nonlinearly loaded loop in the resonator (a circle of 40 cm radius, loaded by 8 diodes), the electric field had increased additionally by 50 dB in comparison to the case of the empty chamber, both in resonant and non-resonant case. (That is, the increment from the non-resonant case for the empty chamber and the resonant case of chamber with nonlinear scatterer is about 80 dB). The observed effect was explained qualitatively in [5]: the initial signal excites the nonlinearly loaded loop, in which the scattering current is demodulated, and the amplitude of its low-frequency components in the frequency spectrum increases dramatically. In turn, this current serves as a source for the scattered field which low frequency amplitude also strongly increases.

The investigated phenomenon is important in two practical aspects. First, the model describes the interaction of high-frequency modulated pulses with electronic equipment which is placed in a well shielded cavity (with, however, slots and apertures), by the effect of a

so-called high-to-low frequency conversion [5]. Second, the demodulation processes in tested devices can strongly disturb the field in reverberation chambers during corresponding tests.

The “first – principle” quantitative consideration of this effects requires to use a direct numerical method, as the Transmission Line Matrix method, for example, or to consider several thousands linear differential equations corresponding to the number of resonator modes that need to be taken into account, with nonlinear relations between these equations. Both ways are extremely time consuming.

In the present paper we use a phenomenological modelling of a nonlinearly loaded reverberation chamber, using the operator approach, where the modelled object is represented as a “black box”, and its functional operator connecting input value (the fed voltage of the exciting antenna in frequency domain $U(j\omega)$) and output value (the electrical field in some point of the resonator in frequency domain $E(j\omega)$) is approximated by a functional polynomial [6–8]. To obtain such polynomials we use the splitting method [8]. (Earlier, the operational method was used to examine the demodulation effect of two-tone disturbances on nonlinear elements [9–11]).

The splitting method is one of known universal methods of nonlinear operators approximation on basis of input-output ratio [8]. The advantages of the splitting method consist in the following:

- the constructed polynomial is adapted to a class of input signals, hence, this polynomial is more simple than alternative models (Volterra polynomial, NARMAX-model, neural perceptron networks [6, 7]);
- the multidimensional polynomial of split signals is free from a problem of convergence. It is important at modelling essentially nonlinear processes. Accuracy of modelling is raised by increase of the polynomial degree;
- the multidimensional polynomial of split signals contains linear parameters therefore solving an approximation problem is a global optimum in uniform and root-mean-square metrics [8].

Thus, the peculiarity of offer approach is that we can design the polynomial using the experimental (or numerically calculated) ratio between input and output values.

In the first step of modelling the input and output signals are represented as follows:

$$X(\omega) = 1/|U(j\omega)|, Y(\omega) = 1/|E(j\omega)|.$$

The function $U(j\omega)$ is a Fourier transformation of the input signal $u(t)$ of the chamber. The input signal is a harmonic fluctuation modulated by a chain of rectangular pulses [5]

$$u(t) = \sum_i f(t - iT_m), \quad (1)$$

where $f(t) = \sin(\omega_c t) \delta_1(t) \delta_1(T_p - t)$, $\delta_1(t)$ is a step function, $T_c = 2\pi/\omega_c = 1/f_c$, $f_c = 900$ MHz is a carrier frequency, $T_p = N_p T_c$, N_p is an integer constant chosen at $n=1$ from the condition of filling half-period $T_m = 2\pi/\omega_m$ of a pulse, ω_m is a modulating frequency determined from approximate equality $\omega_1 \approx n\omega_m$ (hence, $T_m \approx nT_1$ at $T_1 = 2\pi/\omega_1$), n , $n \in [2; 10]$ is a number of harmonic of the signal (1), $\omega_1 = 2\pi f_1$ is a frequency of the first resonance in the chamber, $f_1 = 30.78$ MHz. Then, $T_p = T_1/2 = \pi/\omega_1$.

The input signal $u(t)$ is shown in Fig. 1.

In the next step the input signal is "split" [8], i.e. represented in vector form. In the considered frequency range this vector has to be non-zero, and for any two different frequencies corresponding vectors have to have different values. We have used the simplest possible splitting for the considered input signal (sinusoidal pulse with rectangular modulation):

$$X(\omega) \rightarrow \vec{X}_P = \left[X(\omega), \frac{d(X(\omega))}{d\omega} \right].$$

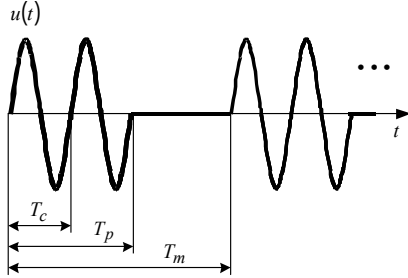


Fig. 1

In the next step we synthesize the operator of the non-linear transform as a two-dimensional polynomial of the second order (for the considered problem)

$$\begin{aligned} \tilde{Y}(\omega) &= P^Q [\vec{X}_P(\omega)] = \\ &= \sum_{i_1=0}^{I_1} \sum_{i_2=0}^{I_2} C_{i_1 i_2} [X(\omega)]^{i_1} \left[\frac{d}{d\omega} (X(\omega)) \right]^{i_2}, \end{aligned} \quad (2)$$

where $I_1 + I_2 = Q = 2$.

The coefficients $C_{i_1 i_2}$ are found as result of the solution of the approximation problem

$$\|Y(\omega) - P^Q [\vec{X}_P(\omega)]\| \rightarrow \min_{C_{i_1 i_2}}$$

in the square metric

$$\|Y(\omega) - P^Q [\vec{X}_P(\omega)]\| = \frac{1}{G} \sqrt{\sum_{g=1}^G \left(Y_g(\omega) - P^Q [\vec{X}_P(\omega)] \right)^2},$$

where the summation extends over all measured (calculated) points.

The results of the modelling of the reverberation chamber with a nonlinearly loaded loop by the second-order polynomial (2) are represented in Fig. 2. Fig. 2 shows on a logarithmical scale the frequency spectrum of the electrical field $20 \lg(|E(j\omega)|)$ from [5] (the solid curve) and $20 \lg(|\tilde{E}(j\omega)|)$, where $|\tilde{E}(j\omega)| = 1/\tilde{Y}(\omega)$ and $\tilde{Y}(\omega)$ is the result of modelling (2) (the dashed curve). The number of the curve corresponds to the number n of the low-frequency harmonics in the exciting modulated signal. From this figure one can conclude that the model (2) with degree $Q = 2$ yields a good description of the non-linearly loaded reverberation chamber.

The developed method gives a possibility to obtain information, which is not contained in the initial data, which can be used to define the matrix of coefficients $C_{i_1 i_2}$. This matrix of coefficients corresponds to the fixed parameters of the chamber, scatterer, loads and time dependency of the exciting signal. However, we can use the method to describe the amplitude dependency of the electrical field in the chamber, $20 \lg(|\tilde{E}(U_0, j\omega)|)$, where U_0 is the amplitude of the initial exciting signal.

The graphs in Fig. 3 correspond to three frequencies and $n = 2$. The analysis of such curves, in principle, can give important information about the field oscillations in the nonlinearly loaded chamber (doubling of the frequency, chaotic character of the solution, etc.).

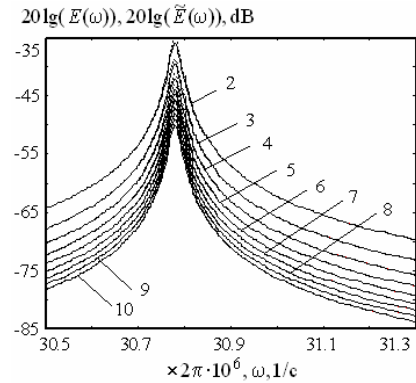


Fig. 2

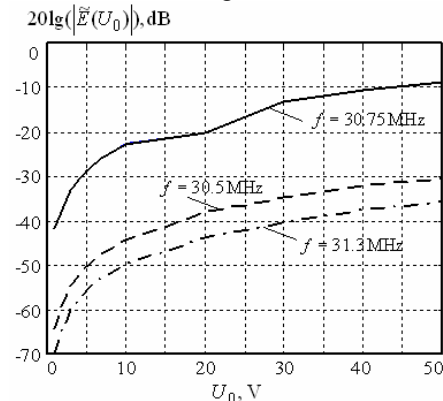


Fig. 3

Thus, it is shown in this paper that the abnormal phenomenon in the reverberation chamber with the nonlinear object, caused by nonlinear demodulation processes at high-frequency influence on the chamber can be modelled on basis of the splitting method. This method describes the input-output ratio of the reverberation chamber and gives high accuracy of chamber modelling.

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