ANALYSIS OF SOLITARY ELECTROMAGNETIC TRANSIENTS BASED ON THE K/E PULSE CONCEPT

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Application of kill-pulse and extinction-pulse concepts for natural resonanses analysis of solitary electromagnetic pulses are discussed. The main problems considered are: 1) choice of the initial moment to extract the late time part of the pulse; 2) separation of natural resonances originating from the source of pulse radiation from the poles correlating with the propagation trace. For the purpose of illustrating the use of the poles extraction procedures for solitary non-repeated pulses generated by lightning discharges the set of Matlab programs was created. Some algorithms for the analysis of pulses registrated on different distances from lightning strokes are described. Efforts to evaluate irregularities in processed signals are demonstrated.

Keywords: *convolutional model, natural resonances, poles estimation*

1. Introduction

Traditionally, the K (kill) - pulse and E (extinction) - pulse theories were used for the problems addressed to the discrimination of radar targets [1]. These approaches consist of applying the convolution of K or E - pulse with late time response of the radar return in order to neutralize the complex natural resonances (CNR's) of the target. Mathematically, one can consider some pulse *u(t)* as a solution of a linear ordinary differential equation. Then

$$u(t) = \sum_{n=1}^{N} A_n \exp(s_n t), \tag{1}$$

where A_n and s_n are complex amplitudes (residues) and complex frequencies correspondingly, inherent in *n*-th natural resonance. *N* is the whole number of exponential members, or the order of decomposition in (1). Laplace transform of (1) generates images of CNR's in *S*-domain as a set

$$U(s) = \sum_{n=1}^{N} \frac{A_n}{s - s_n}, \tag{2}$$

of isolated poles.

In radar applications the specific residues and complex frequencies of the CNR's are imposed by geometrical and electrophysical structures of the demanded target. These parameters are estimated from reflected radar return. Several approaches for analysing that inverse problem have been proposed. Historically classical Prony's method was the earliest one; different versions of modified Prony's and pencil functions methods [2, 3, 4] appear to be in preference more recently. Related solutions, in particular based on singular value decomposition (SVD) of the received signal, are under research [5]. Evaluated parameters of expansion are dependent on many factors, e.g., the length of response, signal-to-noise ratio, model order, etc.

Obviously, multiplication by $(s - s_k)$ leads to elimination of *k*-th CNR from eq. (2). In theory, the K-pulse has to suppress all the CNR's completely, while the purpose of E-pulse is to annihilate the certain CNR's only.

2. Structures of Pulses under Research

It would be logical to assume that any pulsed signal with limited duration and suitable average damping could be represented by means of its CNR poles. Poles analysis could be done to more clearly describe the signal properties caused by both its source and trace of propagation. However, the scientific publications devoted to non-radar applications of K/E - pulses concepts are quite rare.

In common case a signal *u(t)* observed at an output of a linear time-invariant system (LTIS) appears as convolution of a source pulse $u_0(t)$ with a system pulse function $h_s(t)$:

$$u(t) = u_0(t) * h_s(t). \tag{3}$$

The asterisk is symbol of convolution.

In this context electromagnetic pulses generated by lightning strokes (atmospherics) offer very interesting objects for research. Atmospherics *u(t)* at a receiving point could be considered as a pulse of current *i(*0*, t)* in an origin of lightning channel (for a return stroke it is the pulse on the ground level) convolved in series with both pulse function $h_c(t)$ of lightning channel EM radiation and pulse function $h_{tr}(t)$ of a propagation trace:

$$u(t) = i(0,t) * h_{\mathrm{c}}(t) * h_{\mathrm{tr}}(t) = i(0,t) * h_{\mathrm{s}}(t)\,. \tag{4}$$

Expression $h_{\mathrm{s}}(t) = h_{\mathrm{c}}(t) * h_{\mathrm{tr}}(t)$ is the pulse response of a LTIS excited by $i(0,t) = \delta(t)$ where $\delta(t)$ is Dirac's delta function. This system transforms a channel base current *i*(0, *t*) to an EM field impulse *u(t)* observed at the receiving point. The form of $h_c(t)$ in (4) depends on the structure of the lightning channel. In actual environment the trace in (4) becomes a multipath channel resulted by reflection, diffraction, scattering, etc.

The problem considered becomes more complicated by non-recurrent features of atmospherics. It is impossible to find two identical pulses even generated in the same lightning channel as repeated discharges are occurred in it. In common case all the convolutional components in (3) are uncertain. However, the first term at right hand could be described by the Bruce-Golde's simplified model [6] as

$$i(0,t) = I_0\,(e^{-\alpha t} - e^{-\beta t})\,. \tag{5}$$

In general, energy of a lightning stroke depends on current amplitude I0 and damping coefficients α and β. As a rule, β >> α . Immediate estimation of their values from atmospherics could be used to research some significant scientific and applied problems. Among them there are investigatings in physics of lightning channel, lightning distant sounding, methods of lightning protection of ground objects, forest fires detection and others.

3. Some algorithms and examples

Separating the members in eq. (3) is an important inverse problem. As a forced solution of an ordinary differential equation the signal (3) could be represented by a set of exponents likewise (1). One can suppose the source pulse $u_0(t)$ damps sufficiently rapid in time. Then a tail part of the pulse (3) would include just these exponents which describe the system function $h_s(t)$ only. Therefore it is necessary to find the left bound for windowing the signal (3) to isolate the tail part of it and to retain the exponents mentioned. This algorithm permits to estimate the system pulse function $h_s(t)$ in expression (3) by neutralizing the CNR's of a source using E-pulse method directly.

In principle, these parameters in (5) can be found from the spectrum of the atmosperics directly using some methods of optimization [7]. However, it is advisable to search the solution based on non-oscillate features of the twice-exponential form of the current pulse in (5). In order to realize that approach following consecutive operations could be proposed.

1. Prepare the researching signal for further analysis based on followed reasons. If the distance from lightning stroke to receiving point is known one can try to restore the induction component of EM field from received atmosferics (3). It has to be proportional to the current (4) directly. If the distance is unknown but it is presumably great (some tens of kilometers or greater) then integral from (4) would be considered as a input signal. If the distance is presumably little then the own atmospherics (4) should be in work.
2. Find the expansion (1) for the signal determined above.
3. Select the exponents with real negative indexes only from (1) using E-pulse method.
4. Make sure the chosen exponents conform to the model (5).

Unlike the foregoing this algorithm permits to estimate the source pulse function.

The following example has to do with a task to separate the convolutional members in (4). The solution is based on decomposition of an atmospherics as in (1) by classical Prony's method. The atmospherics under research is demonstrated in Fig.1, *a* as the pulse 1. The symbol *p* is the whole number of exponential members, or the order of decomposition in (1).

Mean square error was computed as relative discrepancy of energies contained in originate signal *u(t)* and its estimation $u_A(t)$:

$$\mathrm{MSE} = \| u(t) - u_{\mathrm{A}}(t) \|^2 \Big/ \sum_{m=1}^{M} u^2\,(m\Delta t) \tag{6}$$

where || **.** || is a symbol of the quadratic norm. It is seen there is good coincidence for starting parts of these signals. The source pulse is predominant along this time segment. Duration of it is controlled by conventional choice for value of *p*.

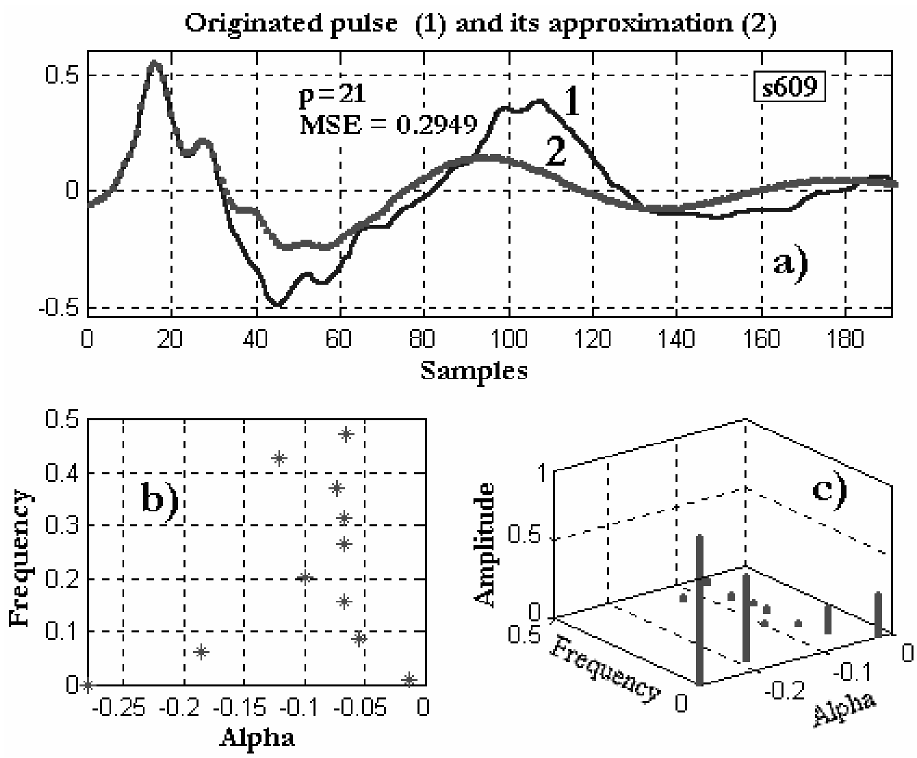

Fig. 1. Prony's exponential approximation for an atmospherics

Figure 1, *b* is a map demonstrating the positions on complex plane for that poles only which participate in reconstruction of the signal $u_A(t)$: It is obvious there are two poles among them with zeroed or atmost zeroed imagine parts laying on or nearly the real axis of the map.

In accordance with (5) just that very poles have to appoint the initial current pulse in a lightning channel. Figure 1, *c* is 3-d map showing additionally the amplitudes of residues in the expansion (1). It is clear from it that the poles referred above have sufficiently large amplitudes.

These poles form the twice-exponential sourse pulse $i(0, t)$ in (5) signed in Fig. 2 as 1. Knowledge of it permits to find a solution of convolutional equation (4) computing the system pulse function $h_s(t)$. Proper deconvolution had to be done by inverse filtering method using FFT.

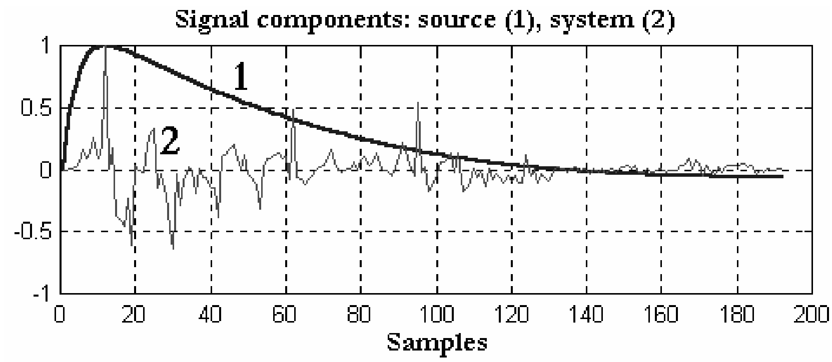

Fig. 2. The source and system pulse functions

It is seen that the system pulse function signed as 2 is highly complicate. In accordance with (4) structure of it includes images of features inherent the both lightning channel and propagation trace of the atmospherics under research. Sharp peaks could be resulted in reflections of current pulse from channel inhomogeneities and/or multipath features of propagation trace, etc. In common case we could write a system pulse function approximately as a train of impulses [8]

$$h_s(t) = h_c(t) * h_{tr}(t) = \left[1 + \sum_{m=1}^{M} b_m \, \delta(t - \tau_m) \right] * \left[1 + \sum_{n=1}^{N} a_n \, \delta(t - \tau_n) \right] \tag{7}$$

where every δ-impulse forces either channel inhomogeneities or reflections along propagation trace. Indexes *m* and *n* are attributed to a channel and to a trace correspondingly, *b* and *a* are amplitude coefficients, τ_n and τ_m are delays.

Attributing these peaks in (7) to a channel or to a trace is a greatly difficult problem. As it seems to the author some possible way to solve it would be in searching hidden periodicities in system pulse function and determination of sequential order and parentage of individual peaks.

Some inherent features of a pulse considered could be studied using the sliding window of a certain duration which should be moved along the signal. In the time of it the trajectories of the poles have to be computed. Inspecting these trajectories one can see the jumps of the separate poles. As a rule, that fenomenon points at structural variations in the source of pulse and/or the trace.

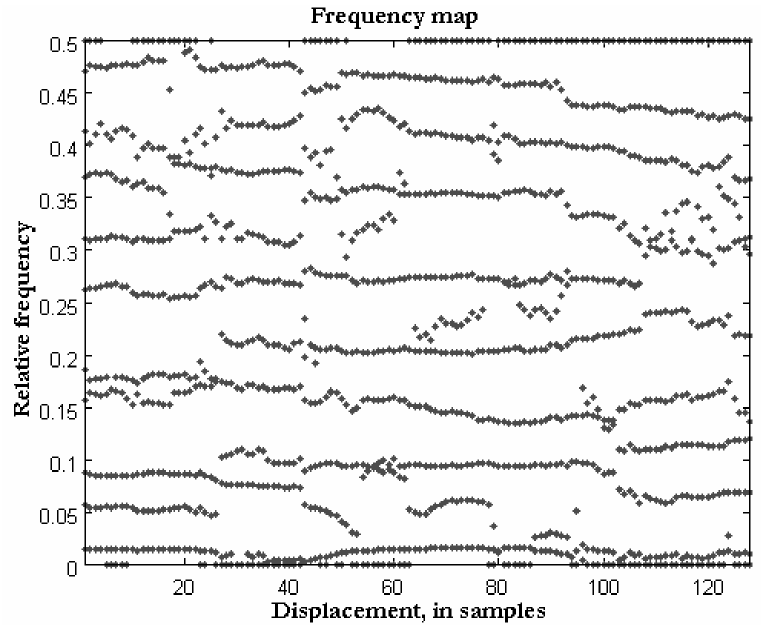

Fig. 3. Trajectories of the frequencies

Fig. 3 represents the trajectories for the of imagine parts of poles for the same atmospherics which was represented in Fig. 1 and 2. It is substantial to note these locations of jumps correlate approximately with the positions of peaks in system pulse function viewed in Fig. 2.

All the procedures described above have been realized in Matlab.

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