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PULSE-PHASE CODING OF INFORMATION IN NEURAL NETWORK

Improved method of phase-pulse coding of information in neural networks has been developed. Evaluation of errors while performing operation of synapse multiplication has been performed. Electric circuit of neurons input signals and synapse weights multiplicator is suggested. Simulating and study of input signals and synapses weights multiplicator circuit based on FET are performed applying MicroCap V program.

Key words: *pulse-phase, neural network, coding, synapse, error.*

Introduction

Recent years witness intensive studies of the possibility to apply the apparatus of artificial neural networks in the problems of control of complex engineering objects and technological processes. As compared with adaptive control systems, level of fuzziness in neural networks could be higher, and what is more important, the application of neural networks does not require analytical description of the object of control. Neural networks find wide application for the solution of a number of problems dealing with operation of telecommunication networks and systems, namely:

– for identification of satellite channels [1];
– for elaboration of receivers for CDMA signals [2];
– for modeling of non-linear super high frequency memory-free amplifiers [3].

Problem set up

Since in biological neurons signals are sequences of pulses, artificial neurons also use pulse-modulated signals [4]. Four types of coding are used in neural networks – pulse-amplitude, pulse-frequency, pulse-width and pulse-phase [5]. According to [6] pulse-phase elements differ from pulse-potential and pulse-frequency ones.

According to [6] pulse-phase elements differ from pulse-potential and pulse-frequency ones by the simplicity of multifunctionality provided at minimum of circuit engineering redundancy. Principle advantage of pulse-phase elements as compared with pulse-potential and pulse-frequency ones is independent amount of their components on numeration systems used [6]. That is why, the aim of the given research is to study the possibility and expediency of using pulse-phase coding in neural networks.

To achieve this aim the following problems are to be solved:

– elaboration of pulse-phase coding of information in neural networks;
– evaluation of errors of synapse signals with pulse-phase coding;
– development, simulation and study of FET-based multiplicator circuit of input signals and synapse weights.

Definition of pulse-phase coding method

In accordance with one the methods of synapse multiplication realization, any of pulse parameters – amplitude, frequency, duration, time shift corresponds to the values of input information, another one – to synapse weight, two latter parameters are constants [4]. The analysis of existing methods of neural networks signals coding has been performed in [7]. The drawback of the existing pulse-phase method of cording is that zero phase shift of pulse sequence corresponds to zero value of neuron input signals. To eliminate this drawback we suggest own method of pulse-phase coding of information in neural networks. Taking into consideration the above-mentioned, we improve the existing method of pulse-phase coding of information in neural network.

Assume that pulses have constant period T and constant duration τ (fig. 1).

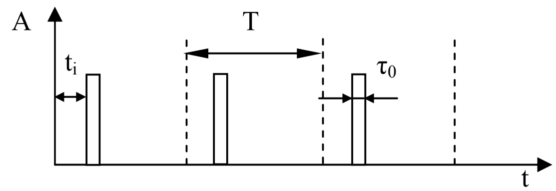


Fig.1. Pulse-phase sequence

Let the value of input signal x_i be proportional to pulses time shift t_i, i.e.

$$t_i = t_\alpha \cdot x_i + t_\beta$$

where t_a, t_b – initial time pulses shifts.

3. Let the value of synapses weight x_w be proportional to the amplitude of pulses A_s, i.e

$$A_w = A_\alpha \cdot x_w + A_\beta$$

where A_α, A_β – initial time pulses amplitude.

Then multiplication operation having been performed, amplitude of synapse signal pulses A_s and their time shift are determined in the following manner:

$$A_s = A_i + A_\gamma$$

$$t_s = t_i \, .$$

Input signal of neuron is determined as

$$A_n = \sum A_s$$

$$t_n = \sum t_s \, .$$

Output signal of neuron is determined as

$$A = f(A_n)$$

$$t = f(t_n) \, .$$

Hence, in accordance with the suggested coding method the value of input information is set by pulse time-shift of pulse – phase sequence, and synapse weight is set by the amplitude of constant voltage and determines current amplitude of output pulse sequence, phase of which coincides with the phase of input pulse sequence, zero value of neuron input signal corresponding to initial phase shift, distinguishing the given method from existing ones and enables to avoid the possible error due to phase jump.

Evaluation of errors of synapse signals with pulse-phase coding.

As we know, synapse noise stability depends on errors, occurring while defining of the values of input signal parameter and synapse weight. Let us calculate the error, occurring while performing synapse multiplication operation. Synapse error has two components [7]:

$$\delta = \delta_{sig} + \delta_A \, ,$$

where δ_{sig} is a definition error of input signal parameter value,

δ_A is a definition error of synapse weight.

Definition error of synapse weight is calculated by the formula:

$$\delta_A = \frac{\Delta_A}{A_{min}},$$

where Δ_A is a deviation of determined voltage amplitude of synapse weight from actual value; A_{min} is a minimum value of voltage amplitude of synapse weight.

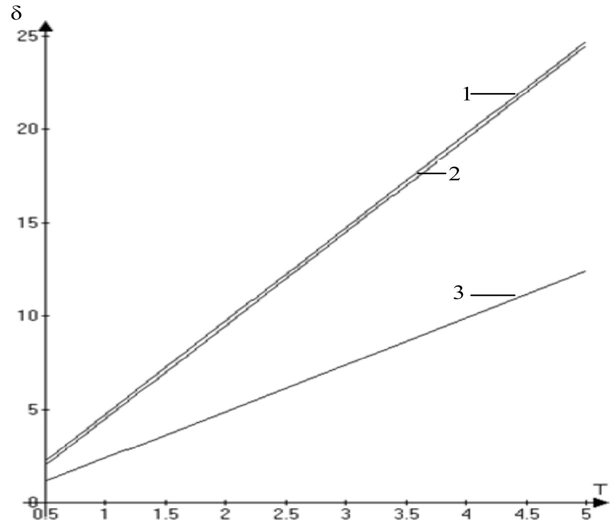


Fig.2. Graph of dependence of synapse error on signal

If pulse-phase signals are applied, deviation $\Delta t = \frac{1}{2}(T - \tau_0)$ then synapse error with pulse-phase signals is calculated by the following expression:

$$\delta_{PPM} = \frac{\Delta t}{t_{min}} = \frac{T - \tau_0}{2t_{min}}$$

Graph of dependence of synapse error on signal period for various values of pulse duration and minimum time shift is shown in Fig. 2.

In the first case $t_{min1} = 0{,}1\mu s$, $\tau_{01} = 0{,}05\mu s$; in the second case $t_{min2} = 0{,}1\mu s$, $\tau_{02} = 0{,}1\mu s$; in the third case $t_{min3} = 0{,}2\mu s$, $\tau_{03} = 0{,}05\mu s$.

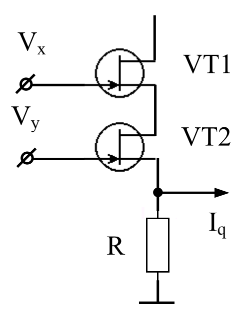


Fig. 3. Scheme of multiplicator on FET

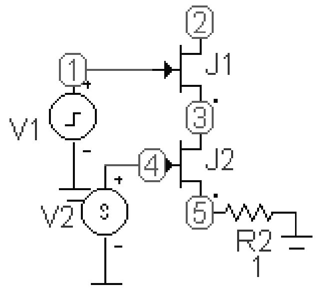
Thus, we can state, that pulse duration value is of minor influence on the error. To reduce the error it is necessary to reduce T period and increase minimum duration of pulses phase t_{min}.

Pulse-phase multiplicator

In [7] multiplicator for pulse-width signals, realized on two MOS-transistors is presented, the output signal is taken from the source of the first transistor. To perform the operation of synapse multiplication of pulse-phase signals multiplicator on two FET was developed, the output signal is taken from the source of the second transistor.

Circuit diagram of the multiplicator of neuron input signal and synapse weight is elaborated. The circuit realized on two FET is shown in Fig. 3. The sequence of pulses is delivered to the gate of the first transistor VT1, the phase of these pulses determines the value of neuron input action. Constant voltage is supplied to the gate of the second transistor VT2, its value determines the synapse weight value. Source current of the second transistor is the sequence of pulses, their phase coincides with the phase of input pulse sequence and the amplitude depends on the synapse weight.

For verification of operation ability of the multiplicator we will simulate its operation by means of Micro Cap V Software. The circuit will be the following:



Input pulses, synapse voltage and output current pulses if $t_i = 100ns$ and $V_{sig} = 0.1V$ are shown in fig 4, and if $t_i = 300ns$ and $V_{sig} = 0.5V$ – in Fig 5.

Dependence of current amplitude of output pulse sequence on synapse voltage is shown in Table 1.

Dependence of current amplitude of output pulse sequence on synapse voltage

Phase of neuron input signal	Pulse amplitude of neuron input signal	Phase of neuron output signal	Amplitude of synapse signal pulse	Pulse amplitude of output signal
0,125μs	1 V	0,125 μs	0,1V	0,151mA
0,25 μs	1 V	0,25vмкс	0,5V	0,179mA

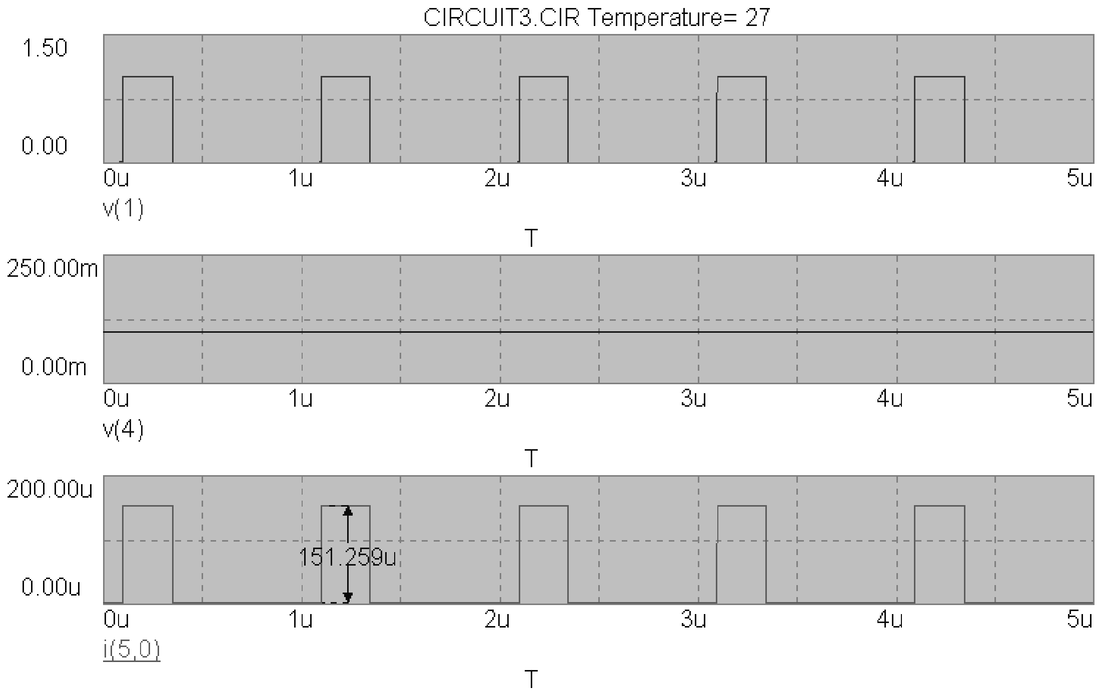


Fig. 4. Amplitude-time characteristics of the multiplicator

Therefore, pulse phase of output sequence coincides with the phase of input signal and pulse amplitude of the output sequence depends on voltage amplitude of synapse weight signal, i.e., the operation of synapse multiplication is performed.

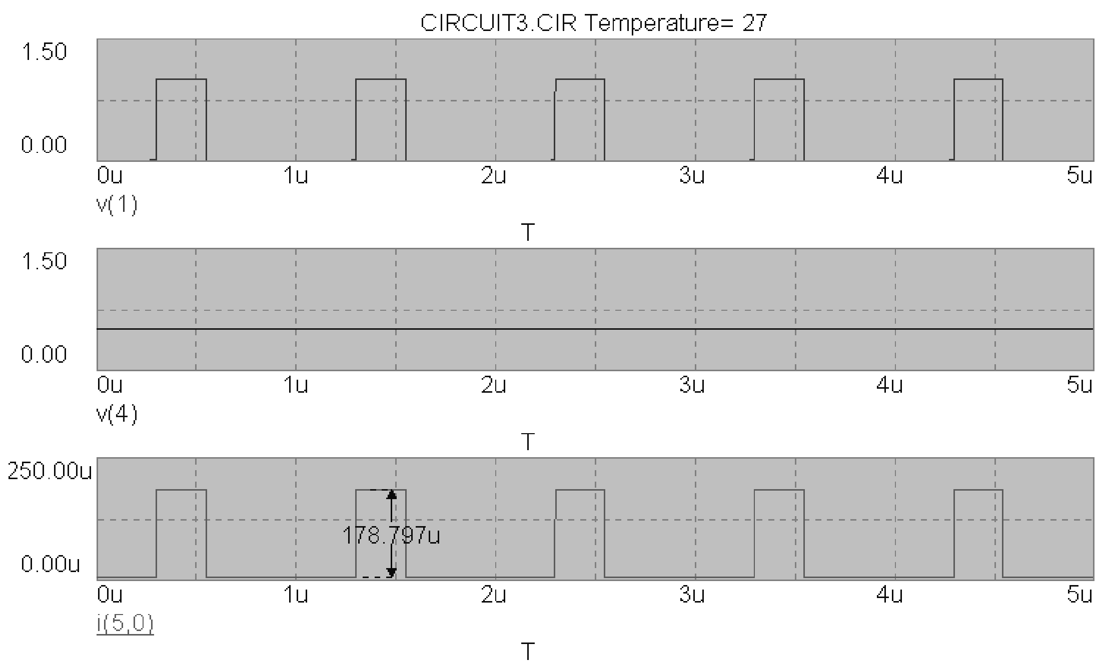


Fig. 5. Amplitude-time characteristics of the multiplicator

Experimental research

To carry out experimental research we use double gate transistor – tetrode, which is the constructive variant of FET.

Let us use mixing properties of double gate transistor in the circuit of pulse – phase multiplicator. The scheme of the device, realizing multiplication effect of the input signal and synapse, is shown in Fig. 6. Synapse voltage is sent to the first gate, phase-modulated sequence of pulses is sent to the second gate. Dependence of pulses amplitude on the synapse voltage is presented in the Table 2, oscillograms of input and output signals are shown in Fig 7 and 8.

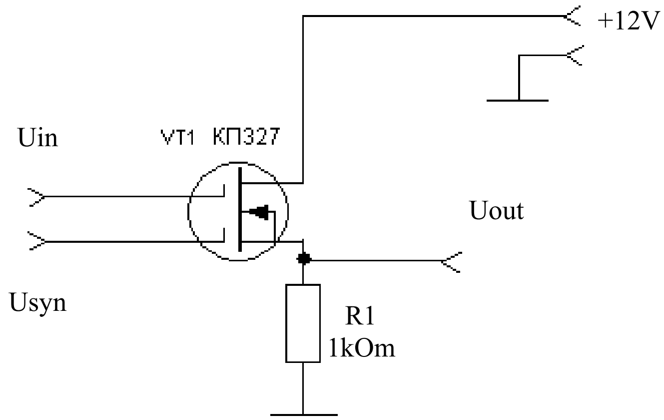


Fig. 6. Circuit diagram of the pulse-phase multiplicator

Table 2

Dependence of pulses amplitude on synapse voltage.

№	T, ms	τ , ms	U_{imp}, V	U_{sig}, V	U_{out}, V
1	400	200	1	1,5	0,8
1	400	200	1	0,25	0,3

Using data, presented in table 2 and oscillograms, shown in Fig 7 – 9, we can make a conclusion, that, when corresponding signals are sent to the inputs of the device, shown in Fig 6, the given device performs the functions of pulse-phase multiplicator - i.e., multiplication of neuron input signal and synapse weight, that proves the validity of the computations and simulation.

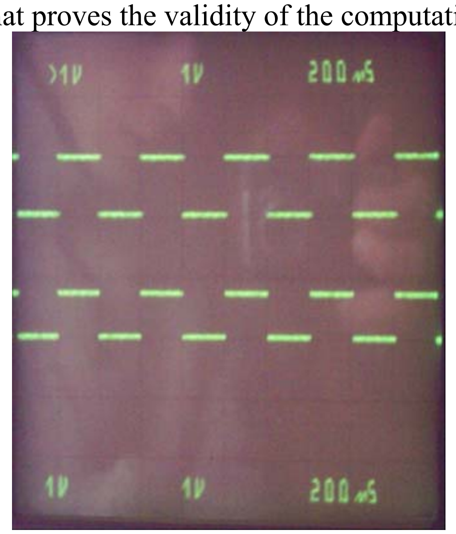


Fig. 7. Oscillogram of input and output signals, at U_{imp} = 1V, U_{syn} = 1.5V

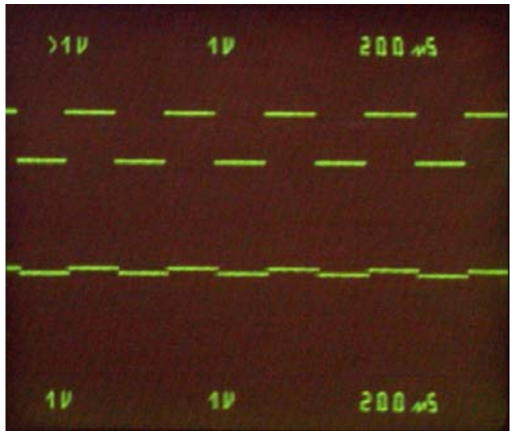


Fig. 8. Oscillogram of input and output signals, at U_{imp} = 1V, U_{syn} = 0.25V

Conclusions

New method pulse-phase coding of information in neural networks is suggested. The essence of the suggested method is the following: the value of neuron input information is set by pulses time shift pulse-phase sequence and the synapse weight is set by the amplitude of constant voltage and determines current amplitude of output pulse sequence, the phase of which coincides with the phase of input pulse sequence, initial phase shift corresponding to zero value of neuron input signal, that differs the suggested method from existing ones and enables to eliminate the possibility of error due to phase jump and simplify neuron schemes.

Evaluation of errors while performing synapse multiplication operations is carried out. It is shown, that error value of synapse multiplication of pulse-phase signals is directly proportional to the period and duration of the input signal and is inverse proportional to minimum of the phase shift.

The electric circuit of the multiplicator of neuron input signals and synapse weights is suggested, the suggested circuit differs from the already existing that it can be realized at one transistor.

Simulation of multiplicator operation in MicroCap V environment is performed. The value of input action is set by sequences of pulses with different phase shifts. Synapse weight is defined by voltage value. At the output we obtain the sequence of current pulses, time shift of which coincides with the shift of the input signal and current amplitude depends on the value of synapse weight.

Experimental tests of elaborated multiplicator prove the validity of computations and workability of the circuit.

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