AN ADAPTIVE ANTENNA ARRAY WITH THE TIME MULTIPLEXED SIGNAL PROCESSING

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Abstract

An adaptive antenna array with the digital signal processing requires an independent receiver for each antenna element. This fact significantly influences the cost of the system. The presented paper answers the question what will happen if high-frequency signals from outputs of two antenna elements are time multiplexed and processed by only one receiver.

It is shown that such a system is a bit slower in comparison with the classical devices but, on the other hand, it requires only the half number of receiving chains what reduces the price of the adaptive antenna.

Key words:

Adaptive antenna array, digital signal processing, least mean square algorithm.

Introduction

An adaptive antenna array changes amplitudes and phases of signals at the outputs of its elements in such way so that the directivity pattern can have its minima in directions from which interferences come. In this way, the antenna system does not receive disturbances, which may be very powerfull and in classical systems they can totally destroy information borne by the signal.

Adaptive antenna arrays are usually steered by the least mean square (LMS) algorithm, which requires two-step work of the system.

Learning is the first step . A transmitter transmits signal, which is generated in antenna system at the same time too. Amplitudes and phases at antenna element outputs are set in such way so that the mean square of the error signal, which equals the difference between received and generated signal, can be the least one. When this aim is met, the phase shifters and atenuators at element outputs are set properly and the second step of the work, a transmission of an information, can be started.

After a certain time interval, which is given by the rapidity of variations of electromagnetical environment, the system returns to the learning mode and the two steps described above are repeated.

An adaptive antenna system can be implemented by analog or digital circuitry.

In analog systems, the controllable amplitude settings and phase shiftings are achieved by a taped delay line with a steered weight at each tape. This type of implementation requires a delay line and a relatively high number of exact controllable weights for each antenna element. Hence, the device is very complicated and expensive.

In a digital system, the output signal of each antenna element goes through the receiver and the A/D-convertor to the signal processor which performes operations of delay lines and weights. So, the digital implementation of an adaptive antenna array is simplier then the analog one.

On the contrary, the digital system must work in the low-frequency band because of the speed limitations of a signal processor. That is why each antenna element needs its own receiver which is not cheap in the microwave band especially.

The question is whether exists the way of reduction of the number of receiving chains.

The partially adaptive arrays

If the adaptive array consists of M adaptively steered elements then it is able to cancel interferences coming from $M-1$ directions.

The partially adaptive array consisting of N antenna elements steers adaptively M elements, $M < N$. There are two approaches :

1. Some antenna elements are steered, some not.
2. Antenna elements are joined into groups and these higher units are then steered.

The partially adaptive systems with M adaptive controllers have got better properties then the fully adaptive systems with M elements but they are not able to cancel more than $M-1$ interferences.

The time multiplexed signal processing

Let us suppose the electromagnetically quiet environment with only one plane wave modulated by the harmonic signal

$$s(t) = S \, . \sin(\Omega t) \tag{1}$$

where S is a constant amplitude and Ω a single frequency.

Let the 4-element antenna array (Fig.1a) be situated in such way so that its main beam can look to the direction of the arrival of the wave. Then the signal

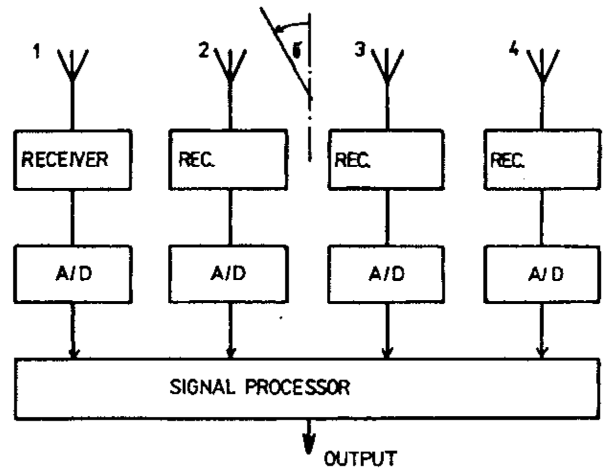

Fig.1a
Full implemented adaptive antenna array.

$$s(k) = S \,.\, \sin(\Omega k T_v) \tag{2}$$

appears at all outputs of A/D-convertors.

Symbol k denotes number of the sample and T_v the sampling period.

Let the sampling period equal

$$T_v = \frac{2\pi}{4\Omega} \tag{3}$$

In such a special case the signals (2), which enter the signal processor, can be obtained by the half number of receivers (Fig.1b).

At the beginning, the input of the first receiver is connected with the first antenna element and the input of the next one with the third element. The output

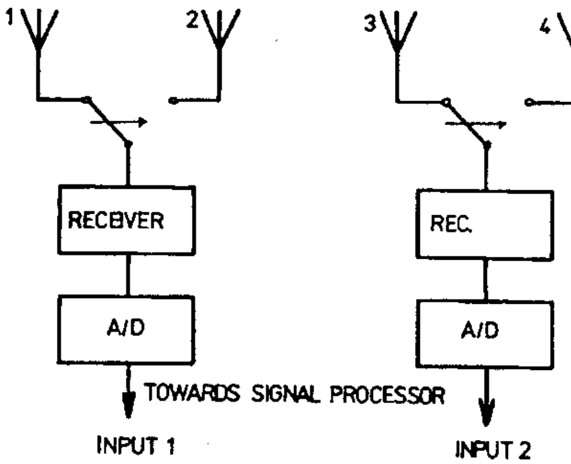

Fig.1b
Time multiplexed adaptive antenna array.

signals of elements 1 and 3 are processed by receivers and sampled. In the moment when the samples are taken off, the high-frequency switchers connect receivers with elements 2 and 4 as quickly as possible so that transient effects in receivers can settle down before taking off new samples.

Let the output signals of elements 1 and 3 be

$$s_1(k) = s_3(k) = s(k) = S \,.\, \sin(\Omega k 2\tau) \,. \tag{4}$$

If

$$\tau = \frac{T_v}{2} \tag{5}$$

then equations (2) and (4) are equivalent and there is no difference for signals of elements 1 and 3 in comparison with the fully implemented system.

For elements 2 and 4 we can write

$$\begin{aligned} s_2(k) = s_4(k) &= S \,.\, \sin[\,\Omega(2k-1)\,.\,\tau\,] = \\ &= S \,.\, \sin(\Omega k 2\tau - \Theta) \;, \end{aligned} \tag{6}$$

where

$$\Theta = \Omega \,.\, \tau \tag{7}$$

is the phase error due to the removal of the half number of receiving chains. Because we know both the frequency Ω and the new sampling period τ we can calculate the value of the phase error and compensate it.

If (1) is a narrow-band signal with the central frequency Ω then the compensation can be done as well.

What will happen if the compensation is not performed? This question is answered by figures 2a,b,c.

We can see that weighting of the antenna array elements by their phase errors influences the shape and position of the main beam minimally. The sidelobe area is deformed by the phase error but the process of adaptation will rebuild it anyway.

Hence, we can do the partial conclusion that the adaptive antenna system can work with the half number of the receivers, each of which processes the time multiplexed highfrequency signals from two antenna element outputs, with no serious influence on properties of the narrow-band device.

For verifying this hypothesis we did further computer simulations. We were interested in time responses of the error and the output signals in the learning mode of the adaptive antenna array both with the phase correction and without it.

We used the electromagnetic scene consisting of four electromagnetic waves for the experiment. The wave bearing the desired signal came from the direction $\sigma_d = 0°$, the waves modulated by interferences arrived from directions $\sigma_1 = 90°$, $\sigma_2 = -45°$ and $\sigma_3 = -135°$ (directions of sidelobes of deformed directivity pattern from Fig.2b). The amplitude of the received desired signal was $S = 0.5$ V, the amplitudes of received interferences were $D_1 = D_2 = D_3 = 10$ V.

The simulated system consisted of four FIR* adaptive filters (Fig.3) controlled by the leaky LMS algorithm

$$W(k+1) = \mu \,.\, W(k) + \alpha \,.\, e(k) \,.\, X(k) \,, \tag{8}$$

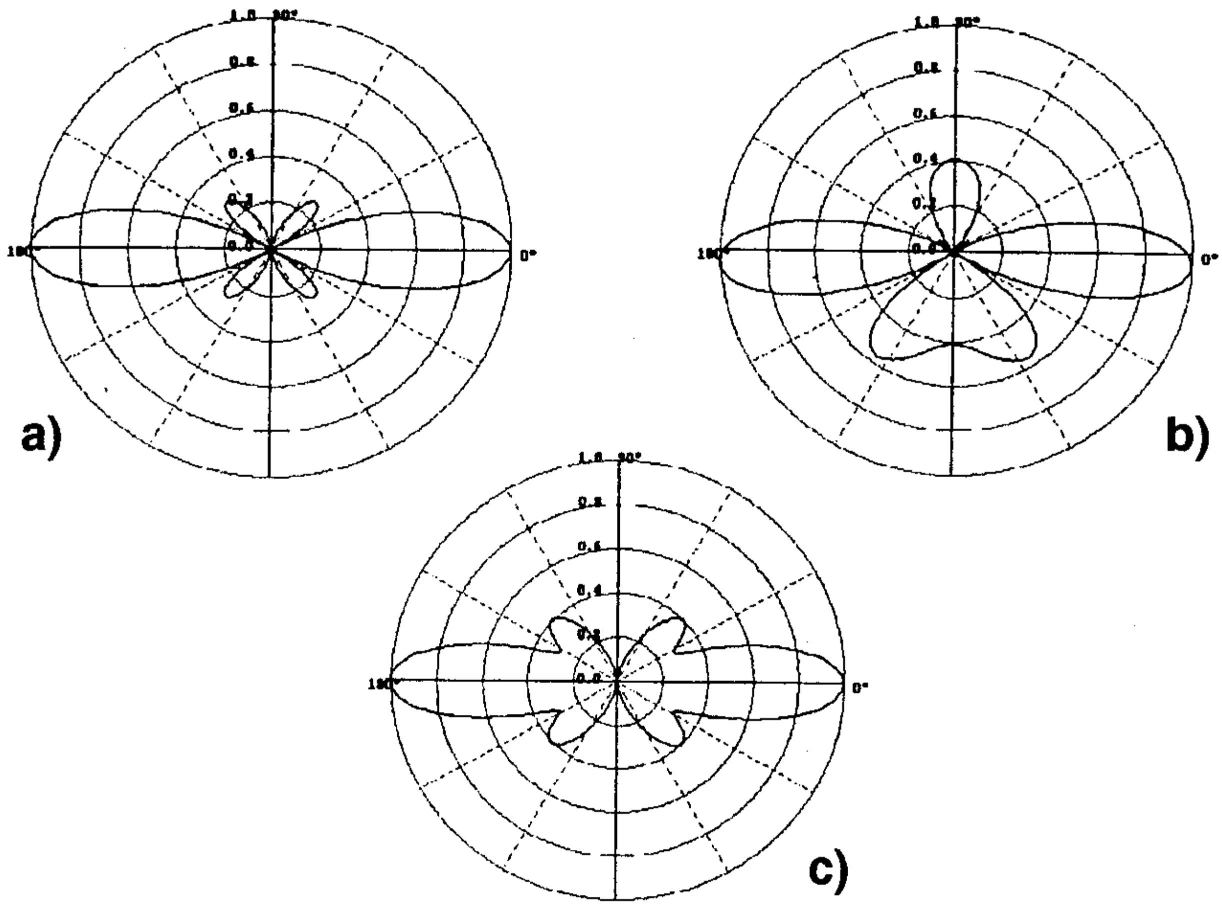

Fig.2

Directivity pattern of the 4-element array
a) without weighting,
b) elements 1 and 3 weighted by the phase error,
c) elements 1 and 4 weighted by the phase error.

where μ is a coefficient ($\mu = 0.999$ in our simulation),
α is the learning constant ($\alpha = 10^{-4}$),
W is the column vector of filters weights,
X is the column vector of weighted samples,
e is sample of the error signal

$$e(k) = p(k) - W^T(k) \,.X(k)\,. \qquad (9)$$

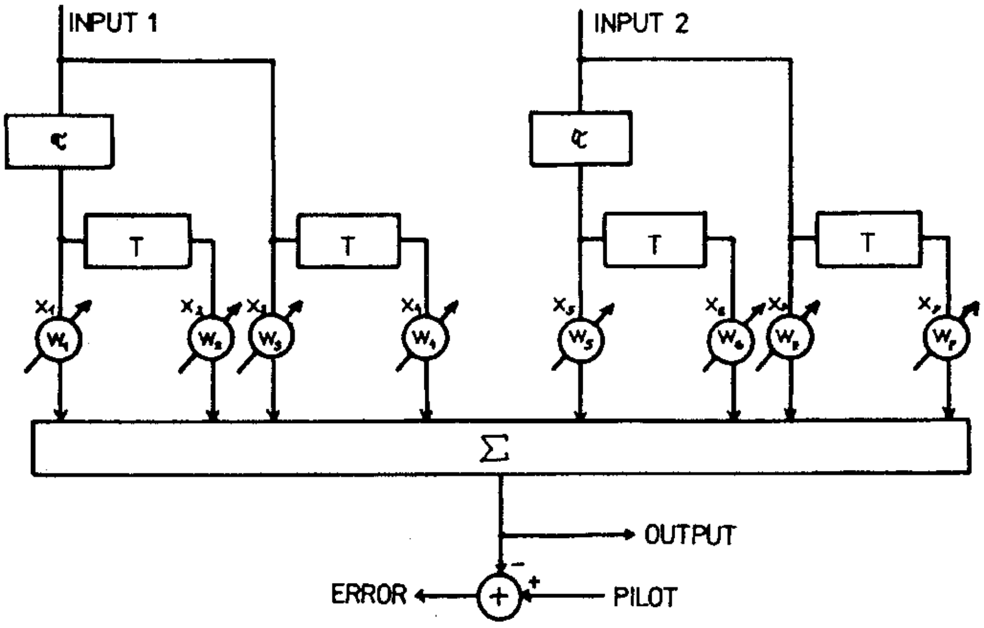

Fig.3
The simulated signal processing.

The symbol ^{T} denotes the transposition and $p(k)$ is k-th sample of the pilot signal (signal transmited by a transmitter and at the same time generated in the adaptive system).

The leaky LMS algorithm was derived in [3] for the system with white noise on the input. The phase error may be supposed for a special kind of noise (even if not !) but anyway the leaky LMS steers our system better than the classical LMS algorithm.

The simulation results (from the 1st upto the 600th iteration cycle) can be seen in figures 4a,b.

The system with the phase correction equals the classical adaptive antenna array. Its output signal (in the figure is signed summa) converges very quickly towards

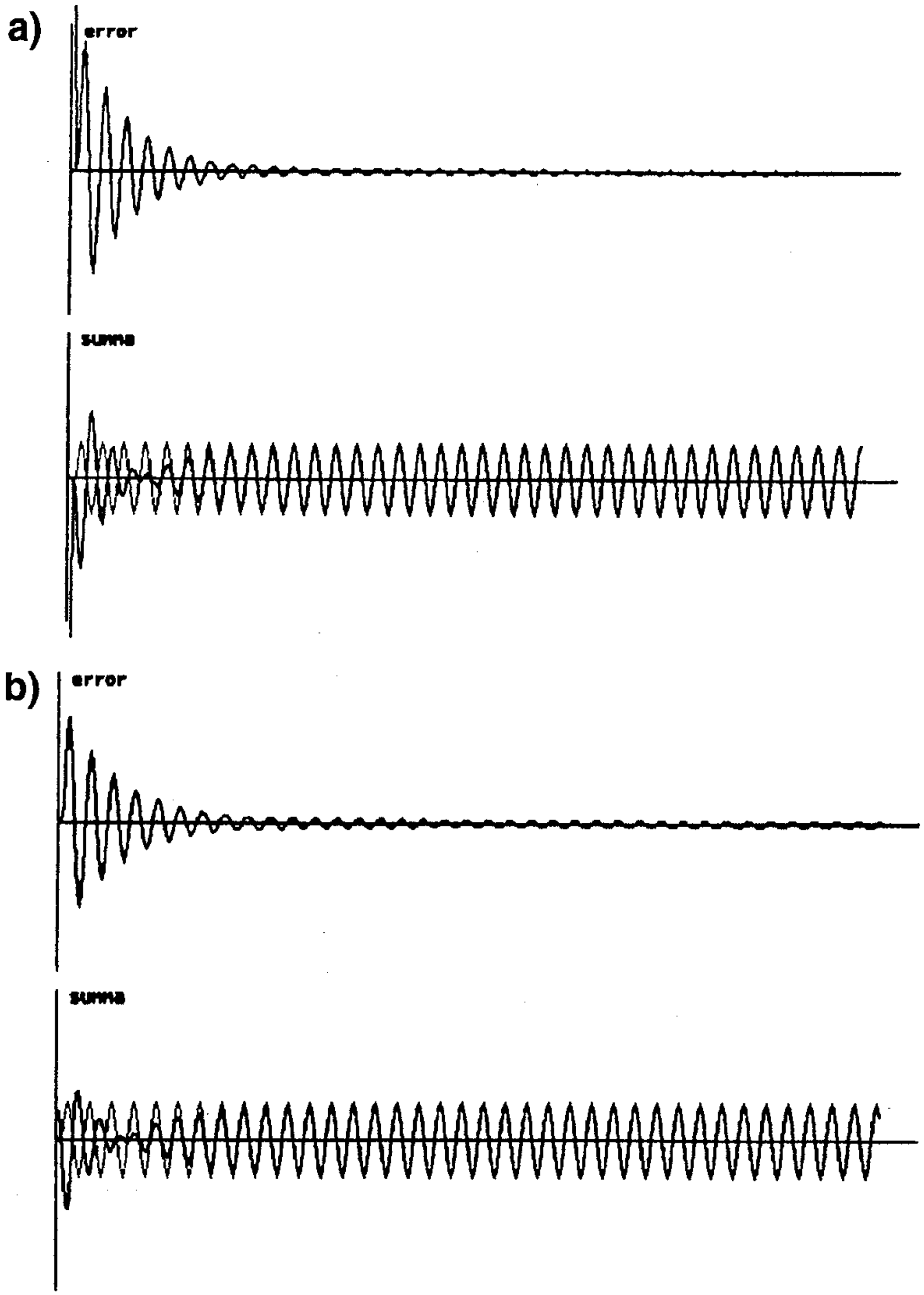

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Fig.4

Time response of the error and output signals in the system
a) with phase error correction,

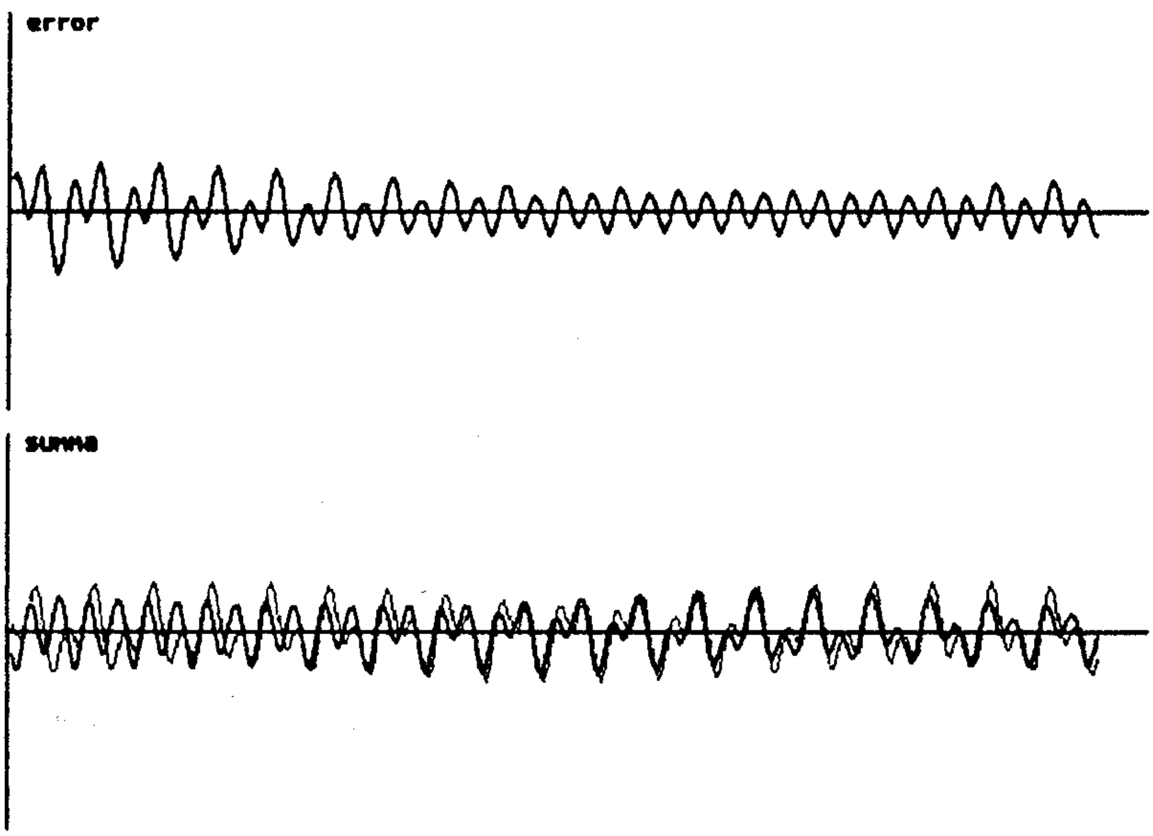

Fig.5
Broadband simulation of the time multiplexed system

the desired signal (drawn by the light gray color) and that is why the level of the error signal falls rapidly.

The system without phase correction responds on the teaching process a bit slower then its fully implemented friend but that is its only negative property.

Behavior of the antenna with high-frequency time multiplexing does not depend on the fact what two elements are joined by the multiplex (we obtained the same time responses both for the system with directivity pattern from Fig.2b and for the system with pattern from Fig.2c).

Computer simulation of the broadband system

We tried to use the time multiplexed adaptive antenna array for the processing of broadband signals too. The results of this experiment are drawn in the Fig.5 which shows the time response of the error and output signals between 600th and 1200th iteration cycle ($\mu = 0.999, \alpha = 10^{-7}, \sigma_d = 0°, \sigma_1 = 90°, \sigma_2 = -45°$ and $\sigma_3 = -135°$ (directions of sidelobes of deformed directivity pattern from Fig.2b), $S = 100V, D_{1,2,3} = 100V$).

The steady state level of the error is very high. There are problems with stability of the system. Briefly, it is necessary to answer a lot of questions about the broadband system but it may be probable that the broadband time multiplexed adaptive antenna array will work well too.

Conclusion

The presented paper deals with the original approach to the reduction of the hardware complexity of digital adaptive antenna array. The idea of the time multiplex processing of antenna element output signals is explained and illustrated by results of computer simulations. It is shown that presented system handles well with narrowband signals but there are some troubles with its implementation for broadband problems.

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About author,...

Zbyněk Raida was born in 1967 in Opava. From 1982 to 1986 he studied at the grammar school of Nicolaus Copernicus in Bílovec which is specialised in mathematics and physics.

After graduation in radioelectronics in 1991 in the Technical University of Brno, he started his studies towards Dr.Ing.

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