THE DIRECTIONAL SIGNAL FILTERING BY PROGRESSIVE PHASING

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Abstract

The paper deals with a method of signal filtering in the feed network of a phased array. Two alternative ways of phase control are described here. Both of them enable to set several directions of zero reception independently each other.

Key words
phased array, directional filtering, elimination of undesired signals, beamforming

1. Introduction

Let several signals with nearly equal frequencies be coming from different directions simultaneously to the receiving point. In such situation, the desired signal can be separated (isolated) from the other ones by a directional receiving antenna. Usually,the main lobe of its radiation pattern must be orientated in the direction of desired signal arrival. Then, an adequate small level of sidelobes is mostly sufficient for the required suppression of the undesired signals. An analogous effect may be achieved, when minima of the reception pattern lie exactly in directions, from which the interference come. In such a case, the coincidence of main lobe position and desired signal arrival need not be kept, the signal level at the antenna output will be lower, of course.

The directions of minimum and maximum reception can be controlled by changing of current phases in the array ele ments. The method of progressive phasing described below gives the possibility to set independently several nulls of radiation pattern in prescribed directions.

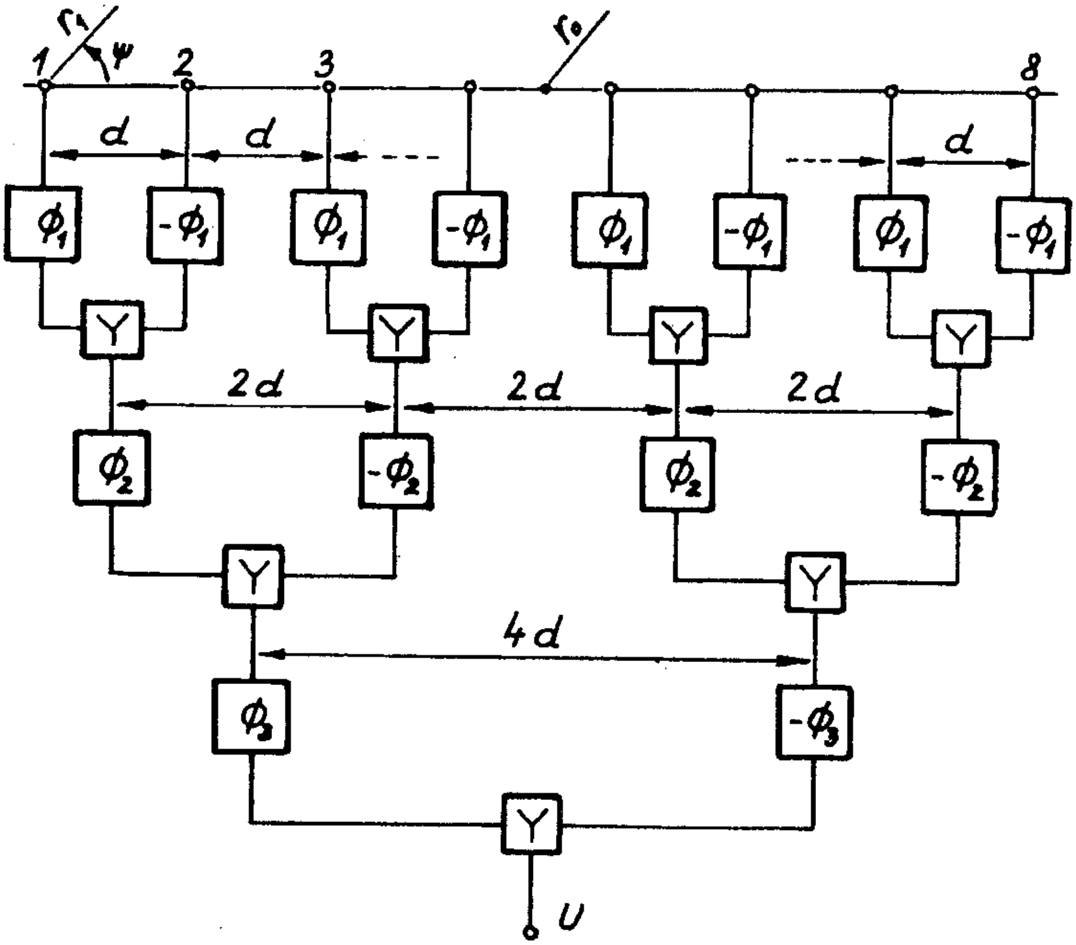

Fig.1
The feed network of the complete array

2. Properties of the complete array

The scheme of the analyzed phased array is drawn in Fig.1.

A linear array consisting of N identical elements has its elements combined in pairs. In each pair, the voltages are shifted by $\pm\Phi_1$ and added. In this way, we obtain $N/2$ outputs of a "new array", which has half number of "elements" , but double distance between their phase centers. This is the 1-st level of signal processing.

The procedure is repeated and the signal processing at higher levels is analogous.The higher is the level,the smaller is the number of elements and the larger is the phase center separation. The phase shift at the i-th level is Φ_i and $\Phi_i \neq \Phi_j$ in general.

Let us consider an array having N elements and M levels of signal processing. Each element delivers the voltage $U_0 = \mathrm{const}\,.\,F_d(\psi)$, where $F_d(\psi)$ is the element space factor and ψ is the arrival angle of the received wave. The output voltage of the complete array is

$$U = U_0(\psi)\prod_{i=1}^{M} 2A_i\cos\left(2^{i-1}k\frac{d}{2}\cos\psi - \Phi_i\right)e^{-jkr_0} \quad (1)$$

The resulting phase center lies at the middle point of the array. Coefficients $2A_i$ in eq. (1) include losses and mismatching at the levels.

An array with M levels of signal processing requires $N = 2^M$ elements, 2^M-1 summing elements (diplexers), and $2\,.\,(2^M-1)$ phase shifters operating in the range $<-\pi/2;\pi/2>$.

If the condition

$$2^{i-1}k\,\frac{d}{2}\cos\psi_i - \Phi_i = \left(2n-1\right)\frac{\pi}{2} \quad (2)$$

is fulfilled at the i-th level, then the signal coming from direction vanishes at this level and,consequently, at the array output as well. Therefore, an array with M levels is able to eliminate M signals independently each other.

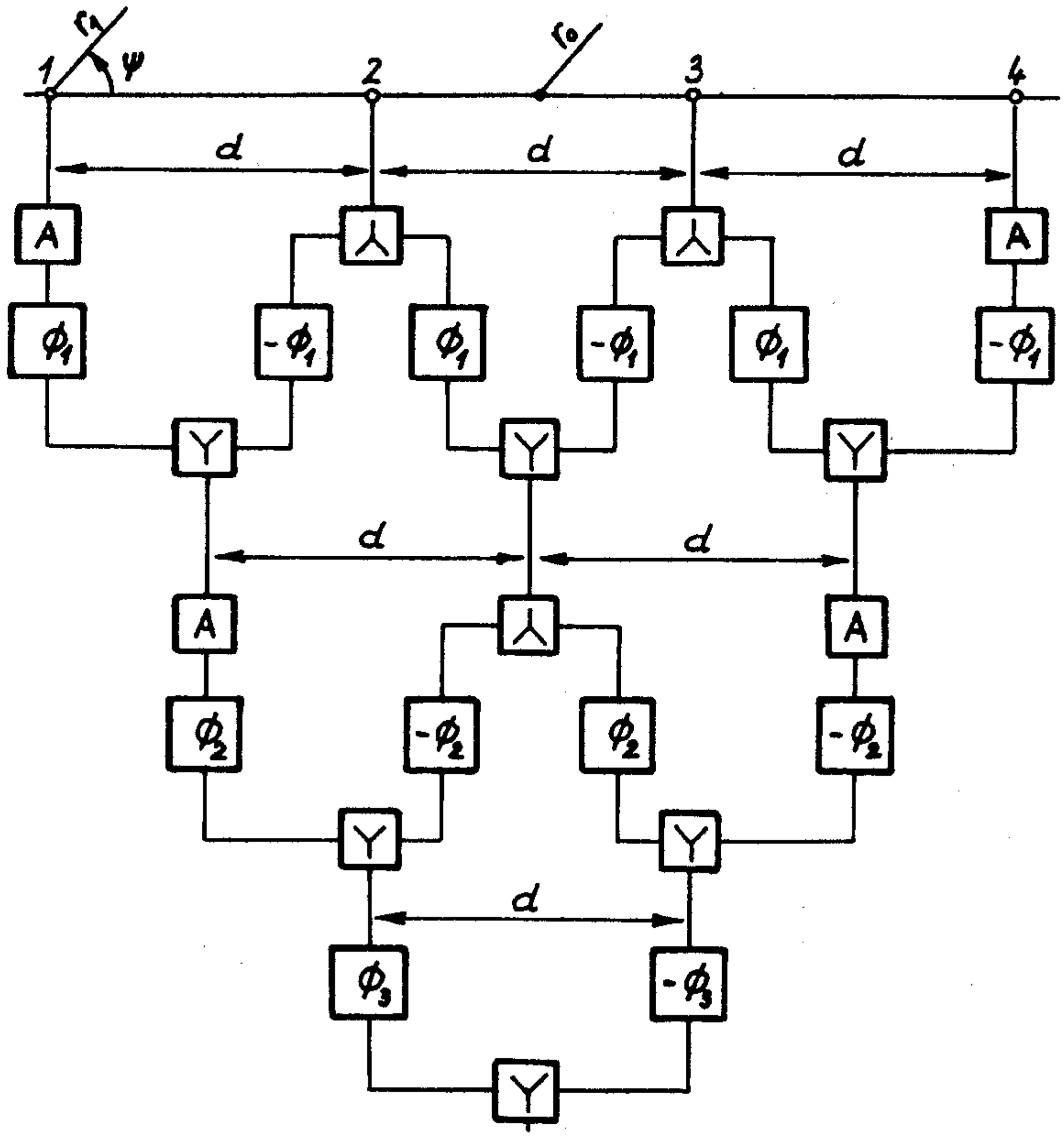

Fig.2
The array with shortened baseline

Let us turn our attention to the transmission of the desired signal. The transfer factor K_i of the desired signal at the i-th level depends on the phase shift Φ_i and on the arrival angle of the desired signal.The factor K_i reaches its maximum $K_i = 2A_i$ when $\Phi_i = \Phi_{0i}$, where Φ_{0i} is given by following equation:

$$2^{i-1}k\,\frac{d}{2}\cos\psi_0 - \Phi_{0i} = n\pi \qquad (3)$$

If $\Phi_i \neq \Phi_{0i}$, then $|K_i| < 2A_i$. Increasing the difference $|\Phi_{0i} - \Phi_i|$, the value of K_i decreases and if $|\Phi_{0i} - \Phi_i| = \pi/4$, than the drop of K_i is equal to 3 dB. For this reason, it is useful to eliminate the individual undesired signals (propagating in directions ψ_i) at individual levels in such sequence so that the difference $|\Phi_{0i} - \Phi_i|$ may be as small as possible at each level and throughout substantially smaller than $\pi/2$. The signals coming from directions nearly equal to the arrival angle of the desired signal can be eliminated easier at higher levels,where the phase center separation is the largest one.

3. The array with shortened baseline

The block scheme of this array is drawn in Fig. 2. The signals of each element are firstly splitted, then shifted by $\pm\Phi_1$ and added again. The attenuators in outer branches compensate the splitting effects in the inner branches. This procedure repeats at each level. The number of outputs decreases by one at each level and the phase center separation remains constant at all the levels of signal processing.

In comparison with the scheme in Fig.1.,the array with shortened baseline requires a considerable less number of antenna elements for equal number of signals that it is able to eliminate.

The output voltage of an array with $M = N - 1$ levels is

$$U = U_0(\psi)\prod_{i=1}^{M} 2A_i\cos\left(k\,\frac{s}{2}\cos\psi - \Phi_i\right)e^{-jkr_0} \qquad (4)$$

In eq. (4), ψ is the arrival angle of the received wave. The phase center of the complete system is at the midway point of the baseline and its position does not depend on the value of Φ_i.The coefficients $2A_i$ include also the effect of signal splitting.

An array of M levels of signal processing has $N = M + 1$ antenna elements, $M \,.\, (M + 1)$ phase shifters and M^2 elements for signal splitting or summing. When the circuitry consists of passive elements only, $2(M - 1)$ attenuators more must be applied.

To suppress the reception from the direction ψ_i, the following condition must be fulfilled at certain level:

$$k\,\frac{d}{2}\cos\psi_i - \Phi_i = \left(2n - 1\right)\frac{\pi}{2} \qquad (5)$$

As all the levels are equivalent from this point of view, each signal can be eliminated at any level.

When comparing the value of Φ_i with the value of Φ_0 according to the condition

$$k\,\frac{d}{2}\cos\psi_0 - \Phi_0 = n\pi \qquad (6)$$

it is possible to judge the values of transfer factor Ki at individual levels.

4. Comparison of results

The properties of both arrays described above can be judged and compared according to a set of radiation pattern. The patterns enable to observe both, the directional filtering and the main lobe deflection or degradation.

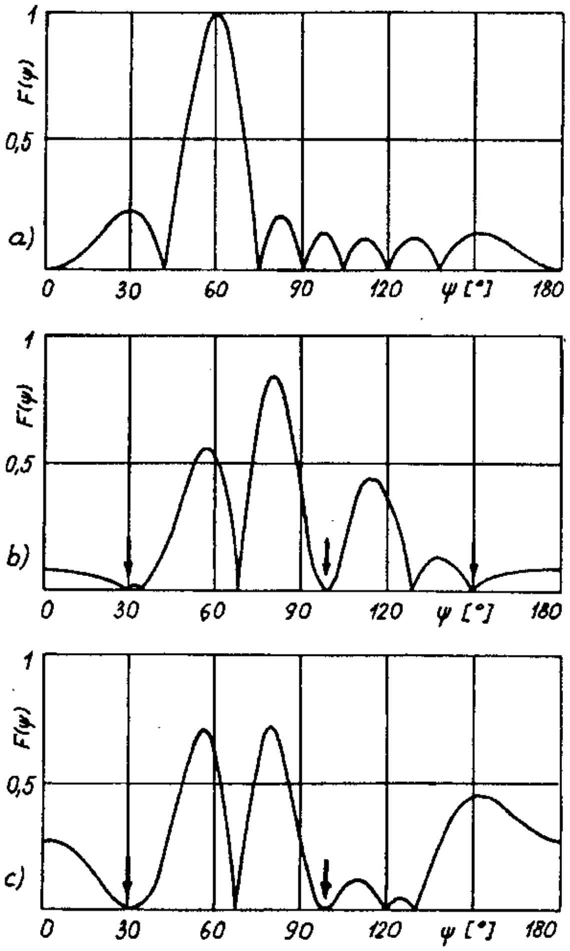

Fig.3
The radiation patterns of the complete array
a) the main lobe deflection (no interference)
b) the suppression of three interfering signals
c) the suppression of two interfering signals
The arrows mark points at the directions of zero reception

For the comparison, the following arrays have been chosen:the 8-element array according to Fig.1 and the 4-element array according to Fig.2. Both arrays enable to suppress 3 undesired signals.The chosen arrival angles of these signals are: $\psi_1 = 30°$, $\psi_2 = 100°$, $\psi_3 = 150°$. The desired signal comes from the direction $\psi_0 = 60°$. With respect to nearly equal frequencies of all signals, the differences of corresponding wave numbers can be neglected. The chosen antenna element separation is $d = \lambda/2$ and the directional pattern has only one maximum and one minimum at the first (lowest) level. The patterns have been calculated according to equations (1) and (4) omitting all the unimportant constants.

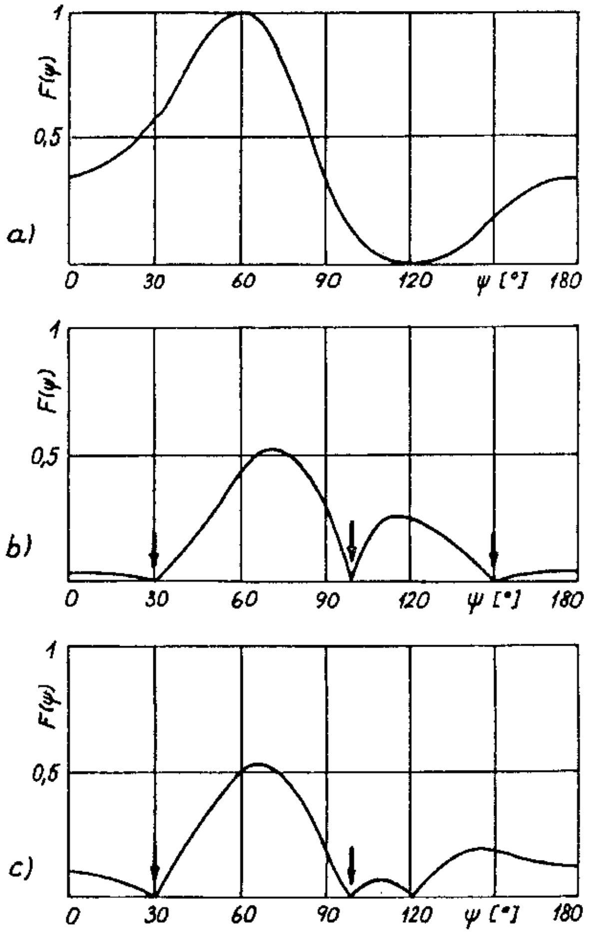

Fig.4
The radiation patterns of the array with shortened baseline.
a) the main lobe deflection (no interference)
b) the suppression of three interfering signals
c) the suppression of two interfering signals
The chosen directions of suppression are marked by arrows

The radiation patterns of the 8-element array (Fig.1.) are drawn in Fig.3. Let us discuss these results.

When the main lobe is set to the direction $\psi_0 = 60°$ (Fig.3a), several nulls appear on [illegible]tern and their directions are given by the condition (2) applied to individual levels. On the contrary, when the reception from all the chosen directions $\psi_1 \dots \psi_3$ is eliminated, the main lobe is deflected from the direction ψ_0 and the magnitude of the desired signal decreases. Its drop is about 6 dB and it is due to relatively small values of the differences $|\Phi_{0i} - \Phi_i|$ at all levels.When, unfortunately, the direction of some interfering signal lies within the limits of the main lobe of corresponding level, the signal drop can increase substantially. Finally, when the number of interfering signals is smaller than the number of levels, it is useful to set phases Φ_i at remaining levels according to eq. (3) - see the situation in Fig.3c, where only two signals in directions ψ_1 and ψ_2 are considered.

The radiation patterns of the 4-element array with shortened baseline (arranged according to Fig.2) are drawn in Fig.4. Let us remind that this array has three levels of signal processing and three independent directions of zero reception like the complete system.

In Fig.4a, the pattern without any interference is shown. The main lobe has been orientated to the direction $\psi_0 = 60°$ by setting the phase shift Φ_0 according to eq. (6) at all three levels of signal processing. The pattern has a main lobe and a single rather wide minimum only. This phenomenon is due to equal phase center separation $d = \lambda/2$ at all levels.

When the phase shifts at individual levels are set in such way so that all the three undesired signals may be eliminated, the pattern drawn in Fig.4b is obtained. It is evident that the main lobe is deflected and the magnitude of the desired signal is lower. When the number of interfering signals is smaller than the number of array levels, it is useful to set phases Φ_i at all remaining (not employed) levels according to equation (6).

The results can be generalized in the following way. The array with shortened baseline is shorter and needs less antenna elements in comparison with the complete array having the same number of levels. If the number of levels $M > 3$, this array needs also less phase shifters and summing and splitting elements. On the contrary,the array with shortened baseline gives substantially smaller output voltage. The reason is in fact that this array has less antenna elements and that a part of energy is lost in attenuators. But the last property need not be a decidive one if the received signal level is sufficiently high.

5. Conclusion

The properties of one type of phased array are deduced in this paper. Due to progressive phasing, the array enables to set several directions of zero reception independently each other. Two alternative arrangements of the array are described and their properties are presented and compared in numerical way. The array of the described type can be applied in various problems of spacing filtering.

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Zdeněk Nováček was born in Kamenná, Czechoslovakia, in 1945. He received the M.E. degree in electrotechnical engineering from VUT Brno, in 1969 and Ph.D. degree in radioelectronics from VUT Brno, in 1980. He is currently the senior lecturer at the department of radioelectronics of the VUT Brno. Research and pedagogical interests: Antennas and propagation of radio waves (signal processing antennas, antenna measurements).