Null Pattern Synthesis of Ferroelectric Smart Antennas

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Abstract **In this paper, new method of null pattern synthesis of antenna arrays without phase shifters and attenuators has been presented. This concept is based on utilizing voltage-controlled ferroelectric array, where variable pattern of each antenna element is used to synthesize array pattern with desired nulls.**

I. INTRODUCTION

In modern radio systems smart beamforming is often required. Communications antennas must offer a large number of operating modes (including pencil and shaped beams with fast switching between them) in order to ensure the best coverage of the service area. Therefore, in designing smart antennas, one of the main challenges is to provide a prescribed shaped antenna pattern that simultaneously suppresses interference signals (which locations are either known or unknown). As a rule, this problem is solved with the use of phased-array antennas. When the interference directions are known, one can synthesize the required pattern by introducing an appropriate amplitude-phase distribution across the array aperture.

Phased-array antenna can steer transmitted and received signals without mechanically rotating the antenna. This type of array consists of multiple stationary antenna elements, which are fed coherently and use variable phase or time-delay control at each element to scan the beam to given angles in space. Variable amplitude control is sometimes also provided for pattern shaping. A typical phased-array antenna may have many elements. Performance of each radiating element has significant influence on the parameters of antenna array, e.g. pattern, beamwidth, directivity, gain, sidelobes, cross-polarization levels, etc. The aim of this paper is to present new array pattern synthesis method by taking into consideration pattern of each radiator specially of the ferroelectric one. Radiating elements employing ferroelectric materials may give much better performance compared with ferrite ones, because of their high power handling capability, low drive power, full military temperature range of operation and low cost [1, 2]. The main feature of the ferroelectric antennas is the change of ferroelectric material permittivity with an applied dc control voltage. The permittivity change (by varying the dc bias) enables to create different radiation patterns. This permits to use such radiating element in several applications, e.g. smart antenna arrays. The main objectives of any smart antenna system are reduction of intersymbol interference, removal of co-channel interference, mitigation of adjacent-channel interference, enhancement of the spectrum efficiency, improvement of bit error rate, reduction of outage probability, improvement of transmission efficiency and reduction of hand-off rate and crosstalk. These objectives may be accomplished through steering nulls in the direction of co-channel interference and multipaths, steering a beam toward the user's direct path or direct and multipaths, thus increasing the signal-to-interference-and-noise ratio at the array output. A linear N-isotropic element array has N-1 degrees of the freedom. Therefore, it is possible to have N-1 independent control nulls pattern. If the pattern of the radiating nonisotropic element has two control nulls, then the linear N-nonisotropic element array has N+1 control nulls (e.g., two more degrees of freedom). This permits to shape assignment pattern for phased arrays and smart antenna.

In this paper, new method of null pattern synthesis of antenna arrays without phase shifters has been presented. This concept is based on the utilizing voltage-controlled ferroelectric array, where pattern of each antenna element is used to synthesize array pattern with desired nulls.

II. NULL PATTERN SYNTHESIS

In conventional form (Fig.1) output signal of antenna *y(t)* can be written as:

$$y(t) = \sum_{n=1}^{N} w_n x_n(t) = \sum_{n=1}^{N} w_n s(t) e^{ikd_n \sin\theta} \quad ,(1)$$

where $x_n(t)$ - input signal of antenna; $s(t)$ - input signal envelope level; $k=2\pi/\lambda$.

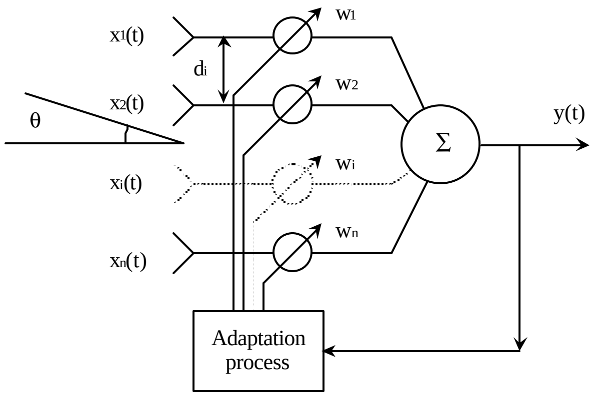

Fig.1. N elements structure of adaptive array

The other way radiation pattern of array (plane $\varphi=\pi/2$) can be written as:

$$F(\theta)=\sum_{n=1}^{N} f_n(\theta)e^{ikd_n\sin\theta}\ , \qquad (2)$$

where $f_n(\theta)$ - radiation pattern of each radiator.

Proposed pattern synthesis method (or null pattern synthesis) is based on searching for appropriate shape radiation pattern for each radiator $f_n(\theta)$. If radiation pattern of each element can be modified, than overall antenna radiation pattern can be synthesized. Ferroelectric radiator has been proposed as a single element of array in [1, 2]. Fig.2 shows section of an array with two ferroelectric elements.

Let current distribution along of the radiation J_x^e be a sinus and cross distribution be constant. For analyzing the multilayered substrate can be represented with a single layer characterized by effective electrical permittivity ε_{ef}.

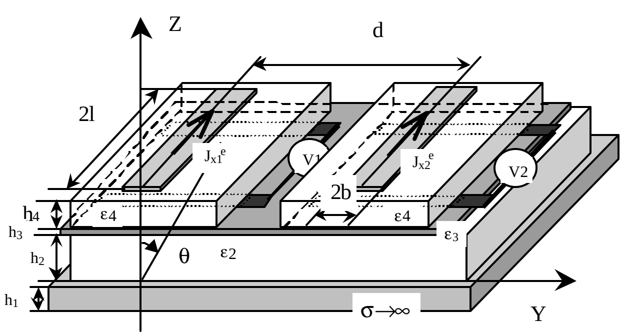

Fig.2. Section of ferroelectric array with two elements

The radiated power of the single radiator, in this case, can be written as

$$P(\theta,\varphi)=\frac{60\cdot\left(I_x^e\right)^2}{\pi\cdot\sin^2(2\pi l)}\cdot \cdot\left\{\frac{\left(\varepsilon_{ef}-\sin^2\theta\right)\cdot\cos^2\varphi}{T_m(\theta)}+\frac{\sin^2\varphi}{T_e(\theta)}\right\}\cdot \cdot\cos^2\theta\cdot\Psi^2(b,l,\theta,\varphi)\,, \qquad (3)$$

where

$$\Psi^2(b,l,\theta,\varphi)=\left\{\frac{\sin\left(2\pi b\cdot\sin\theta\sin\varphi\right)}{2\pi b\cdot\sin\theta\sin\varphi}\right\}^2\cdot \cdot\left\{\frac{\cos\left(2\pi l\cdot\sin\theta\cos\varphi\right)-\cos(2\pi l)}{1-\sin^2\theta\cos^2\varphi}\right\}^2,$$

$$T_m(\theta)=\varepsilon_{ef}^2\cos^2\theta\, ctg^2\left(2\pi h\sqrt{\varepsilon_{ef}-\sin^2\theta}\right)+ +\left(\varepsilon_{ef}-\sin^2\theta\right),$$

$$T_e(\theta)=\left(\varepsilon_{ef}-\sin^2\theta\right)ctg^2\left(2\pi h\sqrt{\varepsilon_{ef}-\sin^2\theta}\right)+ +\left(\cos^2\theta\right).$$

Fig.3 and Fig.4 show calculated magnitude and phase radiation patterns in ZOY plane as a function of the effective electrical permittivity. It can be seen that variation of the magnitude is in the range from 0 to 1 and variation of the phase takes values from 0 to $-\pi$. Those variations are very important for pattern synthesis by proposed method. The radiation pattern of the single ferroelectric element (change of effective electrical permittivity from 6 to 7; thickness $h=0.2\lambda$) has been presented in [1, 2]. Important feature of this radiation pattern is presence of nulls, which location can be changed.

Let array consist of the ferroelectric elements.

The radiation pattern of the linear antenna array is

$$F(\theta,\varphi)=\sum_{n=1}^{N} I_n\left|f_n(\theta,\varphi)\right|\cdot\exp\left[i\psi_n(\theta,\varphi)\right]\cdot \exp\left[ikd_n\sin\theta\right], \qquad (4)$$

where $k = 2\pi / \lambda$; d is element spacing; I_n is the complex excitation and $\left|f_n(\theta,\varphi)\right| \cdot \exp\left[i\psi_n(\theta,\varphi)\right]$ is the radiation pattern of the n-th element. If all elements of the array are similar then array radiation pattern is

$$F(\theta,\varphi) = \left|f_0(\theta,\varphi)\right| \cdot \exp\left[i\psi_0(\theta,\varphi)\right] \cdot \sum_{n=1}^{N} I_n \exp\left[ikd_n \sin\theta\right], \tag{5}$$

where $\sum_{n=1}^{N} I_n \exp\left[ikd_n \sin\theta\right]$ is a space factor or radiation pattern of the isotropic elements linear array. A linear N-isotropic elements array has (N-1) degrees of the freedom. Therefore, it is possible to have (N-1) independent control nulls pattern. If the pattern of the radiating nonisotropic element has two control nulls, then the linear N-nonisotropic elements array has (N+1) control nulls (e.g., two more degrees of freedom). This permits to shape required pattern.

Fig.5 and Fig.6 shows possible null placement in radiation pattern (three elements array with element spacing $d=0.75\lambda$) for different effective electrical permittivity values on each radiator. The permittivity ε_1 is

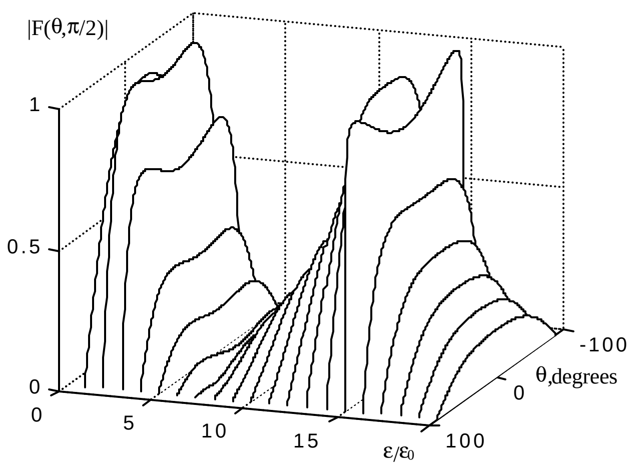

Fig.3. Amplitude radiation pattern as a function of permittivity

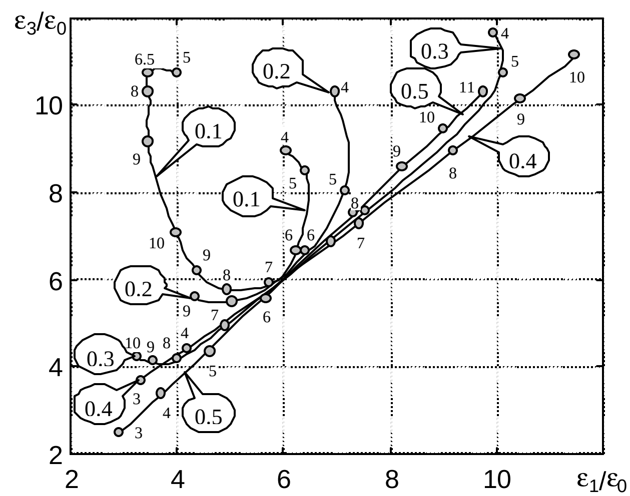

Fig.5. Desired null location in radiation pattern (from 0.1 to 0.5) for different values of the effective electrical permittivity on each radiators

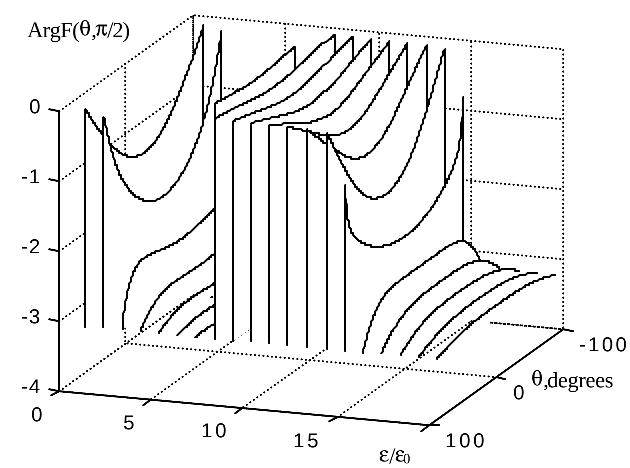

Fig.4. Phase radiation pattern as a function of permittivity

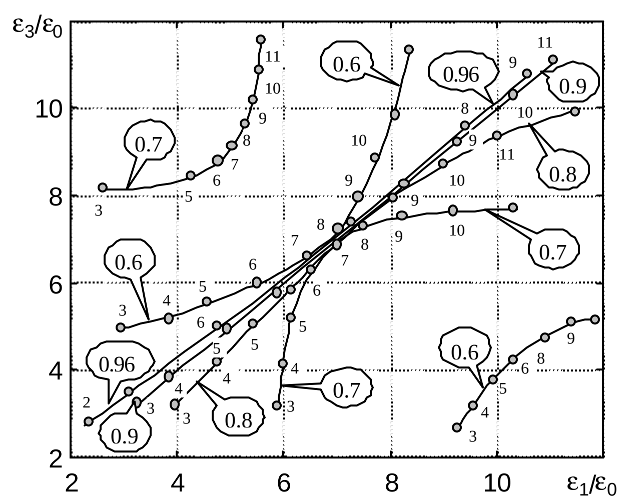

Fig.6. Desired null location in radiation pattern (from 0.6 to 0.96) for different values of the effective electrical permittivity on each radiators

changing along axis X, the permittivity ε_3 - along axis Y and permittivity ε_2 is marked on the plane with numbers 4, 5, ... 10 ... for different values of $\sin\theta_z$, where θ_z is desired null location in radiation pattern. These values change from 0.1 to 0.5 on Fig.5 and from 0.6 to 0.96 on Fig.6.

It can be seen, that general solutions are possible by change of effective electrical permittivity from 5 to 8. Those solutions conform to desired nulls location radiation pattern.

III. SIMULATION RESULTS AND COMPARISON

In Fig.7 and Fig.8 are given as examples of radiation patterns of three element arrays with assumption that desired direction of attenuation is given.

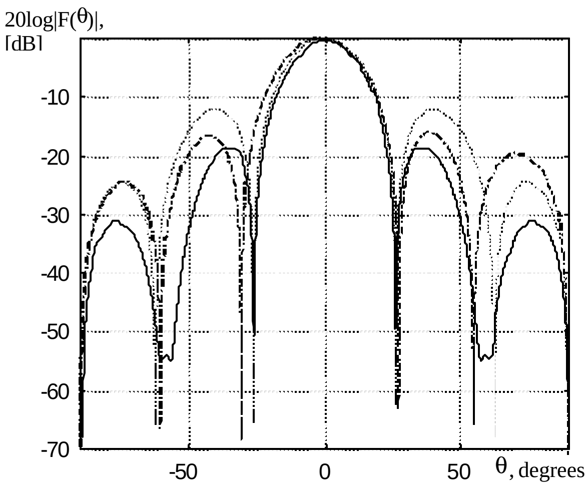

Fig.7. Radiation pattern of three element ferroelectric array with null location at angle 55^0. Permittivity on each radiator are $\varepsilon_1/\varepsilon_0$=6.9286; $\varepsilon_2/\varepsilon_0$=6.9127; $\varepsilon_2/\varepsilon_0$= 6.9206 (solid line - synthesized array, dashdot line - Applebaum's array, doted line - synphased array).

Fig.7 shows radiation pattern with null at angle 55^0, and Fig.8 - at angle 37^0. Moreover, Fig.7 and Fig.8 show radiation patterns of conventional array before and after adaptation (by Applebaum method). In these cases it was assumed that radiation pattern of single element is $f_0(\theta)=cos(\theta)$ and element spacing is $d=0.75\,\lambda$.

Examples plots obtained by new method of null pattern synthesis of antenna arrays (without phase shifters and attenuators) embody the following characteristics:

- directivity D_s of synthesized pattern is higher than directivity D_a of Applebaum's pattern - e.g. on Fig.7 D_s=10.1327dB and D_a=9.5561dB, and on Fig.8 D_s=10.3191 and D_a=9.2771, receptively;

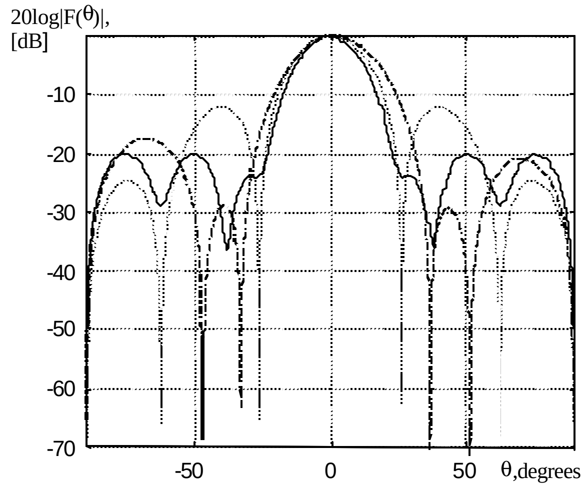

Fig.8. Radiation pattern of three element ferroelectric array with null location at angle 37^0. Permittivity on each radiator are $\varepsilon_1/\varepsilon_0$=6.6619; $\varepsilon_2/\varepsilon_0$=6.6079; $\varepsilon_2/\varepsilon_0$= 6.5667 (solid line - synthesized array, dashdot line - Applebaum's array, doted line - synphased array).

- width of main lobe of synthesized pattern is less than width of main lobe of Applebaum's pattern and it is nearly equal to width of main lobe of synphased array;
- side lobes level (SLL) in synthesized pattern is lower than SLL of Applebaum's pattern;
- the attenuation of signal in desired direction in some cases is less than in Applebaum's method.

IV. CONCLUSION

New method of null pattern synthesis of antenna arrays without phase shifters and attenuators has been presented. This concept is based on utilizing voltage-controlled ferroelectric array, where pattern of each antenna element is used to synthesize array pattern with desired nulls. It was shown that antenna array can provide higher directivity, narrower main lobe and lower side lobes level than conventional phased array.

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[2] J. Modelski, Y.Yashchyshyn, "Investigation of the microstrip antenna on ferroelectric substrates", *30th EuMC*, France, Paris, October 1-6, 2000, p.162-165.

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