# Multipanel Concept for Wide-Angle Scanning of Phased Array Antennas

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*Abstract* — **A method for scanning of the main beam of phased array antennas in wide angular range is presented. The method utilizes several smaller flat antenna panels working at boresight and pointed in the direction of the main beam of overall antenna. The output signal of the overall antenna is summation of the signals from all antenna panels. Investigation of the array performance of such structure with respect to the distance between panels is presented.**

*Keywords* — **Phased arrays, scanning antennas, sub array architecture of a phased array**

## I. INTRODUCTION

Commercial scanning phased array antennas has gained significant role in the last decade since the advent of high power satellites. Their main application is mobile TV reception. Mobile applications require wide angle scanning low cost arrays. Sub-array architecture is one of the approaches for decreasing the cost of the array, because one phase control device is used for a group of radiators called sub-array [1], [2]. Difficulties in realization of wide angle scanning flat phased arrays with sub-array architecture are mainly connected with scan losses at low elevation angles due to the pattern of the sub-array [1], [3] and grating lobe level due to the sub-array architecture [3], [4], [5], [6].

This paper emphasizes on a different approach for wide angle scanning phased arrays. The flat aperture of the array is divided of number of smaller parts or panels. Each panel is separate sub-array with its main beam mechanically slanted in the direction of the main beam of the antenna and all sub-arrays form the aperture of overall phased array. Distance between panels is changed each time when direction of the main beam of the antenna is changed, so that parasitic grating lobes due to equivalent array of panels are suppressed. Phase control is applied on panels for steering of the array factor of the equivalent array of panels.

## II. MATHEMATICAL BACKGROUND AND ANALYSIS

Further in the analysis linear array of slanted panels is considered for simplicity of the derivations. Transition to 2D slanted panels is straightforward. Schematic diagram of the considered phased array is presented on Fig. 1.

Expression for the electric far field using the principle of superposition of the radiations from the radiating elements is as follows [1]:

$$\vec{\mathbf{E}} = \sum_{n=1}^{N} \dot{A}_n \left[ E^e_{\theta_n}(\theta,\varphi)\vec{i}_\theta + E^e_{\varphi_n}(\theta,\varphi)\vec{i}_\varphi \right] exp\left( j\,\vec{\mathbf{k}}.\vec{\mathbf{r}}_\mathbf{n} \right) \quad (1)$$

where $\vec{\mathbf{k}}$ is the wave vector, $\vec{\mathbf{r}}_\mathbf{n}$ is the position vector of each radiating element, $E^e_{\theta_n}(\theta,\varphi)$ and $E^e_{\varphi_n}(\theta,\varphi)$ represent radiation pattern of the n^th^ radiating element for the two orthogonal components of the field. The following expressions are valid for $\vec{\mathbf{k}}$ and $\vec{\mathbf{r}}_\mathbf{n}$ :

$$\begin{aligned} \vec{\mathbf{k}} &= k\,sin(\theta)\vec{i}_x + k\,cos(\theta)\vec{i}_z \\ \vec{\mathbf{r}}_\mathbf{n} &= x_n\,\vec{i}_x + z_n\,\vec{i}_z \end{aligned} \quad (2)$$

where $x_n$ and $z_n$ are coordinates of the radiating elements; $\vec{i}_x$ and $\vec{i}_z$ are unity vectors.

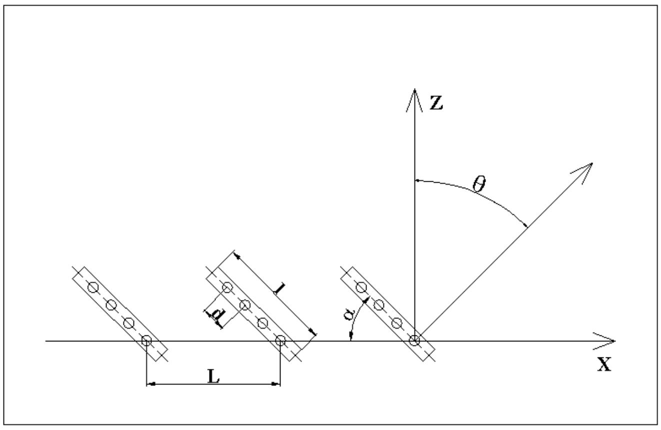

Fig. 1: Shematic diagram of multipanel linear phased array antenna

If all patterns of the radiating elements in are the same, array factor can be extracted from Eq. (1) in the form [1]:

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$$F = \sum_{n=1}^{N} \dot{A}_n \exp\left( j\,\vec{\mathbf{k}}\,.\,\vec{\mathbf{r}}_{\mathbf{n}} \right) \tag{3}$$

where $\dot{A}_n$ are complex coefficients comprising amplitude and phase excitation of the radiating elements.

For further analysis lets assume that the number of radiating elements for each panels is P and total number of antenna panels is S. If $\alpha$ is the angle, shown on Fig. 1, the following expression for the coordinates of the radiating elements is valid:

$$\begin{aligned} x_n &= -mL - qd\cos(\alpha); \\ z_n &= qd\sin(\alpha) \\ m &= 1 \ldots S; q = 1 \ldots P \end{aligned} \tag{4}$$

Using relations given with Eq. (4), expression for the array factor could be written in the form:

$$F(u) = \left\{ \sum_{q=1}^{P} \dot{E}_q \exp[2\pi j(q-1)u] \right\} \times \left\{ \sum_{m=1}^{S} \dot{S}_m \exp[2\pi j(m-1)u_s] \right\} = Fe(u)Fs(u_s) \tag{5}$$

where

$$u = \frac{d}{\lambda}\sin(\theta - \alpha); u_s = \frac{L}{\lambda}\sin\theta \tag{6}$$

Eq. (5) has two terms. The term $Fe(u)$ describes array factor of the single panel slanted on angle $\alpha$, whilst $Fs(u_s)$ describes array factor of equivalent array of slanted panels separated at distance $L$. Since distance between slanted panels is far greater than distance between radiating elements in each panel ($L >> d$), oscillations of the function $Fs(u_s)$ are much more than those of $Fe(u)$ as it can be seen on Fig. 2 a). Maximum of the array of the single panel $Fe(u)$ appears at angle $\alpha$, which is the slanted angle of the panels. There are not additional maximums caused by the term $Fe(u)$. The term $Fs(u_s)$ has one main beam and normally more than one grating lobes, because distance $L$ is far greater than wavelength. Principle of operation of the array of slanted panels is that grating lobes caused by the array factor of the equivalent array of panels, with distance $L$ between elements ($Fs(u_s)$), are suppressed by the pattern of the array factor of the single panel ($Fe(u)$). In order to obtain good shape of overall pattern of the antenna, additional phase should be applied on each slanted panel so that position of the main beam of the array factor $Fs(u_s)$ to coincide with the peak of the function $Fe(u)$. Phase difference between adjacent slanted panels is easily calculated having the distance between panels $L$ and angle $\alpha$:

$$u_s^0 = \frac{L}{\lambda}\sin\alpha \tag{7}$$

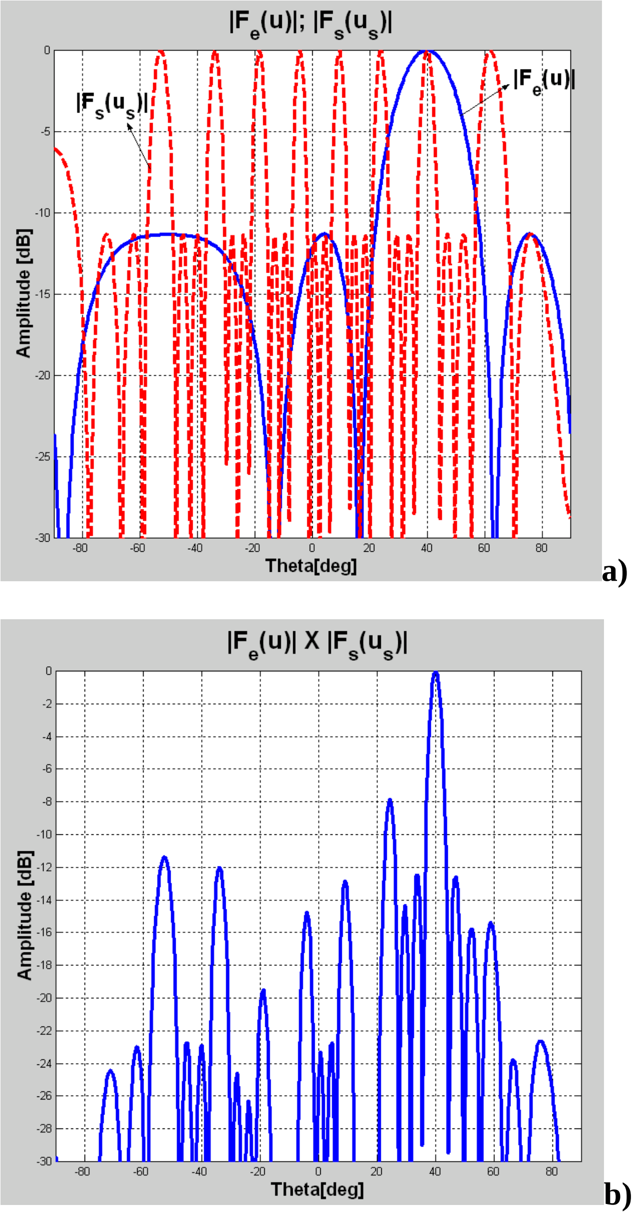

Fig. 2: Graphs of the partial array factors and overall array factor for $d = 15[mm]$, $\lambda = 24[mm]$, $L = 100[mm]$, $P = 4$, $S = 4$: a) - $Fe(u)$ and $Fs(u_s)$; b) - $F(u)$

Using the phase difference defined by Eq. (7) the array factor of overall antenna can be written in the form:

$$F(u)=\left\{\sum_{q=1}^{P}\left|\dot{E}_q\right| exp\left[2\pi j(q-1)u\right]\right\}\times \left\{\sum_{m=1}^{S}\left|\dot{S}_m\right| exp\left[2\pi j(m-1)\left(u_s-u_s^0\right)\right]\right\} \tag{8}$$

where $\left|\dot{E}_q\right|$ and $\left|\dot{S}_m\right|$ take into account magnitude excitation of radiating elements within panel and magnitude excitation of each panel respectively.

An important question is determination of the distance between slanted panels - $L$, corresponding to a given angle $\alpha$ so that good shape of the pattern to be obtained. A criterion for good pattern shape could be ratio between main beam and the highest sidelobe (peak sidelobe) - $b_m$, given in [dB]. Since the pattern of the single panel - $Fe(u)$, is relatively sharp, the first grating lobe of the function $Fs(u_s)$ is of importance for the peak sidelobe level of overall antenna – Fig. 2 a). Positions of the grating lobes of the function $Fs(u_s)$ are determined from the periodicity of the sine function:

$$2\pi\left(u_s^p-u_s^0\right)=-2p\pi \tag{9}$$

where $p$ is the number of the grating lobe. The position of the first grating lobe is obtained from Eq. (9), substituting $p=1$:

$$\theta_s^P = arcsin\left(sin\,\alpha-\frac{\lambda}{L}\right) \tag{10}$$

Having determined the position $\theta_s^P$ of the first grating lobe of $Fs(u_s)$ and given the ratio $b_m$, the equation for determination of the distance between panels could be written in the form:

$$\frac{F(u)_{\theta=\alpha}}{F(u)_{\theta=\theta_s^P}}=\left|\frac{1}{Fe(u)_{\theta=\theta_s^P}}\right|\geq 10^{\frac{b_m}{20}} \tag{11}$$

It is taken into account in Eq. (11) that $Fs(u_s)_{\theta=\theta_s^P}=Fs(u_s)_{\theta=\alpha}=F_e(u)_{\theta=\alpha}=1$. For uniform excitation of the array, Eq. (11) takes the form:

$$\frac{P\,sin\left(\pi u_{\theta=\theta_s^P}\right)}{sin\left(\pi P u_{\theta=\theta_s^P}\right)}-10^{\frac{b_m}{20}}\geq 0 \tag{12}$$

which together with Eq. (10) is used for determination of the distance between panels for uniform excitation. The function for determination of the distance between panels could be designated as $W$, which is the left side of the Eq. (12):

$$W=\frac{P\,sin\left(\pi u_{\theta=\theta_s^P}\right)}{sin\left(\pi P u_{\theta=\theta_s^P}\right)}-10^{\frac{b_m}{20}} \tag{13}$$

For values of $W$ greater than zero, sidelobes of the array factor are less than the value specified by $b_m$.

There is one more restriction when determining the distance between panels $L$. Looking from the direction $\alpha$ in order not to exist overshadowing between panels, the following condition should be satisfied for the distance $L$:

$$L\geq\frac{l}{cos\,\alpha} \tag{14}$$

where $l$ is transversal dimension of the panel. It may happen that value of $L$ determined using (12) to be less than that determined by (14). This normally happens when desired level of the sidelobes is very low. This leads to placement of the panels close to each other and overshadowing is significant. Practically overshadowing of 20% could be accepted for normal operation of the array, which leads to values of $b_m$ of order of -10÷-12 dB.

## III. SIMULATION RESULTS

The theory above has been used for simulation and determination of the distance between panels $L$ of an array antenna comprised of four slanted panels according to Fig. 1. The antenna has been simulated at 12.5GHz. The single panel contains four radiating elements with distance between them $d=0.625\lambda$. Array factor of the single panel ($Fe(u)$) slanted at angle $\alpha=40[deg]$ is shown on Fig. 2 a). On the same figure is shown also array factor of the equivalent array of slanted panels ($Fs(u_s)$) for the distance between slanted panels $L=4.17\lambda=100[mm]$. On Fig. 2 b) multiplication of the two array factors is shown, which is the total array factor of the array.

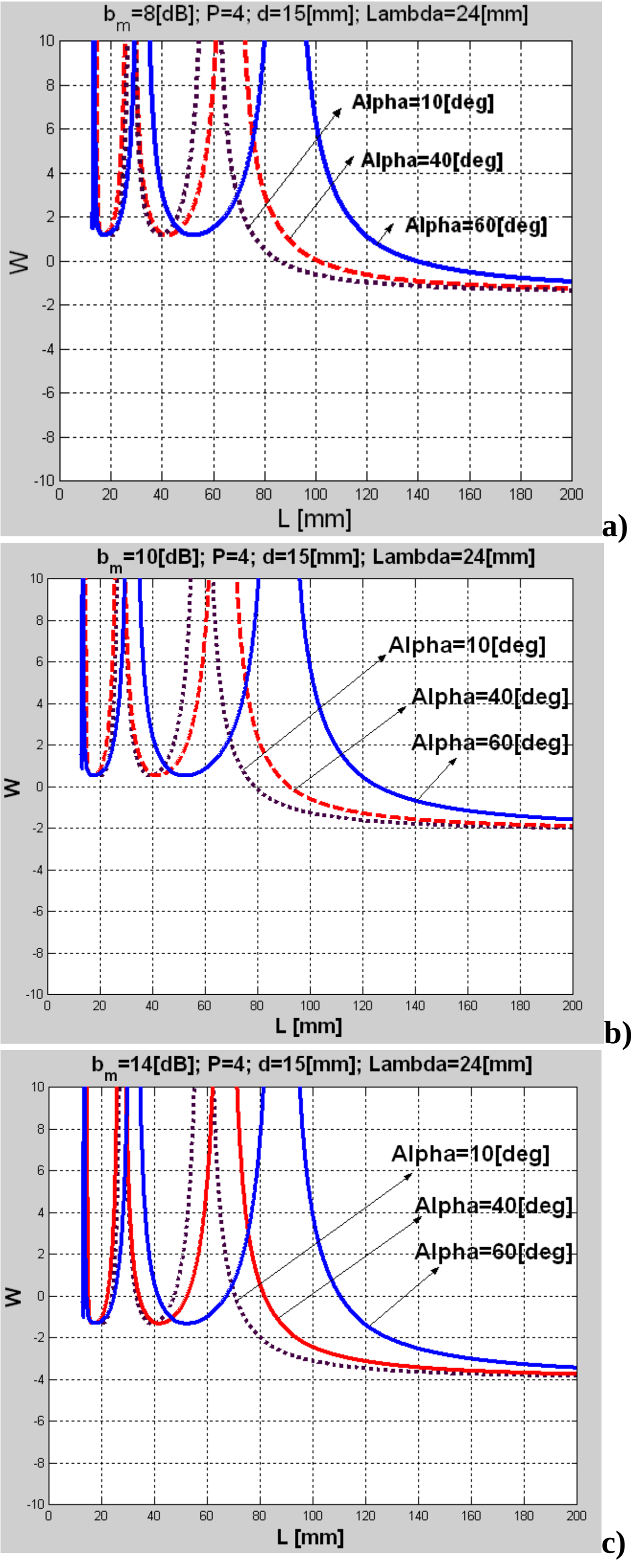

Fig. 3: Graph of the function W for different values of slant angle $\alpha$, $d = 15[\,mm\,]$, $P = 4$, $\lambda = 24[\,mm\,]$ for the values of the ratio $b_m$ as follows: a) - $b_m = 8[\,dB\,]$; b) - $b_m = 10[\,dB\,]$; c) - $b_m = 14[\,dB\,]$

Graph of the function $W$, given with Eq. (13), for the simulated array is shown on Fig. 3 a), b) and c) for different values of the slant angle $\alpha$ and different ratios $b_m$. Crossing between $W$ curve and x-axes gives the distance $L$, for which sidelobes of the array factor are exatly the value specified by $b_m$. For values of $b_m$ lower than the level of sidelobes of the function $Fe(u)$ there are several crossings of the x-axes and the function $W$. This could be explained having in mind that the grating lobe follows the shape of the pattern of one panel ($Fe(u)$). On Fig. 3 a) and b) ratio $b_m$ is above the peak sidelobe level of the single panel, while on Fig 3 c) $b_m$ is below that level.

## IV. DISCUSSION AND CONCLUSION

An effective method for scanning of the main beam of phased array antennas containing several slanted flat panels has been presented. Analysis of the array factor of such construction of a phased array has been performed. Dependence of the array factor of overall array with respect tot the distance between slanted antenna panels has been investigated. Equation has been proposed for determination of the distance between antenna panels given the ratio between main beam of the array and the first grating lobe levels. Simulation results utilizing the theory have been presented.

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