An Antenna Array Synthesis for Large Vertical Aperture Antenna for Secondary Surveillance Radar

Tomas Zalabsky, Tomas Hnilicka
University of Pardubice
Pardubice, Czech Republic
tomas.zalabsky@upce.cz, tomas.hnilicka@student.upce.cz

***Abstract*— This paper briefly deals with a structure of a Signal distribution network for a Secondary surveillance radar. Three typical radiation beams (Sum, Difference and Control) are described. The antenna array synthesis of a Sum beam is performed. The structure of a critical part of a horizontal signal feeder (Central distribution network) is described. This part allows to create a Difference and a Control beams. The sensitivity analysis of the impact of the variations of amplitude of a signal at the outputs of the horizontal distribution network and sensitivity analysis of the impact of the variations of phase of a signal at the outputs of the horizontal distribution network are performed.**

Keywords—LVA antenan, Antenna array synthesis, Secondary surveillance radar, Antenna feeders

I. Introduction

Design of radars for Air Traffic Control (ATC) have a long tradition in the Czech Republic. Secondary Surveillance Radars (SSR) were built and supplied to many countries all over the world [1], [2] and [3]. It is still possible to search for new technologies that will allow achieve better parameters and reduce production prices. This paper deals with an antenna array synthesis for Large Vertical Aperture (LVA) antenna for Secondary Surveillance Radar and briefly outlines the proposal of a horizontal signal feeders.

The antenna of this secondary surveillance radar as a planar antenna array is designed. Consists of a total of 272 radiating elements (planar dipoles). These dipoles are arranged into 34 identical vertical columns. All of these columns contain 8 radiating elements. 33 vertical columns are oriented in the front direction and the last is oriented in reverse direction (is used for the control beam only). This antenna array creates three standard horizontal beams: the sum, the difference and the control beam of the secondary radar (fig. 1).

For achieving the desired radiating beams, the signal feeders are used. This LVA antenna contain two types of signal feeders - horizontal and vertical (fig. 2) For this paper are important only horizontal feeders, which the sum, the difference and the control beam in horizontal plane create. The required shapes of radiating beams in the horizontal plane is given by the setting of amplitudes and phases of a signals on the individual outputs of a horizontal distribution network (horizontal feeders).

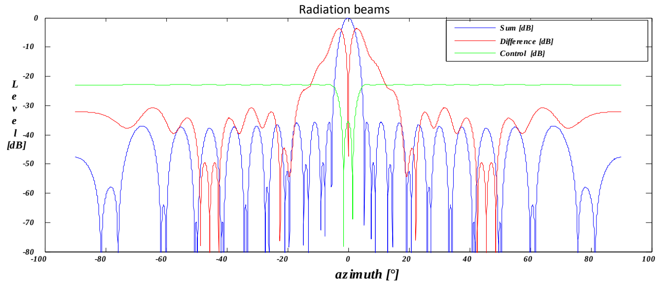

Fig. 1. Typical three beam radiation pattern of SSR

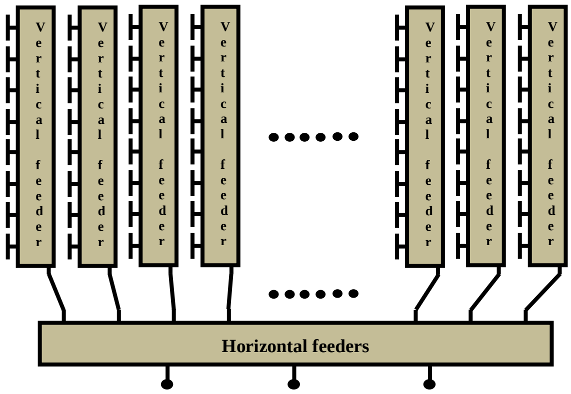

Fig. 2. Signal distribution network for SSR

II. Synthesis of an Antenna Array

Based on the normatives [4], [5] and [6], the fundamental technical parameters of antenna system has been determined. Parameters that has been used for antenna synthesis are in table I.

TABLE I. THE FUNDAMENTAL PARAMETERS OF LVA ANTENNA

Parameter	**Value**	**Notice**
Horizontal beamwidth	*2.4 °*	*-3dB*
Gain of whole antenna	*27 dBi*	*Sum beam*
Frequency	*1030 ± 0.2 MHz* *1090 ± 3 MHz*	
Side lobe level	*-27 dB*	
Zero level of Dif beam	*-30 dB*	
Cross level Sum - Dif	*3.5 ± 0.25 dB*	

To design the sum antenna beam a Taylor synthesis was used. The Taylor $\bar{n}$ distribution provides a certain number of equal sidelobes, symmetrically located on both sides of the main beam with the amplitudes of the remaining sidelobes decreasing monotonically. For a given design sidelobe level, the Taylor distribution provides narrowest beamwidth. The Taylor n amplitude distribution is of the form 1 [7].

$$A(x,A,\bar{n}) = \frac{1}{2\pi}\left\{F(0,a,\bar{n}) + 2\sum_{n=1}^{\bar{n}-1} F(n,A,\bar{n})\cos\frac{n\pi x}{L}\right\}$$

$$F(n,A,\bar{n}) = \frac{[(n-1)!]^2 \prod_{m=1}^{\bar{n}-1}\left(1-\frac{n^2}{\sigma^2[A^2+(-\frac{1}{2})^2]}\right)}{(\bar{n}-1+n)!(\bar{n}-1-n)!} \qquad (1)$$

Where x is distance from center of aperture, L is total length of aperture, A is $1/\pi \; arc\; cosh\; R$, R is designed sidelobe voltage ratio, $\bar{n}$ is number of equiamplitude sidelobes adjacent to main beam on one side.

$$\sigma = \frac{\bar{n}}{\sqrt{A^2 + (\bar{n}+\frac{1}{2})^2}} \qquad (2)$$

Corresponding to this amplitude distribution, the beamwidth of a one-wavelength source is given by equation (3)

$$\beta = \sigma\beta_0 \qquad (3)$$

where

$$\beta_0 = \frac{2}{\pi}\sqrt{(\text{arc cosh } R)^2 - \left(\text{arc cosh } \frac{R}{\sqrt{2}}\right)^2} \qquad (4)$$

For an array with aperture length L, the beamwidth is given by equation (5)

$$\text{Beamwidth } = \sigma\beta_0 \frac{\lambda}{L} \text{ rad} \qquad (5)$$

Application of equation 1 (input parameters R = -35 dB and $\bar{n}$ = 10) the following signal amplitude at each output horizontal distribution we received (table II.)

TABLE II. THE SIGNAL AMPLITUDES ON THE OUTPUTS OF HORIZONTAL DISTRIBUTION NETWORK

n	*-16*	*-15*	*-14*	*-13*	*-12*	*-11*	*-10*	*-9*
a_n	*0,32*	*0,32*	*0,36*	*0,45*	*0,57*	*0,69*	*0,81*	*0,93*
n	*-8*	*-7*	*-6*	*-5*	*-4*	*-3*	*-2*	*-1*
a_n	*1,06*	*1,17*	*1,29*	*1,39*	*1,47*	*1,54*	*1,60*	*1,63*
n	*0*	*1*	*2*	*3*	*4*	*5*	*7*	*8*
a_n	*1,64*	*1,63*	*1,60*	*1,54*	*1,47*	*1,39*	*1,17*	*1,06*
n	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
a_n	*0,93*	*0,81*	*0,69*	*0,57*	*0,45*	*0,36*	*0,32*	*0,32*

In table II the coefficient n is ranking of output of horizontal distribution network and coefficient a_n is an amplitude of an outputs signal. If we applicated this results into the equation for array factor (equation 6) we obtain the graphical version of an antenna factor - fig.3

$$AF = A_n e^{-j\Psi_n}\frac{e^{-j\frac{2\pi}{\lambda}R}}{R}e^{j\frac{2\pi}{\lambda}x_n sin\Theta} \qquad (6)$$

Where λ is a wavelength, R is distance in the space from the antenna arrays, A_n and Ψ_n are real numbers. A_n is an amplitude of n-th radiating elements and Ψ_n is phase of n-th radiating elements. Θ is azimuth angle.

$$x_n = n \cdot d \qquad (7)$$

Where n is ranking of radiated element and d is distance between individual radiating elements.

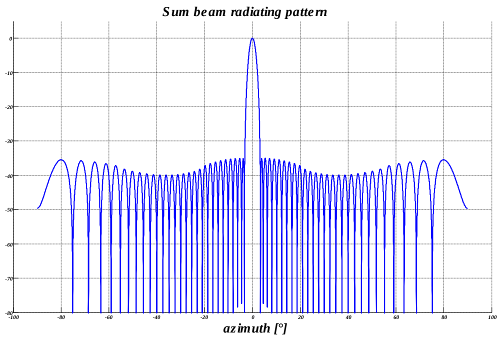

Fig. 3. Array factor of Sum beam

From the figure 3 it is obvious, that the resulting Sum radiation pattern meet the require parameters well. The sidelobe level suppresion is more than -33 dB and the half-power beamwidth is exactly 2.4°.

To create a Differences and a Control beam is necessary to select the appropriate central signal distribution network. The solution which has been selected for this LVA antenna is in the figure 4. The dividing ratios of the individual dividers are shown in Table III.

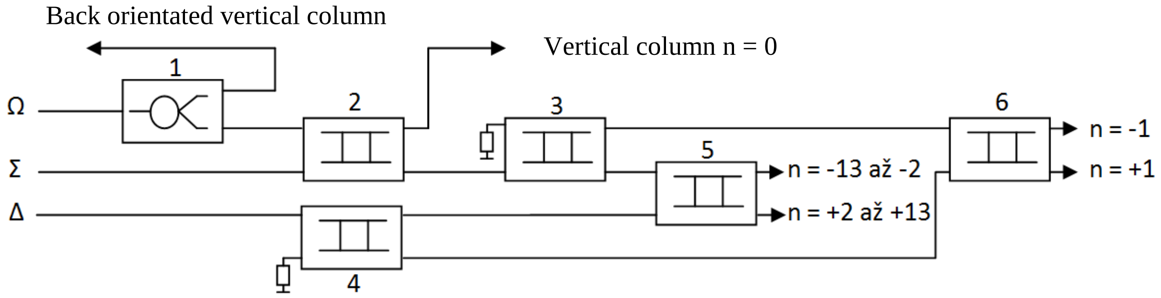

Fig. 4. Diagram of central distribution network of LVA antenna of aSRL

TABLE III. DIVIDING RATION OF THE POWER DIVIDERS IN THE CENTRAL DISTRIBUTION NETWORK

Power divider	Dividing ratio (power)		P1/P2 [dB]
1	0,5	0,5	0
2	0,066976	0,933024	11,43974
3	0,1418	0,8582	7,81913
4	0,043531	0,956464	13,4187
5	0,5	0,5	0
6	0,5	0,5	0

These dividing ratios resulting in the following radiation pattern of the differential beam – figure 5.

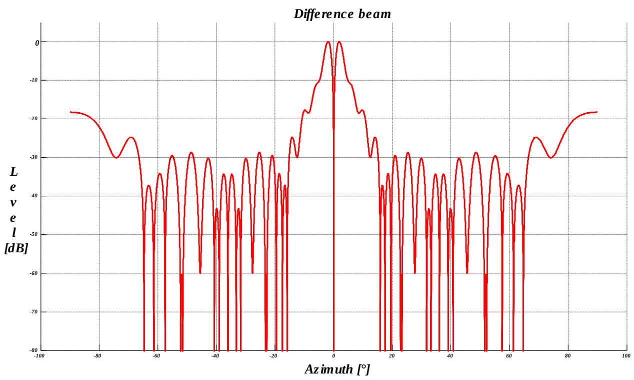

Fig. 5. Antenna array factor of difference beam of LVA antena of SSR

Increased the side lobes in the outer areas of the radiation pattern will be compensated by the diagram of the radiation dipole and also will be below the level of control beam of the antenna. The necessary comparison of the three antenna beams is shown in Figure 6.

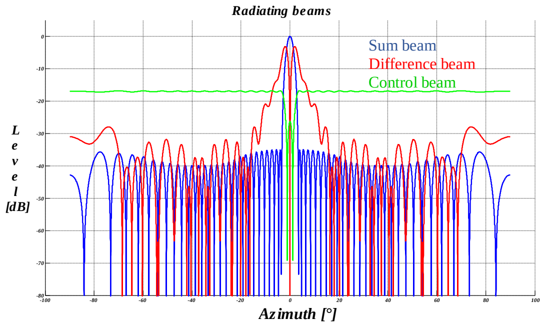

Fig. 6. Comparsion of all three radiating beams (array factors)

From the figure 6 it is apparent that the radiation diagrams well meet the criteria defined in the Table I.

III. SENSITIVITY ANALYSIS

A sensitivity analysis of the LVA SRL antenna can be divided into three parts: Analysis of the impact of the variations of amplitude of a signal at the outputs of the horizontal distribution network, Analysis of the impact of the variations of phase of a signal at the outputs of the horizontal distribution network and Analysis of the impact of failure of a particular vertical columns (Vertical feeder). First, an effect of a random changes in the amplitude of the signal at of the individual outputs of the horizontal feeders has been studied. Average of 20 realizations of a radiation diagram of the sum beam with a standard deviation of amplitudes ± 7% is shown in Figure 8.

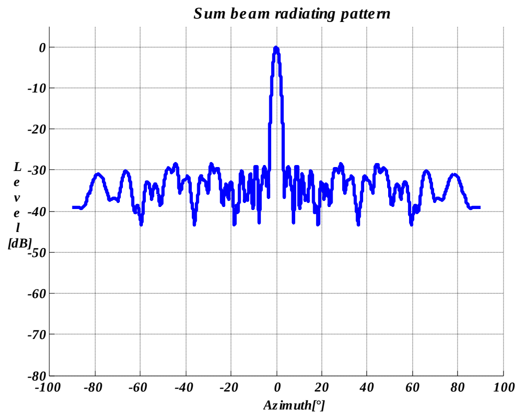

Fig. 7. Average of 20 realization of sum beam with standard deviation of an amplitude of ± 7%

The simulation for standard deviation of amplitude from 1 to 10 % has been performed. It is evident that with an increasing of standard deviation of the amplitude of the signal occurs to an increasing of side lobes of the sum beam. This increase is tolerable till to the values of standard deviation of an amplitude of a signal less than ± 7%.

Average of 20 realizations of a radiation diagram of the sum beam with a standard deviation of phases ± 7% is shown in Figure 8. In case of any random phase variation of a signal on individual outputs of horizontal distribution network (± 1 ° ± 3 ° ± 5 ° ± 7 ° and ± 10 °) does not change half power beamwidth of the main lobe of the sum beam. However, there is a change in sidelobes level. This increase is tolerable till to the values of standard deviation of a phase of a signal less than ± 7%.

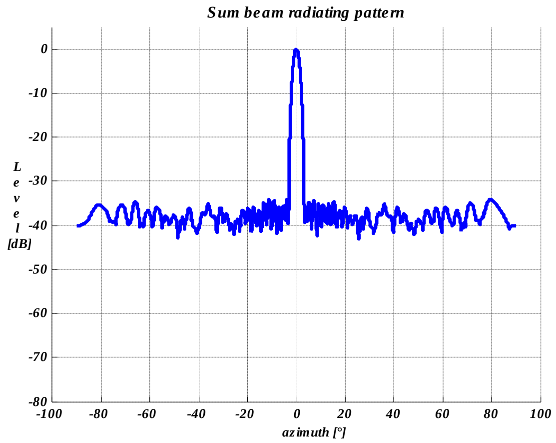

Fig. 8. Average of 20 realization of sum beam with standard deviation of a phase of ± 7%

Now will be describe the effect of failure of individual vertical columns of the antenna or the individual outputs of the horizontal distribution network of a SSR.

The failure of the outer outputs (Nos. 16 to 10) results in a slight extension of the main lobe to approximately 2.44°. In case of failure of other outputs closer to the center of the antenna, this value slightly decreases. In the case of failure of output No. 7, the 3dB beam width is again very close to 2.4 °. In case of failure of output No. 1 and No. 0 the 3dB beam width is already only 2.33 °. It can be stated that the failures of individual outputs of the horizontal distribution network do not have a significant effect at the 3 dB bandwidth of the main lobe of the sum beam.

The failure of individual vertical columns (outputs of horizontal distribution network) has a significant effect on the side lobe spacing. Most of the signal energy is output through the middle inputs. With increasing distance from the center of the antenna, the power output decreases. It is obvious that the failure of the outer outputs takes effect much less to change of the radiation pattern of the sum antenna beam of LVA SRL. Example of a change of SUM beam of radiation pattern with a failure of the third vertical column is shown in Figure 9.

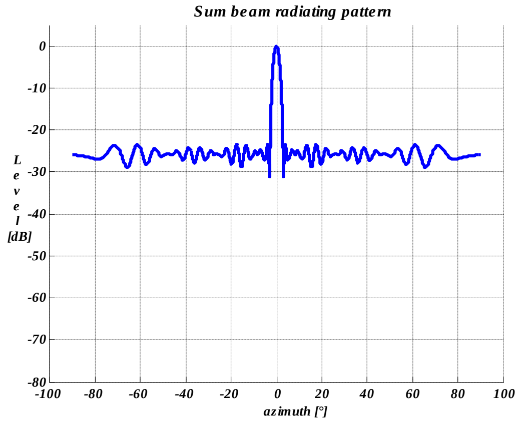

Fig. 9. Failure of the third vertical column

IV. Conclusion

In this paper, the structure of large vertical aperture antenna for secondary surveillance radar has been described. The synthesis of horizontal radiation pattern has been shown and methods of creation of a three radiation pattern were explained.

Based on the antenna synthesis, the sensitivity analysis of has been done. The effects of amplitude, phase and failure of individual vertical columns of the LVA antenna SRL on the radiation pattern of the sum beam in the horizontal plane were presented. Tolerable variations in amplitude are ± 7% and ± 7° in phase. These errors, however, will arise simultaneously. So, with the simultaneous occurrence of both amplitude and phase errors, signal amplitude error should not be greater than ± 5% and signal phase error should not be greater than ± 5°.

Acknowledgment

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Refereces

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