INFOTEH-JAHORINA Vol. 12, March 2013.

An Approach to Analysis of AESA Based Radio Systems

Predrag Jovanović, Mladen Mileusnić, Predrag Petrović
Department of Radio communication
IRITEL A.D.
Belgrade, Serbia
pesccia@iritel.com,

Abstract— **The analysis of radio system based on AESA (active electronically scanned arrays) technology has been presented in this paper. AESA transceiver module at 10 GHz has been described. Analysis in the paper is limited only to planar arrays. System design methodology has been divided into segments. In the first stage, overall architecture was examined. After that, system is decomposed in more details, studying basic modules separately. System model in software environment is created. Extensive simulations and behavioral analysis were carried out in order to gain insight into the influences of different parameters. Also, the suggested specification of the most important components which could be used is included. The results of AESA based system simulation at 10 GHz are shown.**

Keywords – Active electronically scanned arrays; Radiation pattern; Phase shifter; Software simulation;

I. INTRODUCTION

AESA (active electronically scanned arrays) technology has been appeared due to the great advances in solid state and digital electronics. The development of AESA based radio systems in X-band using Gallium Arsenide chips is especially important. AESA World Forum has been established in 2010 ten years after Software Defined Radio (SDR). The importance of AESA technology could be seen by exploring the limitations of conventional mechanically steered antennas and passive electronically scanned arrays (PESA). Mechanical rotation is very slow with low portability. PESA has been characterized by the weak resistance to jamming. That is why this new AESA technology is so promising replacing passive electronically scanned arrays. PESA was a dominant technology in the last few decades, but further development of solid-state and digital electronics enables the prerequisites for AESA systems applications. There are a lot of AESA systems advantages and useful features such as : 1) low probability of intercept, 2) high ECM resistance, 3) multiple of beams, 4) higher scanning speeds and operating ranges, 5) better sensitivity and detection, 6) lower weights and dimensions, 7) better reliability, 8) simple solutions for radiation patterns forms, 9) the use of suitable low power supplies, 10) higher adjustment speeds, and 11) better clutter rejection in radar applications. Signal emission is spread out across a wide band of frequencies, which makes it very difficult to detect over background noise. AESA technology is not very widely used today for commercial purposes mainly due to its military origin and high costs.

II. BASIC PRINCIPLES OF AESA TECHNOLOGY

Main principle of active electronically scanned arrays is constructive interference of radio waves at certain angles, separately emitted from elements of antenna panel [1]. Every element has its own excitation of certain amplitude and phase. These excitations are provided by means of amplifiers with variable gain (variable attenuators and fixed gain amplifiers), phase shifters and filters. Main advantage of AESA based radio systems relies on beam steering agility. Flexible scanning in wide range of angles is provided. AESA technology started with fast development owing to Gallium Arsenide microwave monolithic integrated circuits. This technology enabled the low cost mass production of AESA based radio systems with high reliability and repeatability.

III. ANALYSIS OF AESA BASED RADIO SYSTEM

Analysis of radio system based on AESA technology is divided into number of steps. The first step is to define the basic architecture to start with. General architecture of AESA based radio system is shown in Figure 1. Basic block diagram of this AESA based radio system consists of transmitting and receiving part.

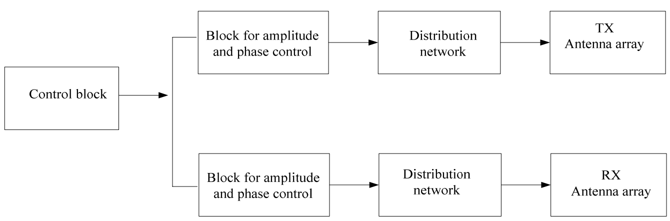

Fig.1 Basic architecture of AESA based radio system

As it could be seen from Figure 1, there are four building blocks of AESA based radio system: 1) antenna array, 2) power distribution network, 3) block for amplitude and phase control and 4) control block.

Antenna panel is based on the selected number of basic elements (micro strip patch antenna) where constructive interference of radio waves formed by all these basic elements, produces beam at certain angle in space. The analysis of antenna array consists of two steps: 1) determination of number of array elements and 2) analysis of array basic element type. Number of elements in antenna array depends on gain that should be obtained. Approximate formula for estimation of number of elements that could be used is [2] :

$$G = g_E(\theta_0, \varphi_0) \frac{\left(\sum_{n=1}^{N} |a_n|\right)^2}{\sum_{n=1}^{N} |a_n|^2}$$

Where:

$g_E(\theta_0,\varphi_0)$- gain of each element;

a_n - excitation coefficient of element n

The second phase is to determine the type of basic element. This analysis is restricted to the planar structures. The shape of patch antenna could be rectangular, circular or diamond one. In order to expand the frequency coverage of antenna, Vivaldi patch antenna could be used. Polarization of antennas can be circular, vertical or elliptic. The choice of polarization depends on particular application. Transmitting and receiving antenna arrays are identical. The basic element as the main building block of antenna array is micro strip patch antenna. Layout of inset-feed patch antenna is depicted in Figure 2.

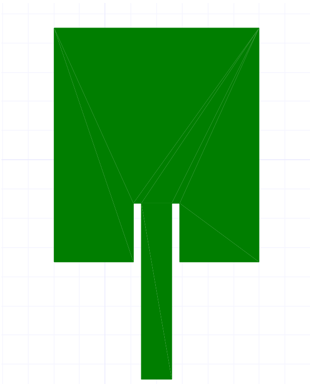

Fig.2 Layout of micro strip patch antenna

Power distribution network represents RF network that delivers excitations with certain amplitudes and phases to the elements of antenna array. It could be used as series fed and/or parallel fed. Depending on the particular application, the one or the other has advantages or disadvantages. When the main criterion is related to compact dimensions, series fed becomes the first choice.

Block for amplitudes and phases control distribution is based on variable gain amplifiers, phase shifters, and filters. For amplitude control, gain block amplifier with variable attenuators could be used instead of variable gain amplifiers. Proper amplitude distribution of excitations decreases side lobes. But this improvement is followed by broadening main lobe width. There are several distributions that can be used for amplitude tapering. Most common distributions are: Tschebyscheff, Taylor, Cosine-on-pedestal, binomial, uniform. Binomial distribution has lowest side lobes, and then it follows Taylor distribution, Tschebyscheff distribution and uniform distribution. But uniform distribution has narrowest main lobe, than Tschebyscheff, Taylor and binomial. Therefore, the choice of amplitude distribution of the excitations depends on the application.

Adjustment of phase of excitations is realized by means of phase shifters. Phase shifters could be analog or digital one. If analog phase shifters are used, we need digital-to-analog converter to control phase distribution. For digital phase shifters, we only need digital input/output lines to control phase distribution.

Control block is the part of the system that controls and supervises all aspects of system. Main function of processor, as a heart of the control block, is to provide certain amplitude and phase coefficients of the excitations by controlling variable gain amplifiers and phase shifters. Control block provides scanning with discrete steps of different size.

One component that should be analyzed separately is phase shifter. Phase shifter is the essence of every AESA based radio system. The particular problem related to phase shifters seems to be their price. It is enormously high. Almost half of all costs of the systems are caused by phase shifters. Also with the increase of frequency, the costs of phase shifters are proportionally higher as well.

There is one very important issue that must be considered dealing where phase shifting is performed. The system performance depends on this parameter. The described system architecture is based on RF domain shifting. This is traditional approach that provides architecture with lowest power consumption. Also, shifting could be realized digitally, at LO (Local Oscillator) level or IF (Intermediate Frequency) level. Advantage of the architecture based on LO shifting is that shifting is not on signal path. Hence, the influence of inherent attenuation of phase shifters is decreased. But disadvantage is that this architecture requires large number of mixers. Architecture based on IF shifting allowed shifting at very low frequencies compared to architectures with RF and LO shifting. This way, phase shifters of very high performance could be built. Disadvantage is that this architecture demands large number of local oscillators. When digitally controlled shifting is performed, problem of large power consumption is present. For applications where flexibility is the most important, digitally controlled shifting is the first choice. But, when the crucial goal is to design system with low power consumption, the architecture based on RF shifting should be considered.

Deriving the coefficients of amplllitude and phase in real-time is performed by processor. Results of this calculation for arbitrary amlitude distribution are shown in Table 1. Based on values of amplitude coefficients, the value of gain for VGA (Variable Gain Amplifier) is set. The same rule is applied if variable attenuators are used instead of variable gain amplifiers.

TABLE 1. AMPLITUDE DISTRIBUTION OF EXCITATIONS

Unit	Amplitude coefficients							
dB	-20	-16	-12	-10.5	-10.5	-12	-16	-20
dB	-16	-10.7	-7	-5.3	-5.3	-7	-10.7	-16
dB	-12	-7	-3.4	-1.7	-1.7	-3.4	-7	-12
dB	-10.5	-5.3	-1.7	0	0	-1.7	-5.3	-10.5
dB	-10.5	-5.3	-1.7	0	0	-1.7	-5.3	-10.5
dB	-12	-7	-3.4	-1.7	-1.7	-3.4	-7	-12
dB	-16	-10.7	-7	-5.3	-5.3	-7	-10.7	-16
dB	-20	-16	-12	-10.5	-10.5	-12	-16	-20

In order to provide depicted amplitude distribution, amplifiers and attenuators are needed. Power amplifier that could be used for this purpose is Hittite HMC441LM1 [3], which refers to transmitting chain. Also, variable attenuator HMC424 is possible choice [4]. For receiving chain, LNA such as Hittite HMC564LC4 could be used [5].

One solution for phase shifting that could be used in this analysis is Hittite HMC538LP4E [6]. This is analog phase shifter that shifts phase up to 600^0 at 10 GHz.

Next step is to performe analysis on the antenna array. Analysis has been performed in order to gain insight to the possibility of scanning by different angles. Each element of array is one micro strip patch antenna. In order to improve radiation pattern of antenna array, instead of one element, sub-array of various dimensions could be used [3], [11]. This way, antenna system with high directivity can be achieved ("Pencil Beam"). Layout of sub array of 2x2 elements is shown in figure 3.

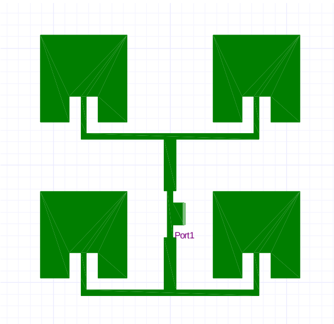

Fig.3 Antenna sub-array : 2x2 matrix

IV. SIMULATION RESULTS

Simulation of antenna arrays including other parts of system is presented in this chapter. Substrate used for antenna array model is RO4003C. Characteristics of this material are:

h=0,508mm	-substrate height
t=0,017mm	-metallization thickness
ε_r=2,1	-substrate permittivity
$tg\delta$=0,0004	-substrate losses

System analysis of antenna array with different number of elements could be performed. Simulations are performed at frequency of 10 GHz. Various software environments are used in order to simulate behavior of such complex system. First task is to determine number of elements of antenna array to provide sufficient antenna gain for certain application. For that purpose PCAAD software is used [8]. Simulation of antenna array has been performed in Ansoft Designer, which is 2.5D solver [9]. Overall system simulation is performed by AWR Design Environment [10]. Here is considered antenna array with 8x8 elements. Simulation results of analyzed systems are shown in Figures 4, 5, 6, 7, 8. These figures show radiation patterns of antenna array with different scanning angles.

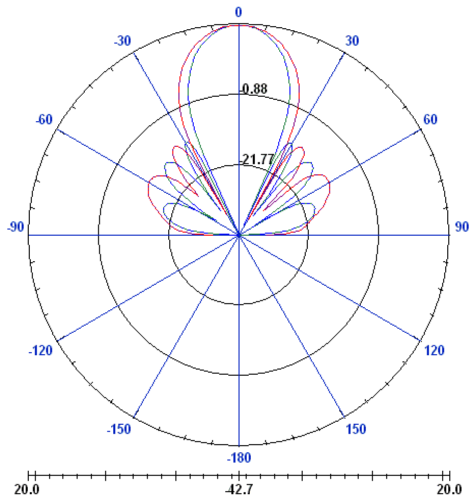

Fig.4 Radiation pattern for main beam angle of 0^0

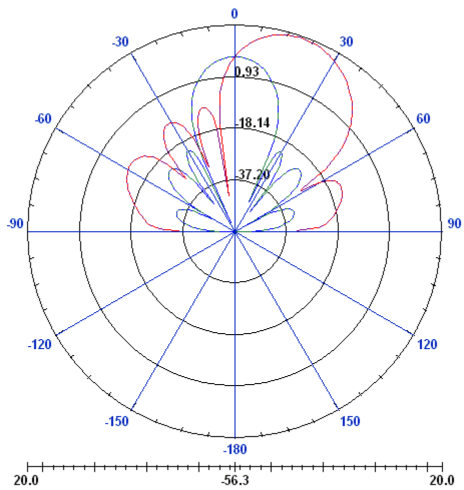

Fig.5 Radiation pattern for main beam angle of 20^0

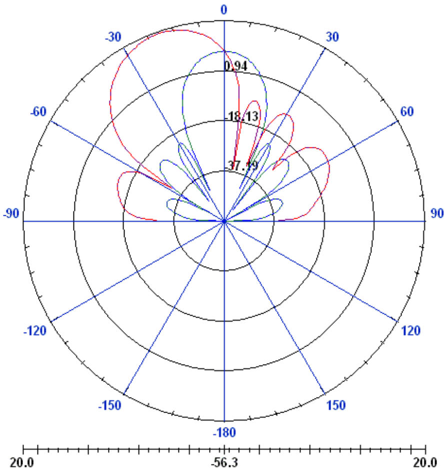

Fig.6 Radiation pattern for main beam angle of -20$^{0)}$

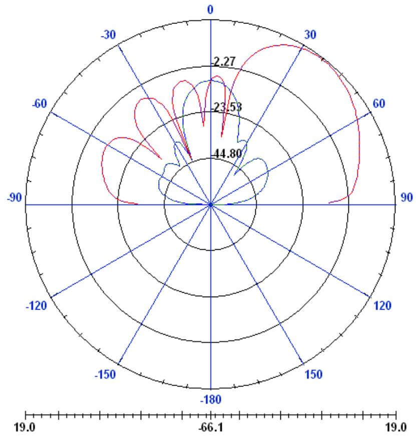

Fig.7 Radiation pattern for main beam angle of 38^{0}

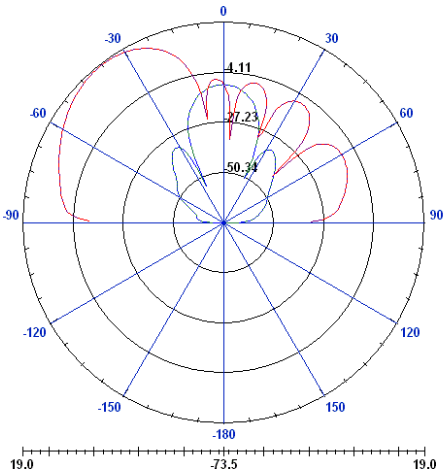

Fig.8 Radiation pattern for main beam angle of -38^{0}

As it can be observed from the previous figures, there is deterioration of radiation pattern with increased scan angle. Complete scanning range that is obtained is from -38^{0} to 38^{0}.

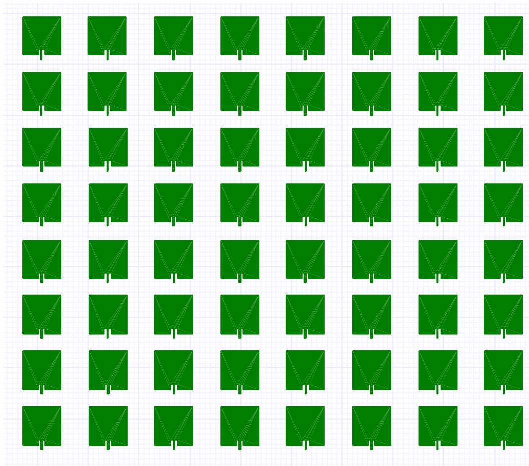

Fig.9 Antenna array : 8x8 matrix

As it can be seen form Figure 9, the layout of complete antenna array is shown. Dimension of antenna panel is critical factor in many applications. This antenna array size is 30x30 cm.

V. CONCLUSIONS

In this paper, the starting approach to analysis of radio systems based on AESA technology is presented. The system analysis is divided into several sections. In the first phase, the overall system architecture has been examined. Then, all system modules are analyzed in details. Simulation of system is performed in different software environments. Preliminary analysis of number of elements necessary to provide the required main beam width is performed in PCAAD software. Analysis of antenna array radiation patterns is carried out in Ansoft Designer software environment. Overall system analysis has been done in AWR Design Environment. Hence, the results of simulation are obtained and shown. Also, suggestions are given about the vital components that can be used in this design. Further steps in the process of research and development of AESA based radio-systems will take the antenna gain into considerations as well as important parameters relevant to radar applications [11].

ACKNOWLEDGMENT

This research has been supported by Ministry of Eduaction, Science and Technological Development of Serbia through the project TR 32051 in the field of software defined radio.

REFERENCES

[1] Constantine A. Balanis, Antenna Theory:Analysis Design, Third Edition, John Wiley & Son, 2005.

[2] R.J. Mailloux, Phased Array Antenna Handbook, Second Edition, Artech House, 2005.

[3] George W. Stimson, Introduction to Airborne Radar, Second Edition,Scitech Publishing Inc.,New Jersey,1998.

[4] HMC441LM1, Datasheet, Hittite Microwave Corporation, 2010.

[5] HMC424, Datasheet, Hittite Microwave Corporation, 2010.

[6] HMC564LC4, Datasheet, Hittite Microwave Corporation, 2010.

[7] HMC538LP4E, Datasheet, Hittite Microwave Corporation, 2010.

[8] *PCAAD 5.0*, Antenna Design Associates,Inc, 2003.

[9] *Ansoft Designer 2.2*, Ansoft Corporation,Inc, 2001.

[10] *AWR Design Environment*, AWR Corporation, 2006. A. J. Fenn, D. H. Temme, W. P. Delaney, W.E. Courtney, The Development of Phased Array Radar Technology, Lincoln Laboratory Journal, 2000

[11] P. M. Petrovic, Researh in Software Defined Radio and AESA Radar Technology, Workshop : Serbia-Italy/Status and Perspectives of the Scientific and Technological Bilateral Cooperation , University of Beograd, June 25-26, 2012.