INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2016, VOL. 62, NO. 2, PP. 115-120
Manuscript received August 26, 2015; revised June, 2016. DOI: 10.1515/eletel-2016-0015

The Idea of Enhancing Directional Energy Radiation by a Phased Antenna Array in UHF RFID System

Piotr Jankowski-Mihułowicz, Damian Kawalec, and Mariusz Węglarski

***Abstract*— The interrogation zone IZ is the most important parameter when RFID systems are considered. Its predictability is determined by the construction and parameters of antenna built in a read/write device. The IZ should be of sufficient size and appropriate to requirements established for an application of object automated identification. The method of shaping an antenna radiation pattern provides effective yet unconventional opportunities in this area. The idea and practical solution of the phased antenna array dedicated to UHF read/write devices are presented in the paper. On the basis of tests carried out, the authors pointed out the possibility of using developed devices for the synthesis of a determined IZ in anti-collision RFID system.**

***Keywords*— RFID, phased antenna array, interrogation zone**

I. Introduction

COMPLEX hardware-software radio frequency identification (RFID) systems are commonly utilized in industry, commerce, science, medicine and many other fields [1-6]. Among other things, this is due to better diagnosis of the issues determining their parameters, the essence of which often must be understood differently than in conventional radio systems [7], [8].

The main parameter of RFID systems is interrogation zone (IZ). It is defined as the space within which it is possible to conduct the radio transmission between read/write devices (RWD) and transponders intended for marking objects. The shape and size of the interrogation zone strongly depends on many factors, e.g. RFID system band (HF/UHF) [7], the transponder type (passive/semi-passive) and its parameters (e.g. sensitivity) [8]-[11], type, orientation and location of the marked object in operation space or how they are recognized in an automated process. In each of these cases, for the correct exchange of data with a predetermined communication protocol, a key factor is to provide energy electromagnetic field with RWD antenna to chip transponders [12], [13].

From the users point of view, the interrogation zone should be as large as possible for the correct recognition of differently placed objects. The primary way to do this without changing transponder and its location is for example to increase power delivered to the long range (LR) RWD antenna [14], [15]. However, it should be noted that in the UHF band systems energy conditions are limited by European standardization: ETSI EN 302 208 – 2 W ERP in the frequency band from 865.6-867.6 MHz, or American: FCC Part 15.247 (1 W of transmitter output power with maximal gain of 6 dBi) – 4 W EIRP in the frequency band 902-928 MHz [12]. Increasing the size IZ can also be obtained through the multiplication of RWD systems and their antennas [16], but this significantly increases the cost of LR systems. Considerable flexibility in shaping IZ can be obtained by using multiplexing array antenna [16], [17]. In this case the complicated, specific arrangement of spatially placed read/write device array antennas should always be examined [18]-[23].

In this respect it is an interesting electronic control characteristic of main beam radiation pattern in phased antennas array. Despite the fact that for a long time this function was used only in military applications, now increasingly, it can also be observed in the civilian areas when identifying objects based on the shapes of their echoes in the radio astronomy or weather forecasting [24]. In this context, new opportunities may be sought for the use of the phase antennas array [25]-[30].

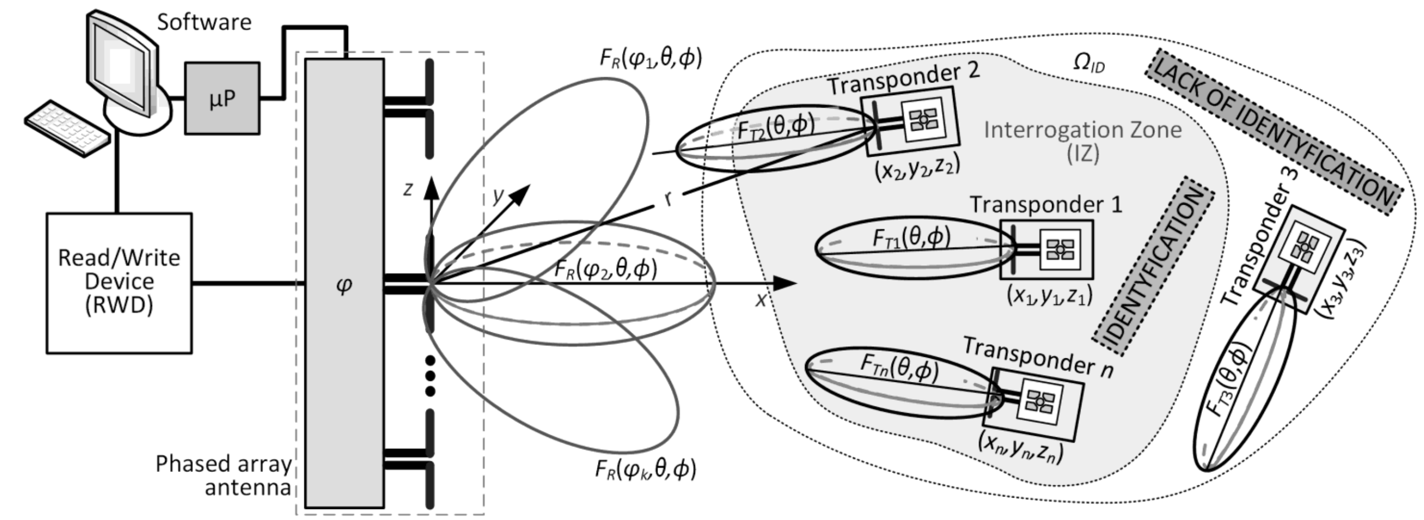
Bearing in mind the limitations of available energy, the article proposes the idea of enhancing directional EM field energy radiation by a phased antenna array RWD, which should enable a predictable increase in the volume of geometric dimensions of the interrogation zone in anti-collision UHF band RFID system. On this basis the design of phased antenna array system has been discussed, which made the first tests directional EM field energy. Developed concept and devices will be used to synthesize interrogation zone of RFID system in the future using the Monte Carlo method [18] where the cases inflicted automated identification processes will be considered.

II. The Idea of Directional Energy

Radiative coupled RFID system in the UHF band – depending on the region of the world – typically operates in the range from 860 MHz to 960 MHz. Data is sent from transponder to the RWD using the backscatter communication. This process is followed by a partial reflection of the carrier wave toward read/write devices, using modulation, which is implemented by using impedance changes swept the chip transponder. Appropriate communication mechanisms are defined by the ISO/IEC 18000-6 protocol (EPC Class 1 Gen 2 [31]).

This work was supported in part by Polish National Centre for Research and Development (NCBR) under Grant No. PBS1/A3/3/2012. The work was developed by using equipment purchased in the Operational Program Development of Eastern Poland 2007-2013 of the Priority Axis I Modern Economics of Activity I.3 Supporting Innovation under Grant No. POPW.01.03.00-18-012/09-00 and the Program of Development of Podkarpacie Province of The European Regional Development Fund under Grant No. UDA-RPPK.01.03.00-18-003/10-00.

All the authors are with the Department of Electronic and Communications Systems, Rzeszów University of Technology, Pola 2, 35-959 Rzeszów, Poland (e-mail: pjanko@prz.edu.pl; damkaw@prz.edu.pl; wmar@prz.edu.pl).



1

Fig. 1. Anti-collision UHF RFID system with phased antenna array.

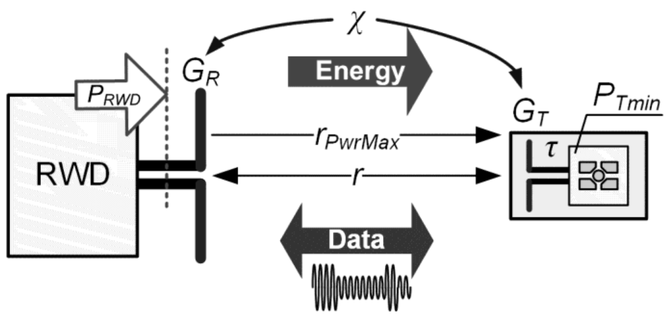


Fig. 2. Communication system of RWD - transponder arrangement in UHF band.

The process of communication is possible only if the transponders are located inside the interrogation zone (Fig. 1). This space is primarily shaped by 50 Ω RWD array antenna, whose EM field is a source of energy for transponders and medium for bidirectional data transmission for the RFID system. However, it is not possible that all tagged objects placed in a certain space Ω_{ID}, have been identified during the implementation of the automated process. Most of these problems stems from the fact that the EM field energy can be transmitted only on a maximum distance (r_{PwrMax}), whose dependence arises from the Friis equation (Fig. 2):

$$r_{PwrMax} = \frac{\lambda}{4\pi}\sqrt{\frac{P_{RWD} G_R G_T \tau \chi}{P_{T\min}}} \qquad (1)$$

where: P_{RWD} means the power supplied to terminals of the impedance-matched RWD antenna, G_R – the gain of impedance-matched RWD antenna, P_{Tmin} – the minimal power, that ensures proper operation transponder, G_T – the gain of transponder antenna (the chip and antenna impedance matching is assumed), χ – the polarization matching factor for given arrangement of radio communication antennas, τ – the coefficient of power transfer from antenna to the chip, λ – the wavelength.

Using the essence of action, e.g. military radiolocation systems, focus electromagnetic field energy to differently localization and orientation RFID transponders can be obtained by using the changing characteristics radiation pattern of the main beam in the space RWD phased antenna array. The proposed concept of maximizing IZ so it can be described using the features, which includes the location of the *k*-th position of the main beam in relation to the *n*-th transponders space Ω_{ID}:

$$IZ(\Omega_{ID}) = f(F_R(\varphi_k,\theta,\phi), F_{Tn}(\theta,\phi), \tau_n, \chi_n, P_{RWD}, P_{T\min}) \qquad (2)$$

where: $F_R(\varphi_k,\theta,\phi)$ means the radiation pattern of RWD phased antenna array, $F_{Tn}(\theta,\phi)$ – the transponder radiation pattern, whereas φ – the angle of phase shift in the course of feeding the individual array antenna.

Assuming constant location and orientation of the transponders in automated process, a key influence on the IZ can be obtained by using the radiation pattern of $F_R(\varphi_k,\theta,\phi)$. Change of the location of its main beam can be made even with the simplest set, consisting of: power divider, phase shift, microprocessor system and two antennas. The proposed layout of the signal strength from the read/write devices is evenly divided on the antenna, and one of them is fed a signal delayed by the angle φ. Equal sharing of power and change of phase shift of the signal component power cord antenna allow the formation of the corresponding radiation pattern of the beam without any mechanical changes in the position of the whole system.

III. Experiment

On the basis of this concept it was scheduled to carry out preliminary experimental work on the basis of which it will be possible to determine the usefulness of the method of directional energy, with a view to its subsequent use to IZ synthesis using Monte Carlo methods [18]. In this context it was necessary to develop a component of the antenna phase system (Fig. 2), dedicated to work in anti-collision UHF band RFID system (EPC Class 1 Gen 2 [31]). Taking into account the aim of the research work as well as the efficiency and operating conditions of the UHF band RFID system, it was assumed that the proposed antenna (compatible with the protocol ISO/IEC 18000-6) should have linear polarization, directional radiation pattern and the standing wave ratio *SWR*=1:1.25 in the frequency band from 865.6 MHz to 867.6 MHz (ETSI EN 302 208 – max. 2 W ERP).

For computational work in Hyper Lynx 3D EM (HL3DEM) developed the numerical model of the component of the RWD antenna phase system (Fig. 3-a). The passive antenna radiator and ground plane were placed on the upper layer of dielectric substrate. The radiator is fed by the proximity of the electromagnetic field produced by galvanic separated, 50 Ω quarter-wave microstrip line. This line is placed under the radiator on the bottom layer of dielectric substrate. The radiator is surrounded by the ground that reduces the antenna sensitivity to the proximity of ferromagnetic objects. Directivity of radiation pattern provides a reflector that is placed at a distance *D* from microstrip line layer. In the future, this construction will allow antenna to be integrated with other electronic systems.

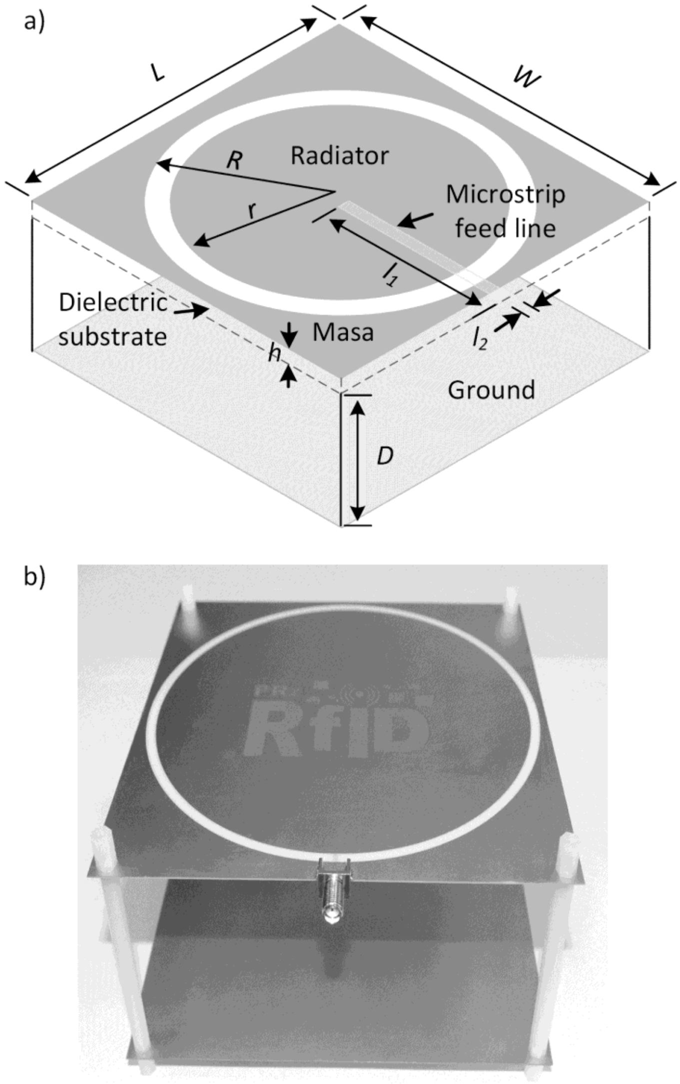


Fig. 3. Constituent antenna of phased array for RWD: a) model, b) practical solution.

The final design parameters have been achieved on the basis of the numerical calculations. The assumptions are met for the following values: W=154 mm, L=149 mm, D=69 mm, l_1=65 mm, l_2=1 mm, R=71.5 mm, r=68.5mm. On this basis, it was the practical implementation of the antenna (Fig. 3-b). The test samples have been realized practically on ISOLA FR408 double sided copper clad laminate (thickness of dielectric substrate h=0.52 mm, thickness of copper clad 18 µm, measured for 1 GHz the value relative permittivity electricity ε_r=4.22 and loss tangent tgδ=0.0102), using the plotter PCB LPKF ProtoMat S100 available in the company HYBRID laboratory.

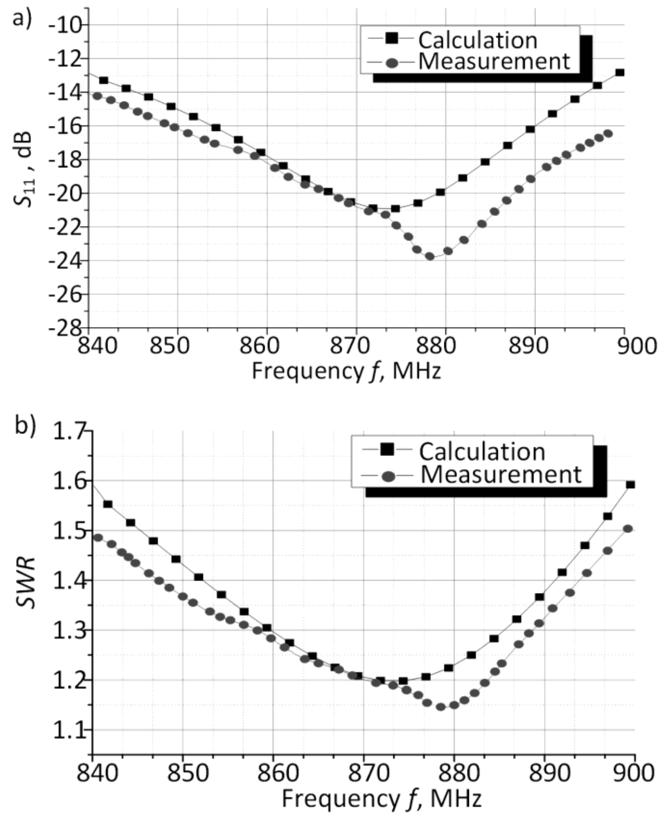


Fig. 4. Results for constituent antenna: a) return loss, b) standing wave ratio.

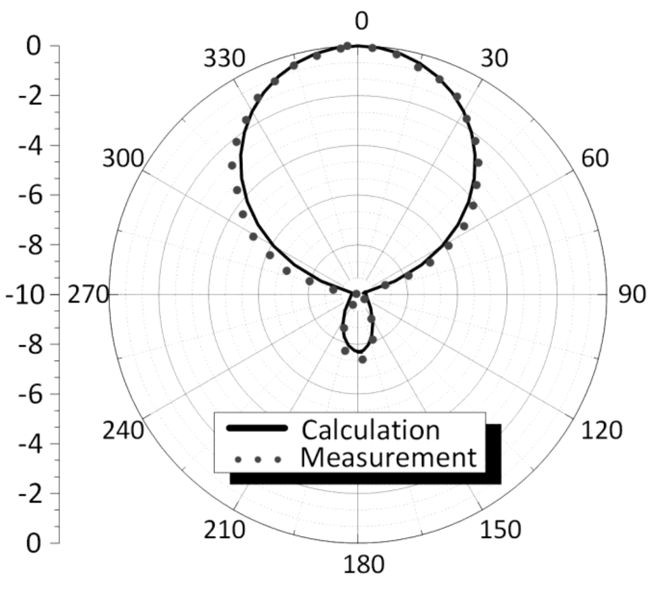


Fig. 5. Radiation pattern at 866 MHz - H diagram.

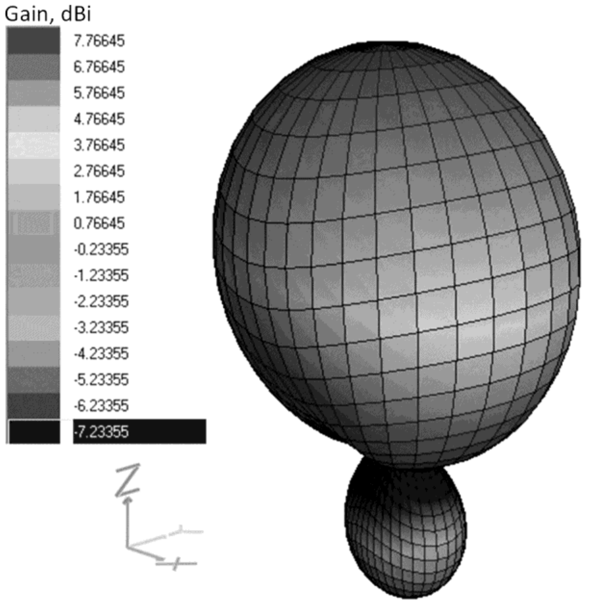


Fig. 6. Radiation pattern at 866 MHz - 3D view.

The investigations have been carried out on the test stand in the RFID laboratory at the Department of Electronic and Communications Systems, Rzeszow University of Technology. Return loss (S_{11}) and standing wave ratio *SWR* have been measured by using the VNA Agilent PNA-X N5242A (Fig. 4-a, b). The radiation patterns (Fig. 5, 6) have been determined in the TDK anechoic chamber using the MI Technologies antenna system consisting of elevation over azimuth positioned ELAZ75 and SC110V Sonul Sciences system controller, Agilent PNA-X N5242A analyzer and MI 3003 acquisition and analysis workstation with MI Arena software (Fig. 7).

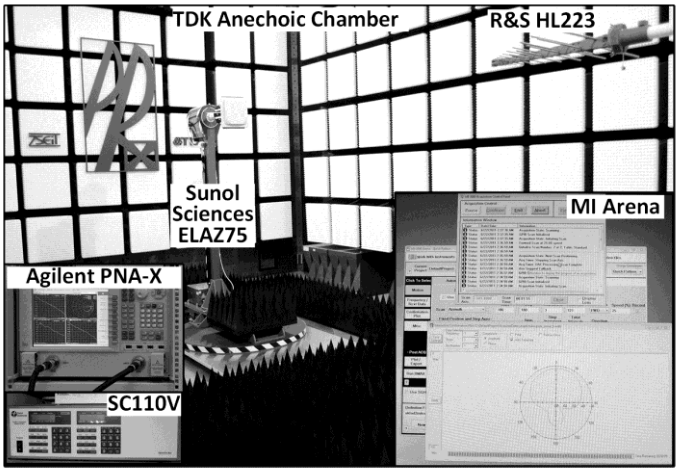


Fig. 7. Measurement test stand.

Satisfactory convergence results of calculations and measurements of antenna confirmed the compliance of the developed design with adopted goals. It has enabled the preparation of HL3DEM numerical model and assemble a set of test phase antenna array UHF band, which includes: two antenna (spaced apart by half a wavelength to frequency *f*=866 MHz), PE2088 power divider and PE8244 phase shifter Pasternack company (Fig. 8).

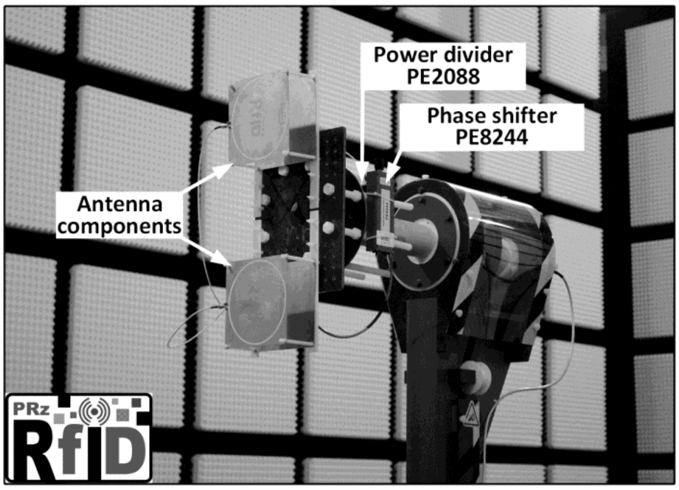


Fig. 8. Experiment - phased antenna array.

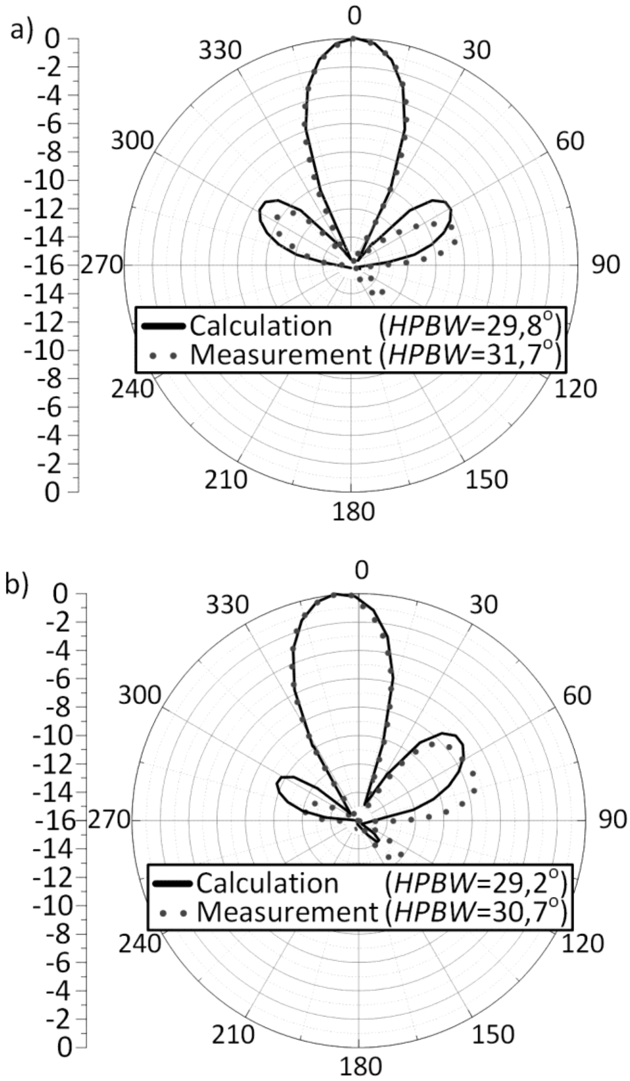


Fig. 9. H diagrams of radiation pattern for phased antenna array dedicated to RWD of the UHF band (*f*=866 MHz): a) φ=0°, b) φ=30°.

Experimental verification of the case were cophasal supply (Fig. 9-a) and phase angle φ=30° (Fig. 9-b). The first of them maximum radiation cover with the axis of the system. In turn, in the case specified a phase angle in signals supply the individual antenna system (φ=30°), resulted in shifting the axis of the main beam of radiation pattern of 7°, with constant value half-power beam width (HPBW).

On the basis of results of the calculations and measurements of the test phased antenna array, it can be concluded that the effective possibility of enhancing directional energy radiation patterns of the main beam in the range of 14° has been received, while maintaining its stable parameters. Results of this work will provide access to comprehensive assessment interrogation zone in anti-collision UHF band of RFID system on the basis of the proposed functions (2).

IV. Conclusion

Anti-collision RFID systems are primarily required to recognize all marked objects in a specified working space. In many areas of life and the economy this has even key economic importance because of the speed and quality of the implementation of automated processes largely depend on the cost of material flows. However the observed progress in this area forces the need to overcome the technical barriers, that stand in the way of dissemination of already developed standards (as is the case for example of the EPC). Therefore it can be concluded that increasing the geometric size of interrogation zone the RFID system (and thus maximizing the reach of read/write data with transponders memory) is one of the factors that leads to predictable recognition of objects in the non-stationary state (e.g. electronically marked fast-moving consumer goods (FMCG)). The RWD antenna array is a device that has a huge impact on the spatial boundary of this space – on the interrogation zone. In this context, the article proposes an unconventional concept and practical implementation of phased antenna array in UHF band of RFID system. Such a solution will allow designers to increase the size of the interrogation zone, especially in dynamic RFID systems. The results of measurements and calculations have been compared, analysed and discussed. The array antenna models have been simulated in the Mentor Graphics HyperLynx 3D EM environment and practically realised in PCB technology. On the basis of predefined tests, the possibility of using the solutions developed for the synthesis of a determined the interrogation zone anti-collision RFID system has been indicated.

References

[1] A. Ustundag, Ed., "*The Value of RFID. Benefits vs. Costs*," London: Springer-Verlag, 2013.

[2] J. Singh, S. Roy, M. Montero and B. Roesner, "Evaluation of an innovative system for improving readability of passive UHF RFID tags attached to reusable plastic containers," *Packaging Technology and Science*, DOI: 10.1002/pts.921, vol. 24, pp. 137-146, Apr./May 2011.

[3] C. James, C. Chen-Huan, B. PoTsang, W. Kung-Jen, H. Chien-Jung and T. Ti-Chen, "Warehouse management with lean and RFID application: a case study," *The International Journal of Advanced Manufacturing Technology*, DOI: 10.1007/s00170-013-5016-8, vol. 69, pp. 531–542, May 2013.

[4] D. Brown, "*RFID Implementation*," Inc. New York: McGraw-Hill, 2007.

[5] P. Kochendörfer, "Entering a secure future," *Global Identification*, vol. Oct., p. 24-26, Oct. 2012.

[6] M. Wheeler, "Automating processes with RFID," *Global Identification*, vol. Feb., p. 10-13, Feb. 2013.

[7] P. Jankowski-Mihułowicz, G. Pitera and M. Węglarski, "The Impedance Measurement Problem in Antennas for RFID Technique," *Metrology and Measurement Systems*, DOI: 10.2478/mms-2014-0043, vol. XXI, no 3, pp. 509-520, Aug. 2014.

[8] P. Jankowski-Mihułowicz and M. Węglarski, "Determination of Passive and Semi-Passive Chip Parameters Required for Synthesis of Interrogation Zone in UHF RFID Systems," *Elektronika ir Elektrotechnika*, DOI: 10.5755/j01.eee.20.9.5007, vol. 20, no. 9, pp. 65-73, Sep. 2014.

[9] P. V. Nikitin, K. V. S. Rao, R. Martinez and S.F.Lam, "Sensitivity and impedance measurements of UHF RFID chips," *IEEE Transactions on Microwave Theory and Techniques*, DOI: 10.1109/TMTT.2009.2017297, vol. 57, no. 5, pp. 1297-1302, May 2009.

[10] J. Grosinger, C. Mecklenbrauker and A. L. Scholtz, "UHF RFID transponder chip and antenna impedance measurements," in *Proc. of the Third International EURASIP Workshop RFID Technology*, La Manga del Mar Menor (Spain), 2010, pp. 43-46.

[11] R. Kronberger, A. Geissler and B. Friedmann, "New methods to determine the impedance of UHF RFID chips," in *Proc.* of the *IEEE Inter. Conf. RFID*, Orlando (Florida), DOI: 10.1109/RFID.2010.5467251, 2010, pp. 260-265.

[12] K. Finkenzeller, "*RFID Handbook*," 3rd Ed. Wiley, 2010.

[13] G. De Vita and G. Iannaccone, "Design criteria for the RF section of UHF and microwave passive RFID transponders," *IEEE Transactions on Microwave Theory and Techniques*, DOI: 10.1109/TMTT.2005.854229, vol. 53, no. 9, pp. 2978-2990, Sep. 2005.

[14] I. Mayordomo, R. Berenguer, A. Garcia-Alonso, I. Fernandez and I. Gutierrez, "Design and Implementation of a Long-Range RFID Reader for Passive Transponders," *IEEE Trans. on Microw. Theory Techn.*, DOI: 10.1109/TMTT.2009.2017291, vol. 57, no. 5, pp. 1283–1290, May 2009.

[15] L. Longfei and Z. Qishan, "Design and implementation of a long-range RFID reader," in *Proc. of the 10th International Conference on Electronic Measurement & Instruments (ICEMI)*, Chengdu (China) DOI: 10.1109/ICEMI.2011.6037735, vol. 1, pp. 297-300, 2011.

[16] S. Sabesan, M. J. Crisp, R. V. Penty and I. H. White, "Wide Area Passive UHF RFID System Using Antenna Diversity Combined With Phase and Frequency Hopping," *IEEE Transactions on Antennas and Propagation*, DOI: 10.1109/TAP.2013.2290114, vol. 62, no. 2, pp. 878-888, Feb. 2014.

[17] S. Azzouzi, M. Cremer, U. Dettmar, R. Kronberger, and T. Knie, "New Measurement Results for the Localization of UHF RFID Transponders Using an Angle of Arrival (AoA) Approach," in *Proc. of the IEEE International Conference on RFID*, Orlando (Florida), DOI: 10.1109/RFID.2011.5764607, pp. 91-97, 2011.

[18] P. Jankowski-Mihułowicz and M. Węglarski, "Determination of 3-Dimentional Interrogation Zone in Anticollision RFID Systems with Inductive Coupling by Using Monte Carlo Method," *Acta Physica Polonica A*, vol. 121, no. 4, pp. 936-940, Apr. 2012.

[19] J. Shi, X. Qing and Z. N. Chen, "Electrically Large Zero-Phase-Shift Line Grid-Array UHF Near-Field RFID Reader Antenna," *IEEE Transactions on Antennas and Propagation*, DOI: 10.1109/TAP.2014.2299824, vol. 62, pp. 2201-2208, Apr. 2014.

[20] B. D. Braaten, S. Roy, S. Nariyal, M. A. Aziz, B. Ijaz and M. M. Masud, "A metamaterial-based series connected rectangular patch antenna array for UHF RFID Readers, " in *Proc. of the 6th European Conference on Antennas and Propagation (EUCAP)*, Prague (Czech Republic), DOI: 10.1109/EuCAP.2012.6206029, 2012, pp. 3164-3167.

[21] L. Wang-Sang, K. Seung-Tae, L. Won-Seok and Y. Jong-Won, "Hemispheric coverage multi-beam switched antenna array using a 4-port feeding network for UHF RFID dead zone avoidance," in *Proc. of the Asia-Pacific Microwave Conference Proceedings (APMC)*, Seul (Korea), DOI: 10.1109/APMC.2013.6695111, 2013, pp. 254-257.

[22] L. Wang-Sang, T. Hyun-Sung and Y. Jong-Won, "Quadruple-feed beam-controlled antenna array for the localisations of ultra-high-frequency radio-frequency identification tags," *Microwaves, Antennas & Propagation*, DOI: 10.1049/iet-map.2014.0158, vol. 9, pp. 923-932, Jun. 2015.

[23] D. J. Kim, S. H. Kim, Y. K. Kim, H. Lim and J. H. Jang, "Switched Microstrip Array Antenna for RFID System," in *Proc. of the 38th European Microwave Conference (EuMC)*, Amsterdam (The Netherlands) DOI: 10.1109/EUMC.2008.4751689, 2008, pp. 1254-1257.

[24] W. Zieniutycz, Ed., "*The antenna of the radar technique beam steering*," Warsaw: WKŁ, 2012.

[25] M. H. Ariff, I. Ismarani and N. Shamsudin, "Design and Development of UHF RFID Reader Antenna for Livestock Monitoring," in *Proc. of the 5th IEEE Control and System Graduate Research Colloquium (ICSGRC)*, Shah Alam (Malaysia) DOI: 10.1109/ICSGRC.2014.6908708, 2014, pp. 125-129.

[26] Y. J. Ren, C. P. Lai, P. H. Chen and R. M. Narayanan, "Compact Ultrawideband UHF Array Antenna for Through-Wall Radar Applications," *IEEE Antennas and Wireless Propagation Letters*, DOI: 10.1109/LAWP.2009.2037985, vol. 8, pp. 1302-1305, 2009.

[27] X. Li, J. Liao, Y. Yuan and D. Yu, "Eye-shaped segmented reader antenna for near-field UHF RFID applications," *Progress In Electromagnetics Research*, vol. 114, pp. 481-493, 2011.

[28] M. Dhaouadi, M. Mabrouk, T. P. Vuong, A. C. de Souza and A. Ghazel, "A capacitively-loaded loop antenna for UHF near-field RFID reader applications," *IEEE Radio and Wireless Symposium*, DOI: 10.1109/RWS.2015.7129755, pp. 193-195, Jan. 2015.

[29] L. Won-Seok, O. Kyoung-Sub and Y. Jong-Won, "Design of spiral-shaped UHF near-field reader antenna for RFID applications," *IEEE MTT-S International Intelligent Radio for Future Personal Terminals (IMWS-IRFPT)*, DOI: 10.1109/IMWS2.2011.6027212, pp. 1-2, Aug. 2011.

[30] R. Caso, A. Michel, M. Rodriguez-Pino and P. Nepa, "Dual-Band UHF-RFID/WLAN Circularly Polarized Antenna for Portable RFID Readers," *IEEE Transactions on Antennas and Propagation*, DOI: 10.1109/TAP.2014.2303971, vol. 62, pp. 2822-2826, May 2014.

[31] GS1 EPCglobal, "EPC Radio-Frequency Identity Protocols Generation-2 UHF RFID; Specification for RFID Air Interface Protocol for Communications at 860 MHz – 960 MHz," ver. 2.0.0., Nov. 2013.