BALKAN JOURNAL OF ELECTRICAL & COMPUTER ENGINEERING, Vol. 10, No. 2, April 2022

A Prospective Look on Optimization Methods For RFID Systems: Requirements, Challenges, and Implementation Aspects

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Abstract—**The radio frequency identification (RFID) is a configuration of wireless communication that uses radio frequency (RF) waves for following up and recognizing data. The RFID system includes important parts as antenna and integrated circuit (IC) for radiating and storing data, respectively. Hence, high performance antenna and IC circuits must be designed for assembling the energy from the radio waves and feeding the RFID chip. One of the important circuit/block in the IC part is the amplifier where the antenna is sensing the radiated output power. For this case, it is substantially important to design high performance antenna and amplifier where the specifications of these circuits must be optimized in a professional way. In this paper, we collect the recently published optimization methods that are employed for designing antenna and RF/analog-based amplifiers. Any researcher by referring to these algorithms can access and find the solutions for their problems, straightforwardly.**

Index Terms—**Amplifier, antenna, radio frequency identification (RFID), radio frequency (RF), optimization methods, power amplifier (PA).**

I. Introduction

THE need of radio frequency identification (RFID) systems is growing day-by-day, and can be used in the internet of things (IoT) networks, healthcare, agriculture, industrial environments, and smart houses [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]. These systems are preferred due to the contactless communication, dense read/write operation, and low-cost profits in modern technologies [4], [11]. Typically, the RFID system includes the tags, readers, and a database server where the reader can prompt the tags and then send/receive data to/from the tags [12], [13] as Fig. 1 shows. The RFID reader is the device that receives data from the identifiers where the electromagnetic provided from the reader antenna can be used as an energy source [14]. As Fig. 2 shows, in the active RFID systems the two significant components are antenna and amplifiers that is connected to the smart card chip. For proper working of RFID system, designing and optimizing high performance antennas [15], [16], [17] and amplifiers [18], [19], [20], [21], [22], [23], [24], [25] are required where advanced optimization methods must be employed for configuring and sizing these designs [26], [27], [28], [29], [30], [31], [32].

Optimization methods are the techniques focusing on minimizing or maximizing aimed objective functions. At the system and circuit level designs, required constrains and goals must be determined and afterwards suitable optimization methods can be considered for designing various designs and circuits. Over the last decade, various optimization methods have been employed for designing and optimizing antennas and amplifiers that can be also used in the RFID applications [33]. The reported optimization methods have significant advantages as speeding-up the process, reducing cost and errors with the least efforts.

This survey devotes to provide a comprehensive summary on various optimization methods that can be employed in the design of RFID systems. Typically, any RFID systems include two important designs as antenna and amplifier circuits. Hence, this paper is to summarize various optimization methods and algorithms used in improving the overall performance of RFID systems. Such kind of survey will enable engineers

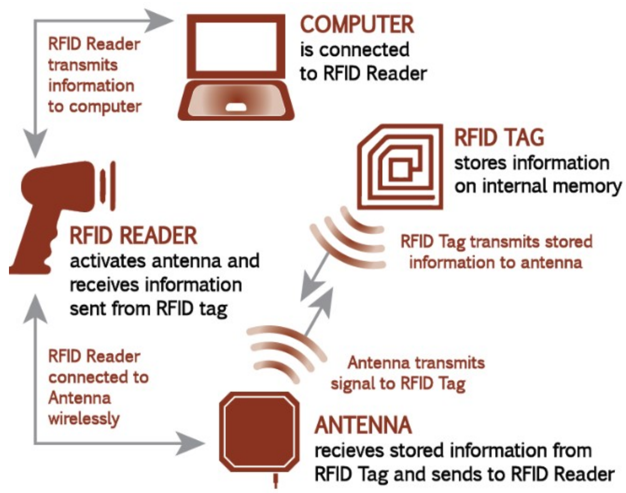

Fig. 1. The RFID system architecture [34].

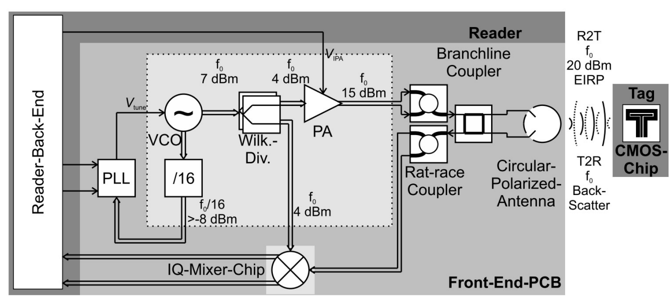

Fig. 2. Components of active RFID system [35]; voltage-controlled oscillator (VCO) and phase-locked loop (PLL).

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Manuscript received January 21, 2022; accepted April 12, 2022.
DOI: 10.17694/bajece.1061375

to figure out successfully the various optimization methods at once and will decide easily on the accurate methods for solving their problems.

The remainder of the article is organized as follows. Section II presents the motivation of employing optimization methods in the RFID systems. Section III devotes to summarize the various optimization methods employed in antenna and amplifier designs. Finally, Sec. IV concludes this manuscript.

II. Optimization methods and RFID designs

Optimization methods have proved their practical uses in the coupled antennas that are used for the RFID systems. As Fig. 3 presents, a large ferrite core is inserted into the tag coil antenna for improving the magnetic coupling that is between the reader and tag antennas.

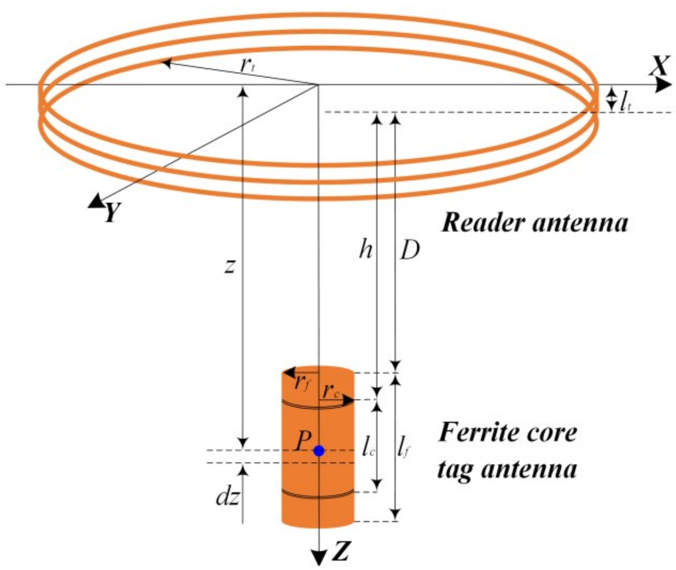


Fig. 3. Schematic of two RFID solenoid antennas presented in [36].

In [37], self-tuning performance is done for solving the optimization problems in the design of ultra-high frequency (UHF) RFID antennas. The presented method leads to maximize the performance of the RFID and to make it independent at the surrounding environment. Figure 4 presents in detail the fingertip tag. For UHF RFID reader, the Quasi-Yagi antenna is presented in [38]. It is a wearable device and can be used in wireless sensing (see Fig. 5) by determining a centered frequency band at 915 MHz.

The RFID sensing antenna is presented in [39] where the detail of antenna structure is shown in Fig. 6, and it has dimensions of (65 × 65 × 4 mm^3). The type of antenna differs with the injected liquid that is inside the presented antenna.

One of the amplifier architecture that can be used in the RFID systems is depicted in Fig. 7 that includes the active transistor, switch, and an antenna in the overall configuration. This circuit can be used in the field of communications by means of reflected power. Another use of amplifier is proved in [40] where a low-power amplifier is presented using tunnel diodes results in stable reflection gain (see Fig. 8).

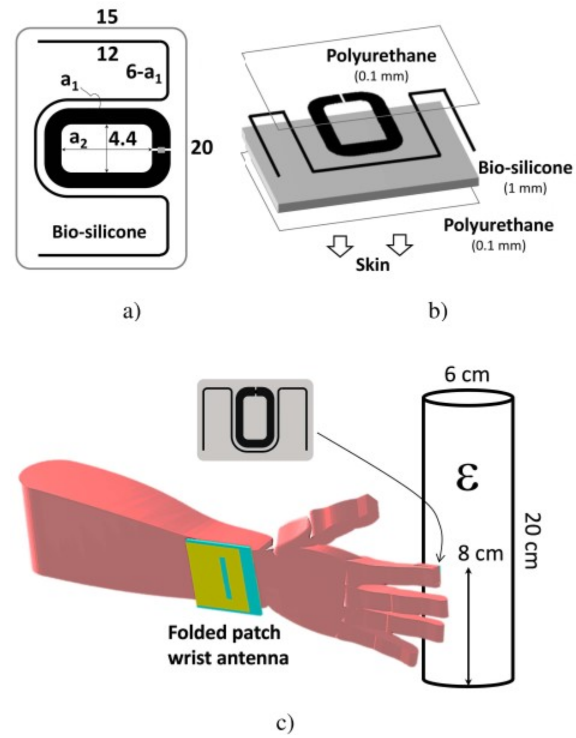


Fig. 4. Presented fingertip tag in [37] to be used as a UHF-RFID Antenna with a) Tag layout in mm size, b) practical use of antenna in the bio-medical applications, c) Tag layout.

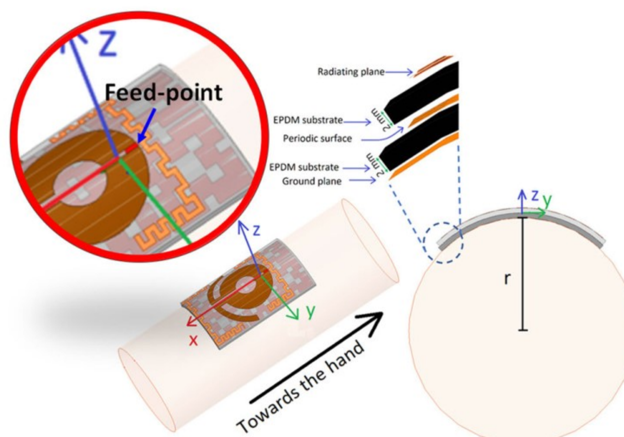


Fig. 5. Wearable quasi-Yagi antenna as UHF RFID reader [38].

III. Optimization methods

This section provides an overview on various optimization methods used for designing and optimizing antennas and amplifiers. The recently published studies include advanced optimization methods are summarized in a comprehensive aspect.

The chicken swarm optimization (CSO) method is a bio-inspired algorithm aims to follow the hierarchical order and the behaviors of the chicken swarm [41]. This optimization method is employed in [42] for deployment of phased array antennas to be used in the RFID networks. In this method, a new indicator is used to reflect the disturbance of frequency selective fading. The general structure of the CSO method is summarized in Fig. 9.

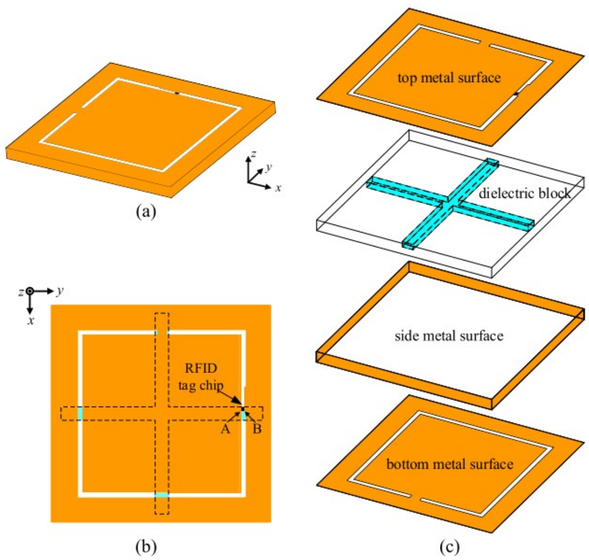


Fig. 6. Presented RFID tag antenna with a) overall structure, b) top, and c) exploded view [39].

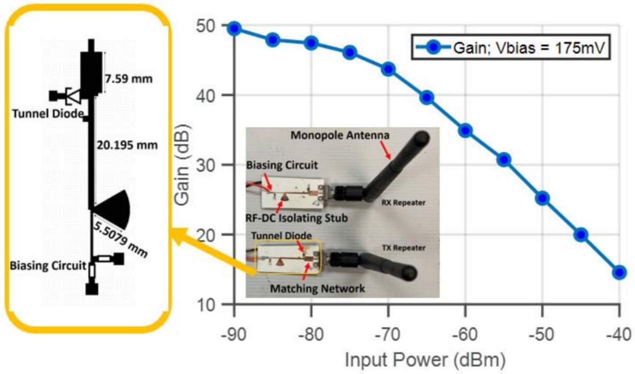


Fig. 7. Presented RFID amplifier presented in [18].

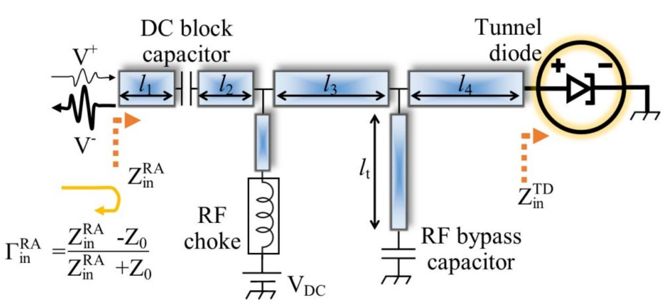


Fig. 8. Tunnel diode-based reflection amplifier presented in [40] to be used in the RFID systems.

The Particle swarm optimization (PSO) method is performed by iteratively trying to enhance a candidate solution and is a stochastic optimization technique based on swarm [43]. This method is employed for the real-time 3D localization of UHF-RFID tags in [28]. In another study presented in [44], the PSO method is used for improving the RFID anticollision model and for optimizing the high-dimensional problem that Fig. 10 illustrates the feature of this optimization.

The hierarchical multilevel bottom-up method becomes important for radio frequency (RF) designs in the recent years where the accuracy simulation of overall system especially for

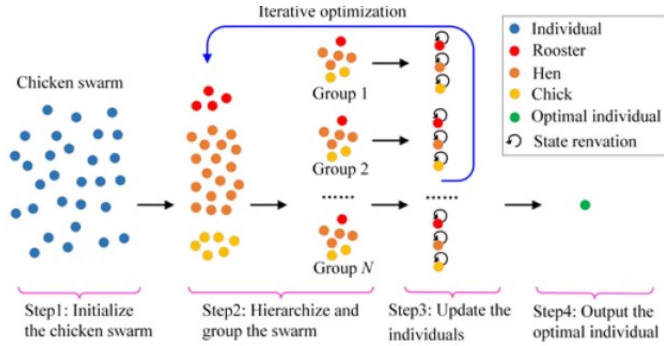


Fig. 9. The CSO method employed in [42] for designing phased array antenna.

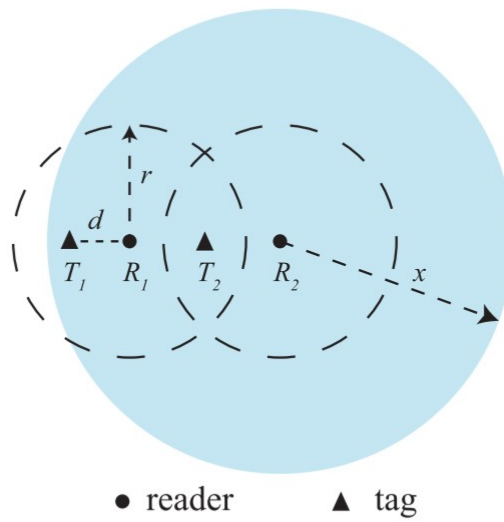


Fig. 10. Employed PSO method in [44].

the electromagnetic simulations have been increased, substantially [45].

The bottom-up optimization (BUO) is the method where it starts with smallest parts and develops to the largest sections. In [46], by using inductor-capacitor networks shown in section A and B of Fig. 11.a, matching networks (MNs) for the power amplifier (PA) with Gallium Nitride (GaN) high electron mobility transistor (HEMT) is designed and optimized. In this method, input and output MNs are started with one MN and sequentially the number of MNs are increasing up to achieving desired output specifications. The detail implementation of this method is shown in Fig. 11.b.

This method is also employed for designing and optimizing the antenna, presented in [47], where the transmission lines (TLs) are increased sequentially and are configuring the structure of antenna. The detail implementation of BUO method used for optimizing antenna is presented in Fig. 12. Additionally, this method is used for designing array antenna [48] where the number of single antennas is enhancing in a latter style as Fig. 13 presents. Hence, the optimal number of single antennas with suitable feeding point can be determined.

Th BUO method can be employed in the system-level design as well [49], [45] where Fig. 14 illustrates one of the useful aspect of this method. This method splits the system into sub-blocks as low-noise amplifier (LNA), voltage controlled

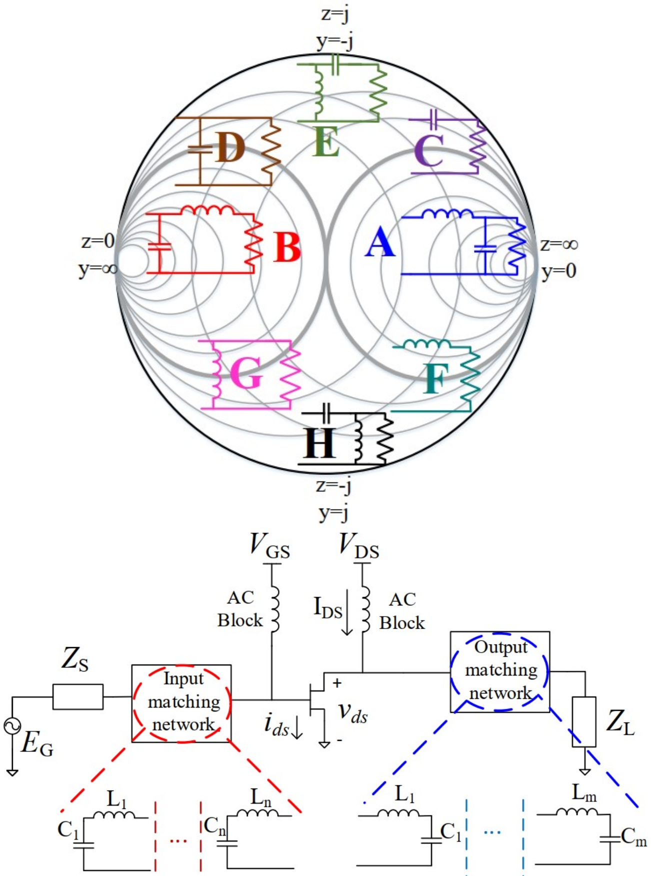


Fig. 11. a) Smith chart with various passive MNs [top]; b) BUO method for designing and optimizing an amplifier [bottom] [46].

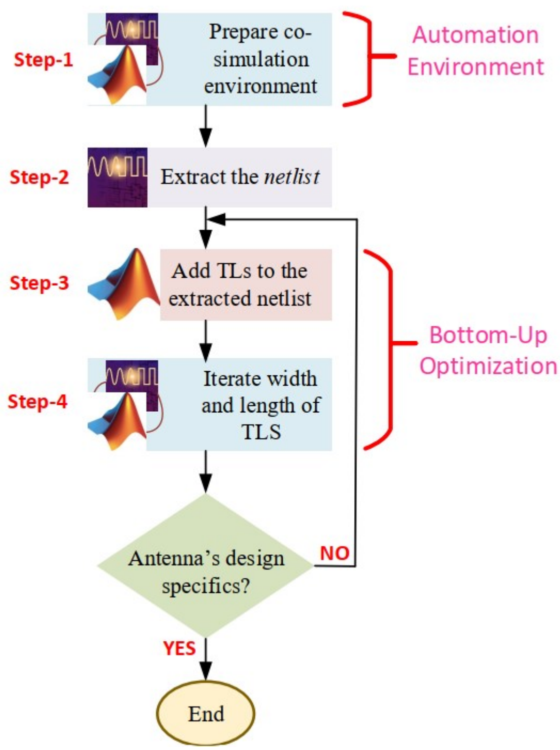


Fig. 12. BUO method for optimizing antenna where the TLs are employed [47].

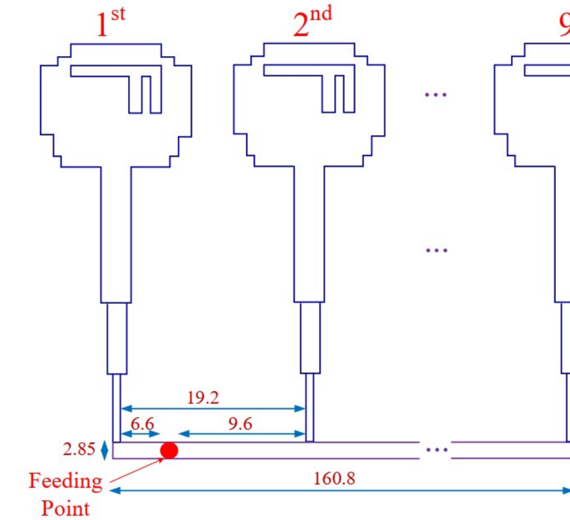


Fig. 13. BUO method for optimizing array antenna [48].

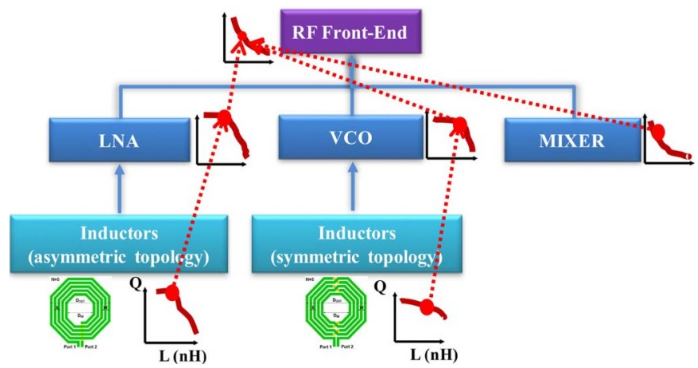


Fig. 14. Designed RF front-end with BUO method [45].

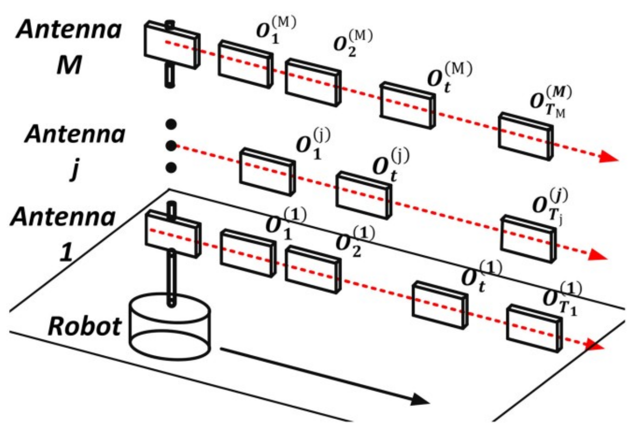


Fig. 15. An illustration of multi-antenna synthetic [2].

oscillators (VCO), and mixer leads to generate and size the layout, effectively.

In [2] for 3D localization of UHF RFID tags, a nonlinear optimization leads to assemble measurements from various antennas is presented (see Fig. 15). This method aims to optimize the cost function where phase measurements are gathered by minimum two antennas, and finally a multi-antenna synthetic aperture is generated.

During designing any antenna or amplifier circuit, time

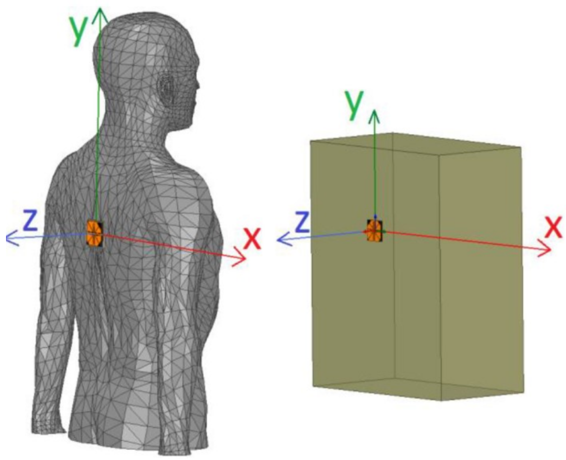


Fig. 16. The comparison between anatomical model (presented in left side) and the cuboid model (presented in right side) [3].

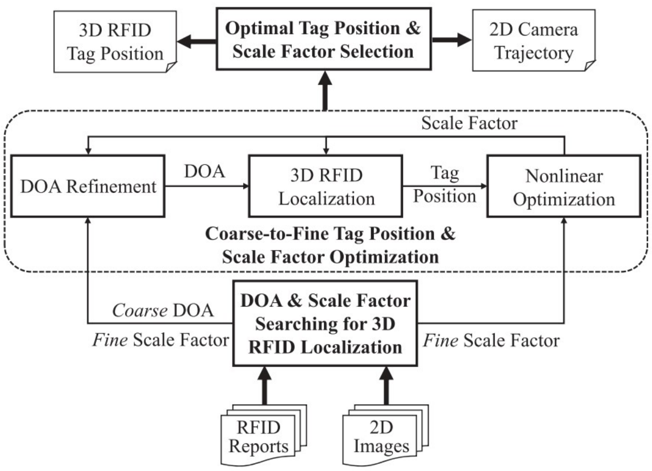


Fig. 17. Presented configuration of RF-MVO in [15].

computation is also another important specification along with the output performances. In [3], the antenna is designed based on the cuboid model since with this model the simulation time with mesh size are reduced, substantially compared with anatomical model (see Fig. 16).

The coarse-to-fine optimization method is employed in [15] for improving the localization accuracy in RFID systems. The presented optimization process is based on the space mapping [50] and uses two models of the same physical system namely as: expensive model (fine model) and cheaper (coarse) model. Based on this method, RF-monocular visual odometry (MVO) is presented that is connecting a light-weight 2D monocular camera to two reader antennas in a parallel version results in reduced localization error. Figure 17 shows the presented RF-MVO architecture with the direction of arrival (DOA) that is azimuth and elevation angles.

QI et al., presents optimization techniques based on the queuing theory and control feedback for minimizing the energy cost where it is illustrated in Fig. 18 that can be used in the industrial internet of things (IIoT) [5].

In [30] efficient global optimization (EGO) method is applied for sizing the designed antenna as Fig. 19 presents. This antenna provides cost-effective option for sensing by using

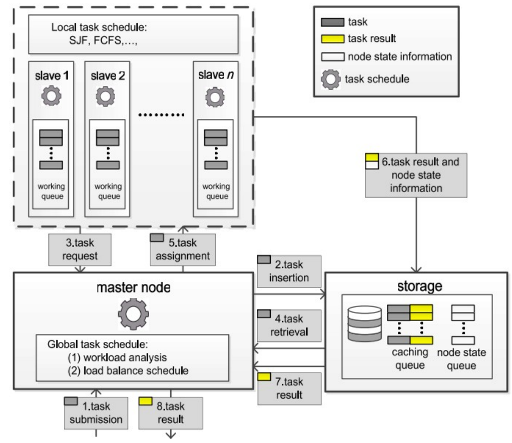


Fig. 18. Configuration of computing service provider (CSP) on Redis in [5].

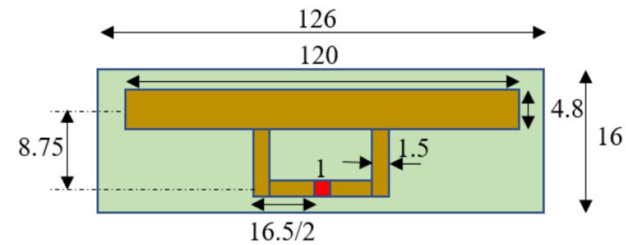


Fig. 19. optimized antenna with EGO method presented in [30].

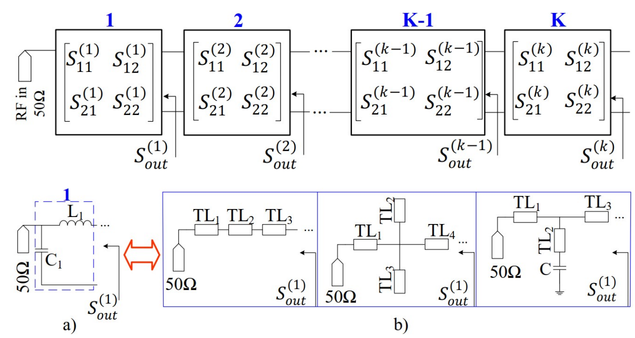


Fig. 20. a) Illustration of TDO method for dividing input/output MNs with S-parameter blocks [top]; b) Replacement choices of each block presented above with various TL-based blocks [bottom] [52].

multidimensional differential measurement.

The top-down optimization (TDO) method is opposite to the BUO method and it starts with largest sections and decreases to the smallest sections [51]. This method is employed in [52] for designing and optimizing amplifier where the input/output MNs are divided into subsections presented with scattering parameters (S-parameter) (see Fig. 20.a) and each of the subsections are replaced and evaluated with various TLs presented in Fig. 20.b.

This method is employed for optimizing the implanted multiple-input and multiple-output (MIMO) antennas leads to generate the configuration of the implanted antenna used for bio-medical applications [53]. As Fig. 21 presents the structure of the implanted MIMO antenna where firstly the various bio-medical tissues as bone, muscle, fat, and skin surroundings are sticked over together. Afterwards, the MIMO antenna mounted on the ground and substrate planes are assembling to

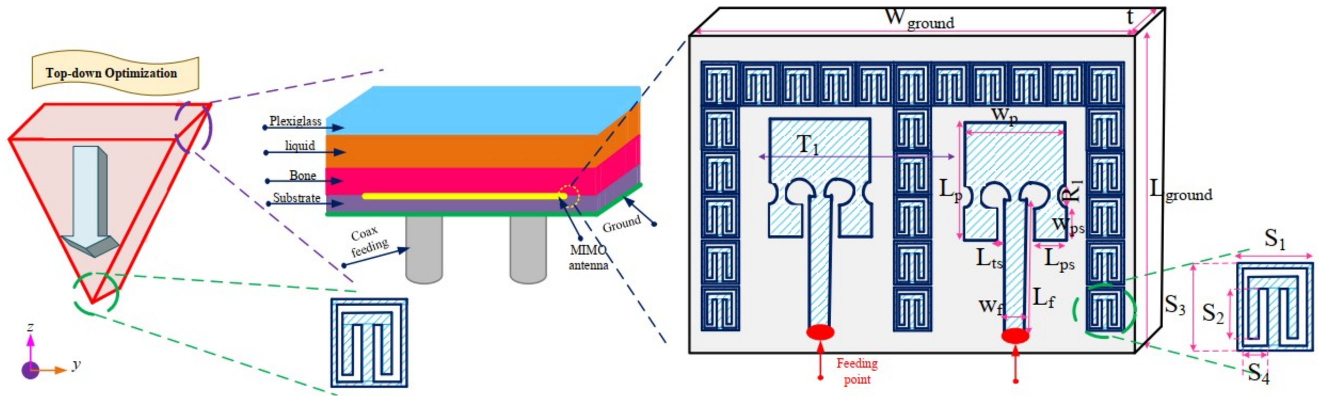


Fig. 21. Presented TDO method for configuring and optimizing implanted MIMO antenna [53].

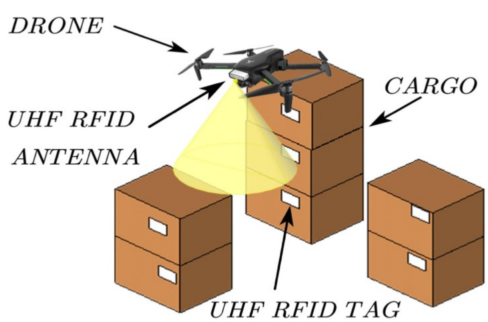


Fig. 22. Stocktaking task-planning with RFID readers [32].

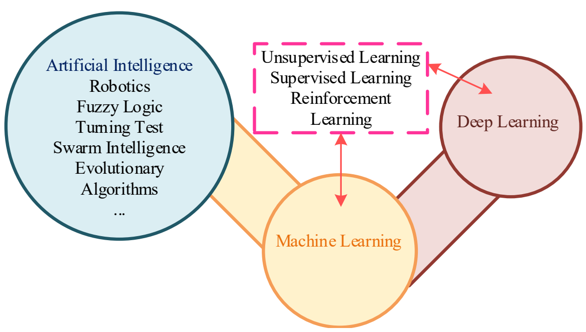


Fig. 23. Subsets of AI and it's applications in various domains and fields.

the bio-medical tissues. With this procedure, the difficulty of configuring implanted devices can be solved and the general structure of these bio-medical devices can be easily generated.

Liu et al., present the use of lion swarm optimization method for presenting a trajectory planning model for equipment with RFID readers [32]. This method enhances the efficiency and safety of overall system by minimizing the length of the flight path. Figure 22 shows the general view of drone stocktaking of goods where it is optimized to the minimal flight path.

For the practical use of RFID systems, artificial intelligence (AI) has gotten attention of researchers in the recent years [54], [55] and the subsets of AI are described in Fig. 23. From another point of view in the developed fifth and sixth generation (5G and 6G) networks, high performance amplifiers and antennas play important roles to improve the communication performance [56], [57]. Typically, the figure of merit (FoM) of each amplifier can be determined by the output power (P_L) that is challenged by the power gain (G_p), drain efficiency (η_D)), phase distortion (AM/PM), and amplitude distortion (AM/AM). Concurrently, considering these specifications are not straightforward and requires strong optimization-based approaches. Conventional electronic design automation (EDA) tools such as ADS, AWR, etc. are good candidates for providing optimizations; however, when the design parameters and specifications are lot, these tools can not be powerful enough.

Recently, learning-based methods that are based on the machine learning (ML) have been successfully used in the RF designs. In this track, shallow neural network (SNN) and deep neural network (DNN) are candidates to model the RF circuits such as amplifiers and antennas by determining the relationship between the input and out data that are design parameters and design specifications, respectively.

The SNN is the neural with one hidden layer that it proves its benefits in designing and optimizing complex circuits. In [58], the SNN is employed for designing an amplifier with TLs. In the presented method, the amplifier design is initialized by using the simplified real frequency technique (SRFT) [59]. Firstly, the suitable SNN for the amplifier with lumped elements is designed. Then the suitable SNN for this amplifier is trained, and finally with the help of constructed SNN, the amplifier with TLs is optimized. Figure 24 presents the general flowchart for optimizing an amplifier with TLs through a pre-constructed SNN.

The SNN is also used in the domain of antenna designs and it is useful in sizing the patch antennas. In [60] based on the Bayesian optimization (BO), the SNN is trained and the configured antenna with the BUO method is optimized results in flat-gain performance. Figure 25 demonstrates the presented optimization method that is based on the BUO and BO methods for configuring and sizing antennas, respectively.

By using the neural network, the antenna shown in Fig. 26 is optimized and sized where the optimal design parameters are predicted [61]. This network is employed uisng the particle swarm optimization (PSO). Another use of neural network is presented in [62] for GPS Beidou dual-mode Yagi microstrip antenna (see 27).

W. Su et al., design and optimize antenna that can be used for cross-body communication using neural network. The comprehensive antenna model with simulation results are depicted in Fig. 28 [63]. In another study, presented in [64], the BO method is employed for converting the lumped

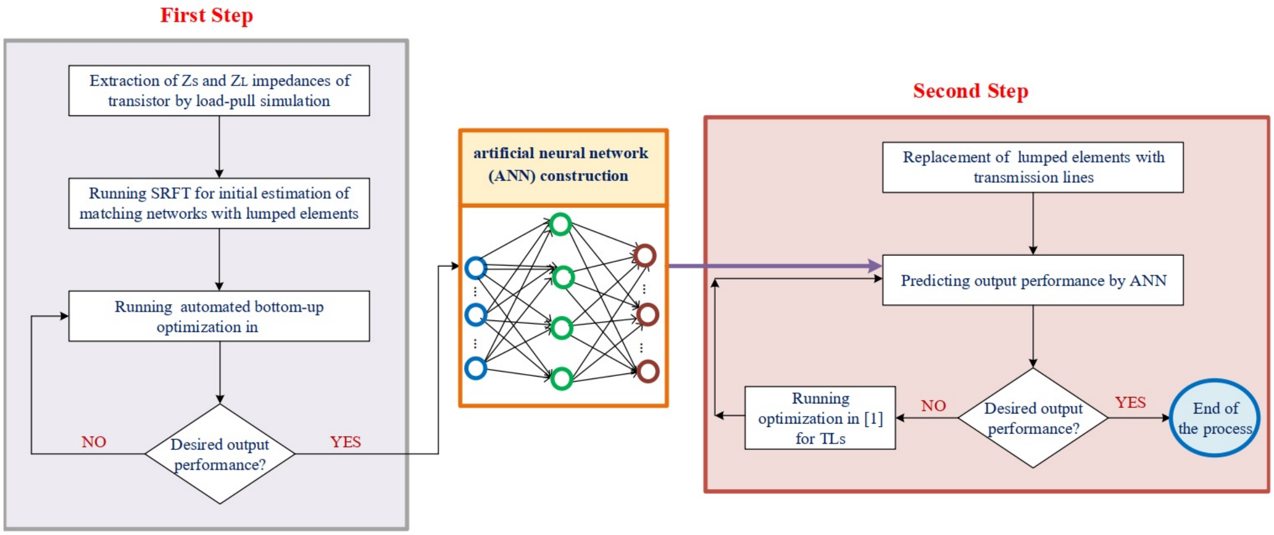


Fig. 24. Optimizing an amplifier with the pre-constructed SNN[58].

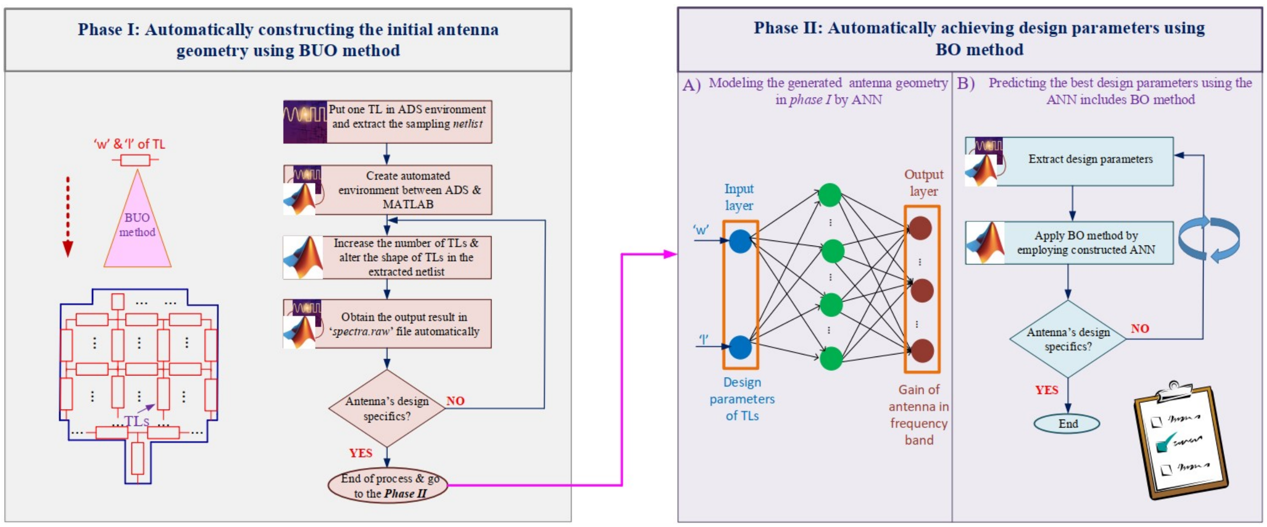


Fig. 25. Presented flowchart for configuring and sizing a patch antenna with the BUO method and SNN network [60].

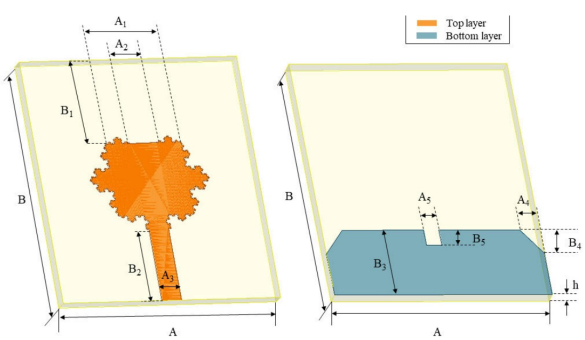


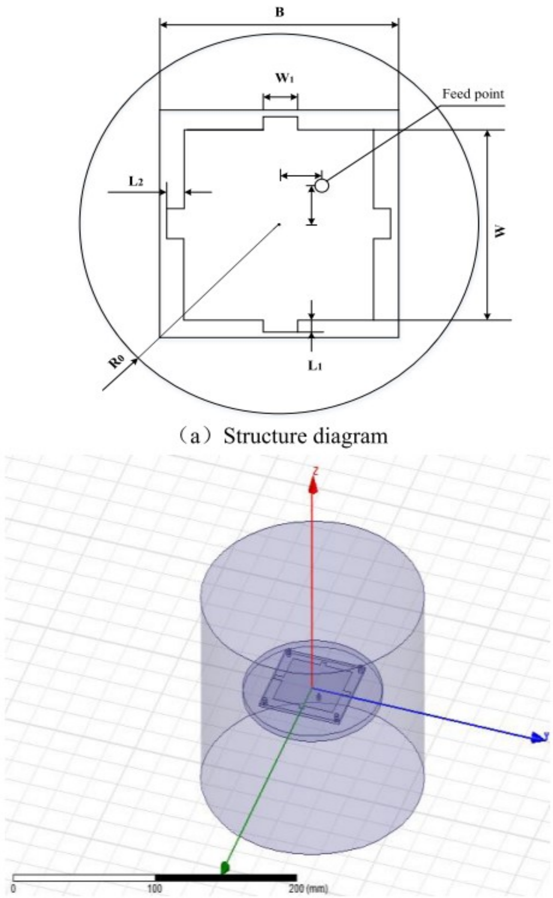
Fig. 26. Optimized antenna in [61].

element (LE) PA to the amplifier with distributed elements (DE). Figure 29 presents the BO-method for generating a PA with DEs where the initial design is with LEs.

The DNN is the multi-layer neural network leads to accurately modeling RF designs with lot design parameters [65], [66]. The practical use of this network is provided in the recently published studies.

The touch screen interaction system can be employed in the innovation of RFID sensing. Hence, many applicant are requesting high quality touch screens. In [54], the DNN structure is used for predicting the the hand finger gesture coordinates (see Fig. 30).

The application of DNNs with previously reported optimization methods is summarized in Fig. 31. It shows that based on the AI methods, once the transistor model is selected, automatically the high power amplifier (HPA) configuration with the electromagnetic (EM)-verified post-layout is generated. The summarized methods in the following will help the designers to achieve the ready-to-fabricate layouts without human interruption and dependency to designer's experience. The main objective is to provide the novel optimization-oriented methods where the transistor model is selected, the optimal configuration and design parameters are predicted automatically that result in post-layout generations. All the process is performed automatically where this platform is created with the combination of electronic design automation (EDA) tool as ADS and numerical analyzer as MATLAB. The EDA tool, working in the background, generates the



(a) Structure diagram

(b) HFSS model

Fig. 27. Sizing of antenna using the neural network presented in [62].

nonlinear simulation results of the PA. Besides, the numerical analyzer gets these data and do mathematical analysis and optimization. These optimized data are used for constructing the DNN to predict the optimal design parameters. Typically, optimizing nonlinear design specifications as $\mathrm{P_L}$, $\mathrm{G_p}$, η_D, and phase distortion are not straightforward and requires intelligent algorithms and methods. Hence, this method proposes the use of artificial intelligent (i.e., DNNs) and also implementation of strong multi-objective algorithms that paves the way of RF designers and generates ready-to-fabricate layouts.

The benefits of using DNNs in the RF designs can be divided into four subsections as:

- Providing an automated optimization-oriented environment which decreases the manual interruptions;
- Employing multi-objective algorithms for concurrently optimizing $\mathrm{P_L}$, $\mathrm{G_p}$, η_D, and phase distortion;
- Constructing the sequential classification and regression DNNs for predicting the suitable PA configuration and also optimal component values;
- Generating the ready-to-fabricate layout of HPAs after providing the transistor model.

Following devotes to present in detail the use of DNNs:

In [67] for enhancing the measurement performance of RFID system, DNN is employed to optimize the 3-D structure of multitag as Fig. 32 presents. This performance will avoid the collision of tags communication importantly and will reinforce the overall specification of the subsequent multitag batch reading.

In another study, the classification DNN and regression DNN are employed for determining the suitable topology of PA and sizing the design parameters, respectively [68]. The regression DNN, presented in [68], is based on the thompson sampling efficient multi-objective optimization (TSEMO) algorithm and the regression DNN, presented in [69], is based on the multi-objective pareto front using modified quicksort (PFUMQ) algorithm. The TSEMO-based DNN is for optimizing output power ($\mathrm{P_L}$) that is challenged by the power gain ($\mathrm{G_p}$), and drain efficiency (η_D)). Additionally, the PFUMQ-based DNN is for optimizing the phase distortion (AM/PM), and amplitude distortion (AM/AM). Figure 33 presents the classification DNN employed in [68] and the two regression DNNs based on the TSEMO [68] (Fig. 34.a) and PFUMQ [69] (Fig. 34.b) algorithms. The input layer features of regression DNN presented in Fig. 34.b are AM-to-AM and AM-to-PM specifications where they depend on the variation of source power (P_S). The output features are the pareto optimal front (POF) of two functions (f_1 and f_2) by using the PFUMQ algorithm.

In summary, the presented summarized methods can be used in designing and optimizing the amplifier and antennas.

1) Constructing and predicting the optimal configuration by:
   - Bottom-up optimization [46], [47];
   - Top-down pruning optimization [52];
   - Classification DNN [68];
2) Predicting optimal design parameters by:
   - Bayesian optimization with SNN [64], [58], [60];
   - Regression DNN based on the Thompson Sampling Efficient Multi-objective Optimization (TSEMO) algorithm [68];
   - Regression DNN based on the multi-objective particle swarm optimization (PSO) and multi-objective pareto front using modified quicksort (PFUMQ) algorithms [69];

In [70], a new method called MWISBAII is presented that is the distributed anti-collision algorithm and is based on the idea of a centralized collision avoidance algorithm. This method is combined with the machine learning leads to improved output responses. An example of RFID system with four readers as (R_1, R_2, R_3, and R_4) is presented in Fig. 35 where R_2 and R_3 are active and R_1 with R_4 are inactive. The overall performance of RFID system is improved by employing presented neural network in Fig. 36. For this case, a single neural network model is trained and the constricted model to every RFID reader is applied. The details of proposed flowchart are presented in Fig. 37.

C. Peng et al., present the deep convolutional neural network (CNN)-based approach for locating multiple tags with acceptable accuracy and stability in the indoor environment [71]. Figure 38 presents the designed CNN model for location scene of RFID readers and reference tags (see Fig. 39). In another use of deep learning, in [72] convolutional neural network structure is presented for activity recognition from

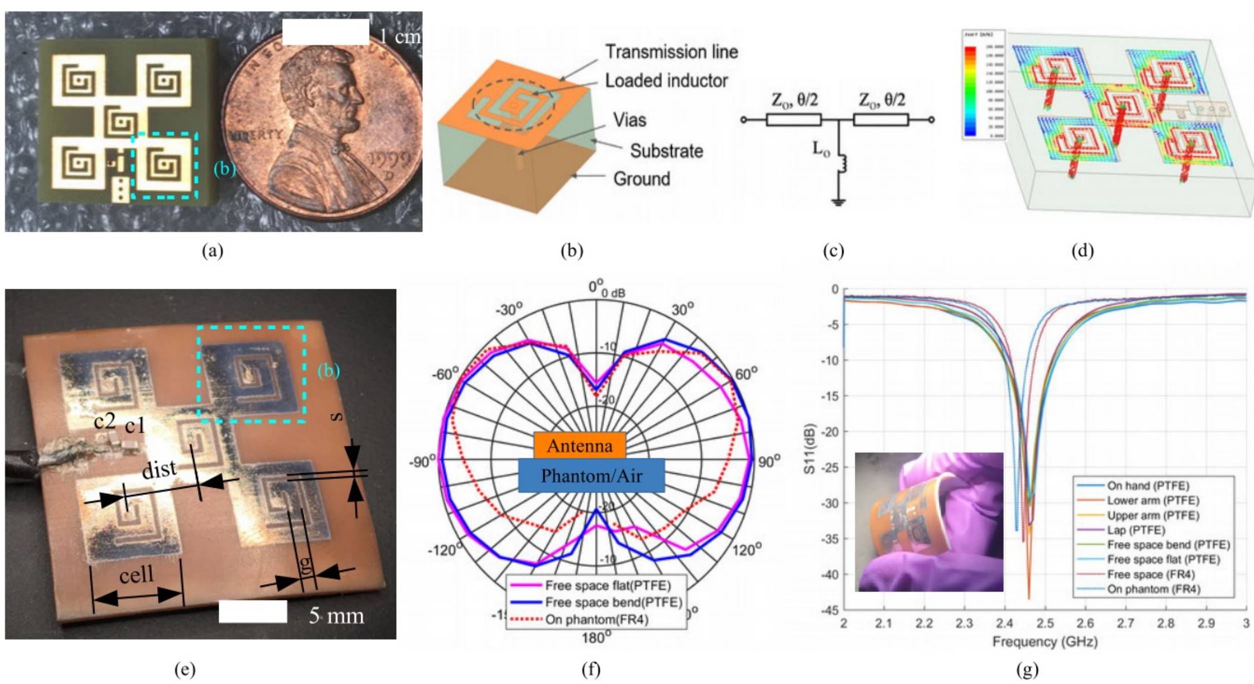


Fig. 28. Presented Mosaic antennas with their performances in [63]. Photo of (a) the presented antenna on FR4 substrate, (e) the flexible antenna on PTFE substrate. (b) the configuration of unit cell of antennas shown in (a) and (e). (c) equivalent circuit of the unit cell in (b). (d) simulated surface current distribution of the antenna. (f) measured radiation patterns of the flexible mosaic antenna. (g) the measured S11 of the flexible mosaic antenna. The inserted photo in (g) presents bending of the mosaic antenna.

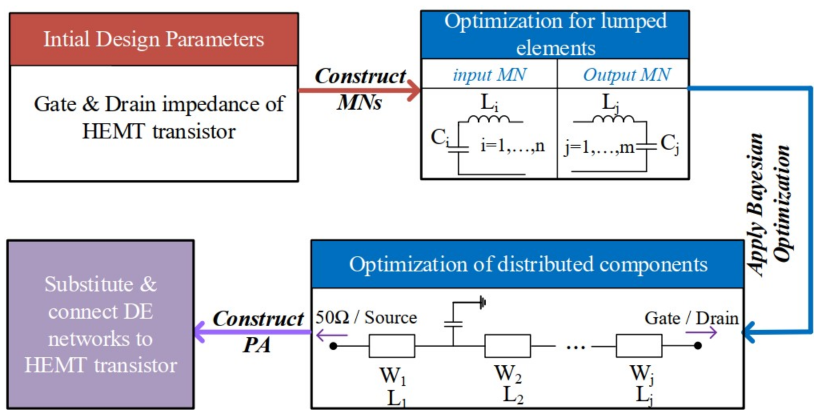


Fig. 29. Presented method for converting the LE power amplifier to the amplifier with the DEs through the BO method [64].

Fig. 30. a) DNN structure employed for the use of touch screens [right]; b) Gestures in touch screens [left] [54].

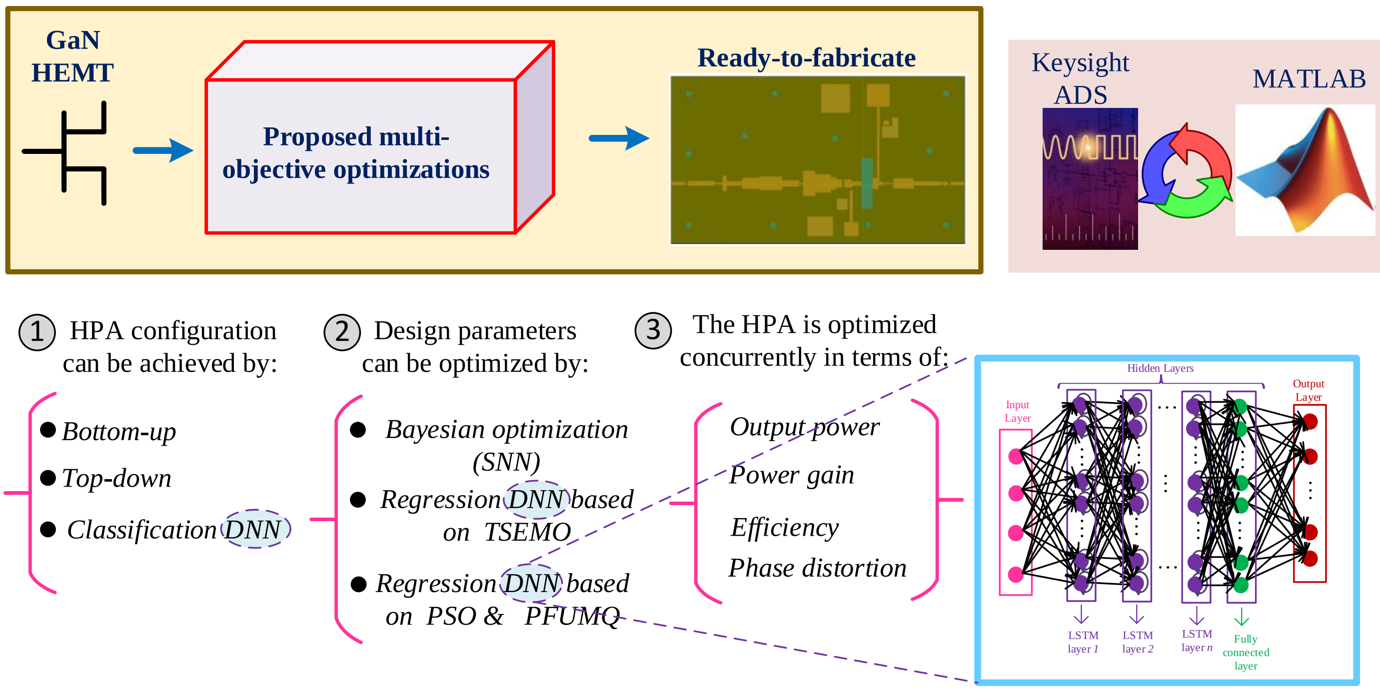


Fig. 31. An overview of the proposed optimization method where the transistor is selected, the EM-verified layout is generating automatically.

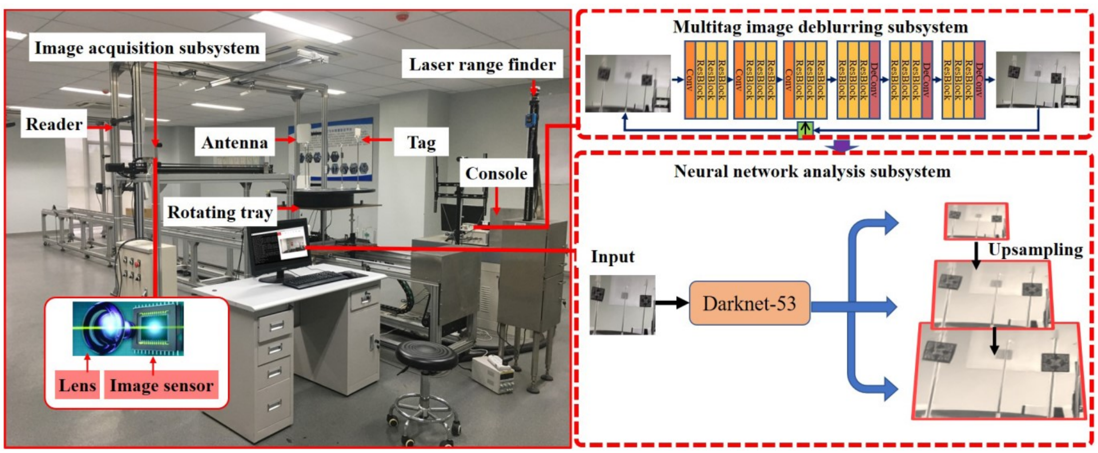


Fig. 32. Presented RFID dynamic performance measurement system through the DNN [67].

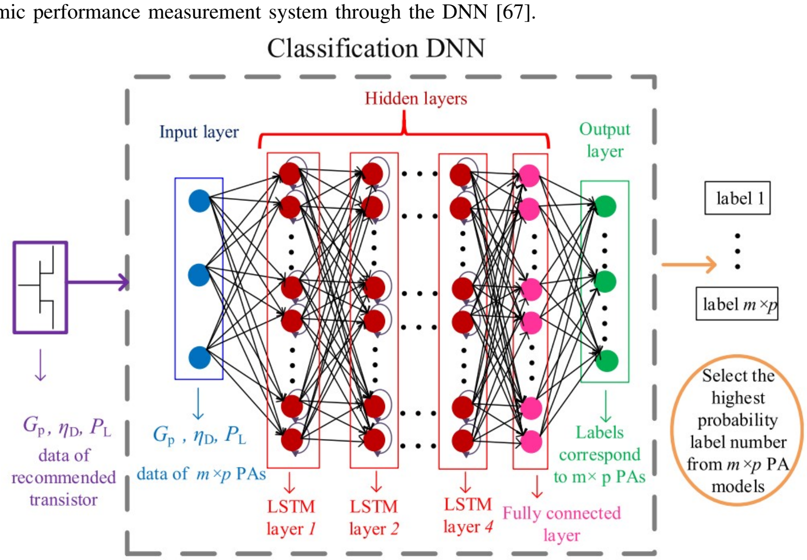


Fig. 33. Presented classification DNN for modeling the power amplifier [68].

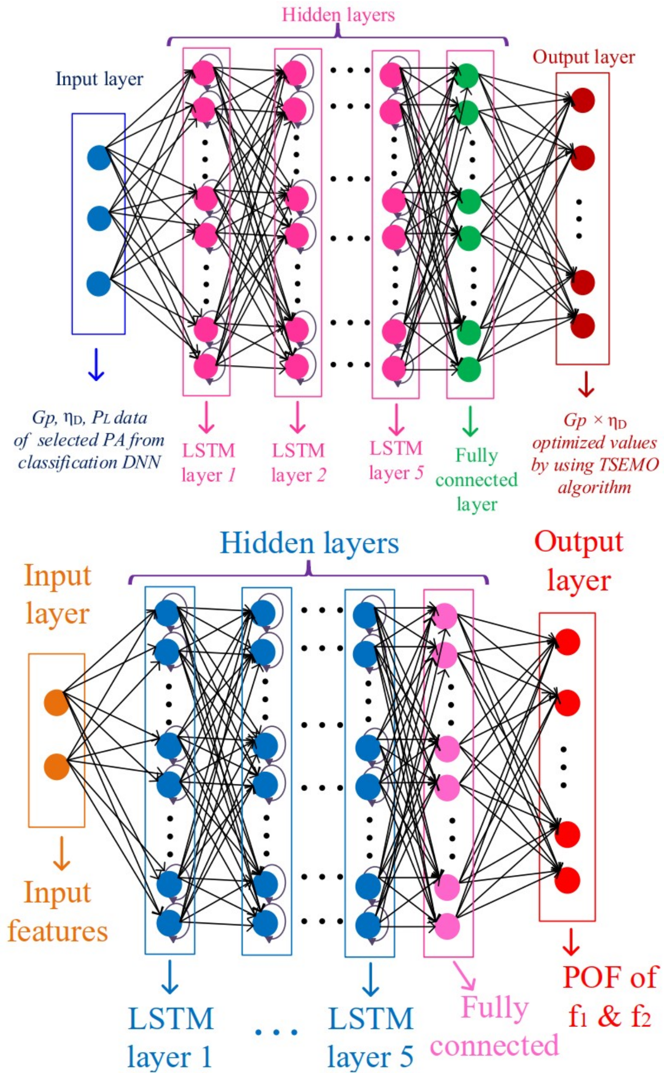


Fig. 34. a) Presented TSEMO-based DNN in [68] [top], and b) presented PFUMQ-based DNN in [69] where f_1=AM-to-AM(P_S) and f_2=AM-to-PM(P_S) [bottom].

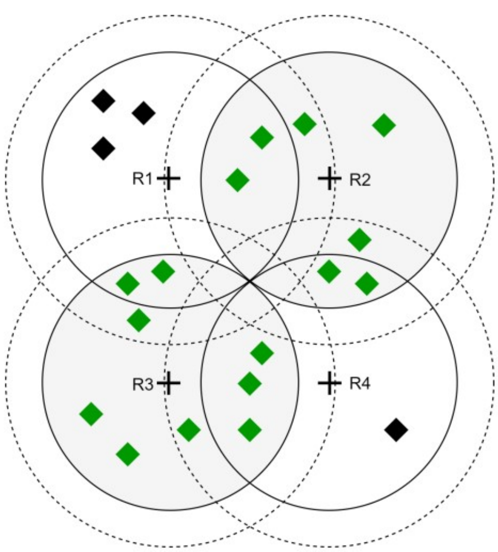


Fig. 35. Illustration of RFID system [70].

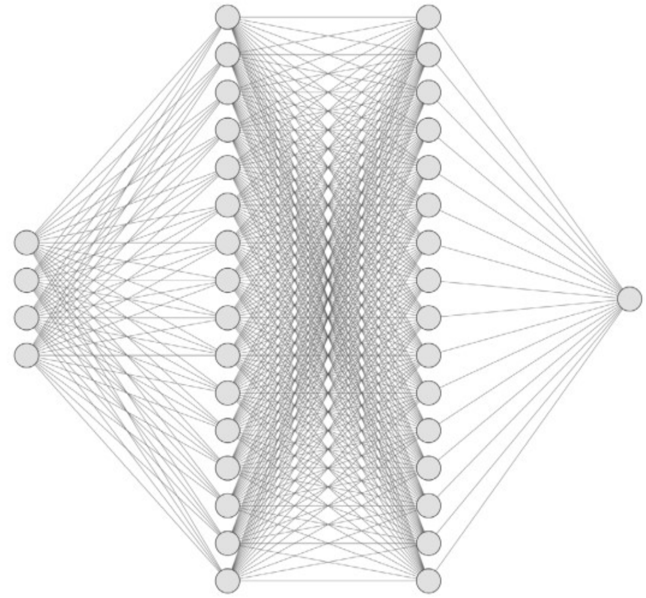


Fig. 36. Proposed flowchart in [70] with 4 neurons,16 neurons, 16 neurons, and 1 neuron in the input layer, first hidden layer, second hidden layer, and output layer, respectively.

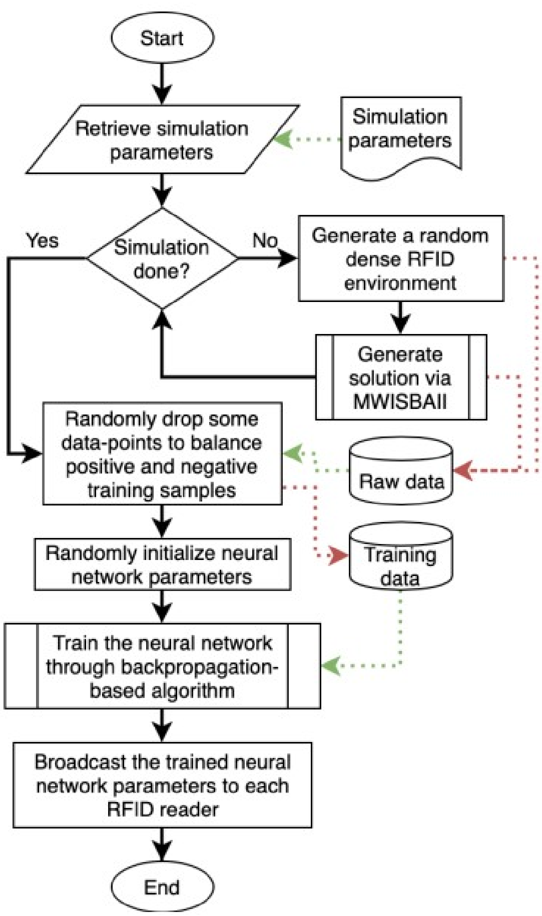


Fig. 37. Proposed flowchart in [70].

passive RFID data and it is appropriate for applications with large number of activity classes (see Fig. 40).

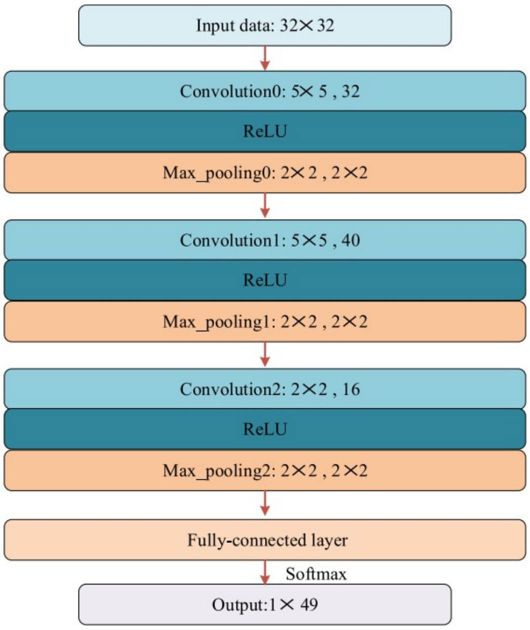


Fig. 38. Training procedure using the designed CNN model [71].

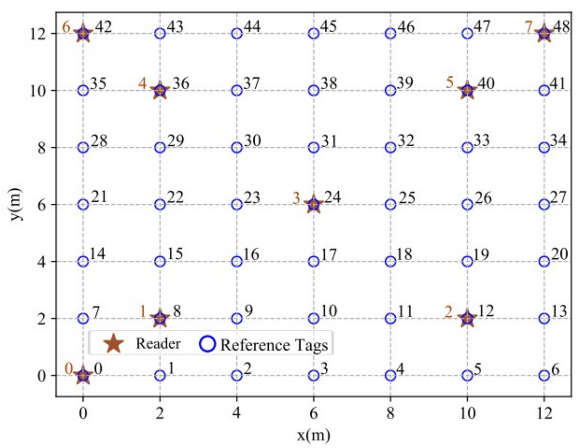


Fig. 39. Layout of readers and reference tags [71].

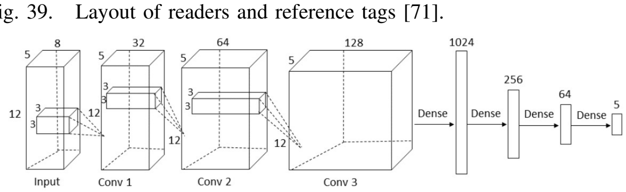


Fig. 40. Convolutional network with 3 convolutional layers and 3 fully connected layers [72].

IV. Conclusion

The RFID system plays an important role in the real world since it can capture and compute information automatically in the wireless communications. As presented in detail, the important blocks of RFID systems are amplifiers and antennas. For this case, this manuscript provides the comprehensive study on the recently published optimization methods used for designing RFID systems. That includes the diverse kinds of optimization methods and algorithms used for designing antennas and amplifiers. The engineers by studying this survey, will get a general idea of various algorithms and will determine a suitable method that can be applied for their design problems.

References

[1] Z. L. Oo, "IoT based LPG gas level detection & gas leakage accident prevention with alert system," pp. 404 – 409, 2021.

[2] A. Tzitzis, A. Raptopoulos Chatzistefanou, T. V. Yioultsis, and A. G. Dimitriou, "A real-time multi-antenna SAR-based method for 3D localization of RFID tags by a moving robot," *IEEE Journal of Radio Frequency Identification*, vol. 5, no. 2, pp. 207–221, 2021.

[3] D. Le, S. Ahmed, L. Ukkonen, and T. Björninen, "A small all-corners-truncated circularly polarized microstrip patch antenna on textile substrate for wearable passive UHF RFID tags," *IEEE Journal of Radio Frequency Identification*, vol. 5, no. 2, pp. 106–112, 2021.

[4] Z. Liu, Z. Fu, T. Li, I. White, R. Penty, and M. Crisp, "An ISAR-SAR based localization method using passive UHF RFID system with mobile robotic platform," in *2020 IEEE International Conference on RFID (RFID)*, 2020, pp. 1–7.

[5] S. Qi, Y. Lu, W. Wei, and X. Chen, "Efficient data access control with fine-grained data protection in cloud-assisted IIoT," *IEEE Internet of Things Journal*, vol. 8, no. 4, pp. 2886–2899, 2021.

[6] R. Seyfert, M. Maibaum, and S. Kroll, "RFID data storage and their key role in exploitation of metallic second life materials," *IEEE Journal of Radio Frequency Identification*, vol. 6, pp. 14–18, 2022.

[7] J. Yu, P. Zhang, L. Chen, J. Liu, R. Zhang, K. Wang, and J. An, "Stabilizing frame slotted aloha-based IoT systems: A geometric ergodicity perspective," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 3, pp. 714–725, 2021.

[8] Y. Zhang, K. Liu, Y. Ma, J. Wang, and S. Li, "Vehicular localization with using china electronic license plate system," *IEEE Journal of Radio Frequency Identification*, vol. 4, no. 4, pp. 322–331, 2020.

[9] P. Avaltroni, S. Nappi, and G. Marrocco, "Antennifying orthopedic bone-plate fixtures for the wireless monitoring of local deep infections," *IEEE Sensors Journal*, vol. 21, no. 18, pp. 21 012–21 021, 2021.

[10] M. Boada, A. Lazaro, R. Villarino, E. Gil-Dolcet, and D. Girbau, "Battery-less NFC bicycle tire pressure sensor based on a force-sensing resistor," *IEEE Access*, vol. 9, pp. 103 975–103 987, 2021.

[11] Q. Liu, Y. Yu, D.-W. Wang, and G. Wang, "An RFID-based wireless multistate controller with quasi-isotropic radiation pattern for remote control applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 10, pp. 2023–2027, 2021.

[12] S. Khan, W.-K. Lee, and S. O. Hwang, "A flexible gimli hardware implementation in FPGA and its application to RFID authentication protocols," *IEEE Access*, vol. 9, pp. 105 327–105 340, 2021.

[13] D. Inserra and G. Wen, "Dual orthogonal port stacked patch antenna with vertical pins for simultaneous transmit and receive application," *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 12, pp. 8908–8913, 2021.

[14] W. Sabat, D. Klepacki, K. Kamuda, and K. Kuryło, "Analysis of electromagnetic field distribution generated in an semi-anechoic chamber in aspect of RF harvesters testing," *IEEE Access*, vol. 9, pp. 92 043–92 052, 2021.

[15] Z. Wang, M. Xu, N. Ye, F. Xiao, R. Wang, and H. Huang, "Computer vision-assisted 3D object localization via COTS RFID devices and a monocular camera," *IEEE Transactions on Mobile Computing*, vol. 20, no. 3, pp. 893–908, 2021.

[16] A. DiNatale, A. DiCarlofelice, and E. DiGiampaolo, "A crack mouth opening displacement gauge made with passive UHF RFID technology," *IEEE Sensors Journal*, vol. 22, no. 1, pp. 174–181, 2022.

[17] M. Kokkonen, S. Myllymäki, J. Putaala, and H. Jantunen, "A resonator enhanced UHF RFID antenna cable for inventory and warehouse applications," *IEEE Journal of Radio Frequency Identification*, vol. 6, pp. 128–133, 2022.

[18] A. Adeyeye, C. Lynch, A. Eid, J. Hester, and M. Tentzeris, "5.8-ghz low-power tunnel-diode-based two-way repeater for non-line-of-sight interrogation of RFIDs and wireless sensor networks," *IEEE Microwave and Wireless Components Letters*, vol. 31, no. 6, pp. 794–797, 2021.

[19] M. Kim, U. Ha, Y. Lee, K. Lee, and H.-J. Yoo, "A 82nW chaotic-map true random number generator based on sub-ranging SAR ADC," in *ESSCIRC Conference 2016: 42nd European Solid-State Circuits Conference*, 2016, pp. 157–160.

[20] V.-H. Duong, N. X. Hieu, H.-S. Lee, and J.-W. Lee, "A battery-assisted passive EPC Gen-2 RFID sensor tag IC with efficient battery power management and RF energy harvesting," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 11, pp. 7112–7123, 2016.

[21] M. Nariman, F. Shirinfar, A. Papió Toda, S. Pamarti, A. Rofougaran, and F. De Flaviis, "A compact 60-GHz wireless power transfer system," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 8, pp. 2664–2677, 2016.

[22] B. Lee, M. Kiani, and M. Ghovanloo, "A smart wirelessly powered homecage for long-term high-throughput behavioral experiments," *IEEE Sensors Journal*, vol. 15, no. 9, pp. 4905–4916, 2015.
[23] J. Lorenzo, A. Lazaro, R. Villarino, and D. Girbau, "Active backscatter transponder for FMCW radar applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1610–1613, 2015.
[24] S. Khaledian, F. Farzami, H. Soury, B. Smida, and D. Erricolo, "Active two-way backscatter modulation: An analytical study," *IEEE Transactions on Wireless Communications*, vol. 18, no. 3, pp. 1874–1886, 2019.
[25] M.-S. Kim, S.-C. Jung, J. Jeong, H. Kim, M. Seo, J. Ham, C.-S. Park, and Y. Yang, "Adaptive TX leakage canceler for the UHF RFID reader front end using a direct leaky coupling method," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 4, pp. 2081–2087, 2014.
[26] A. Bucciarelli, E. Olivetti, A. Adami, and L. Lorenzelli, "Design of experiment rational optimization of an inkjet deposition of silver on kapton," *IEEE Sensors Journal*, vol. 21, no. 23, pp. 26 304–26 310, 2021.
[27] N. Cordeschi, F. De Rango, and M. Tropea, "Exploiting an optimal delay-collision tradeoff in CSMA-based high-dense wireless systems," *IEEE/ACM Transactions on Networking*, vol. 29, no. 5, pp. 2353–2366, 2021.
[28] F. Bernardini, A. Buffi, A. Motroni, P. Nepa, B. Tellini, P. Tripicchio, and M. Unetti, "Particle swarm optimization in SAR-based method enabling real-time 3D positioning of UHF-RFID tags," *IEEE Journal of Radio Frequency Identification*, vol. 4, no. 4, pp. 300–313, 2020.
[29] B.-Q. Zhao, H.-M. Wang, and P. Liu, "Safeguarding RFID wireless communication against proactive eavesdropping," *IEEE Internet of Things Journal*, vol. 7, no. 12, pp. 11 587–11 600, 2020.
[30] X. Zhang, H.-X. Li, and H. S.-H. Chung, "Setup-independent UHF RFID sensing technique using multidimensional differential measurement," *IEEE Internet of Things Journal*, vol. 8, no. 13, pp. 10 509–10 517, 2021.
[31] A. Tzitzis, S. Megalou, S. Siachalou, T. G. Emmanouil, A. Filotheou, T. V. Yioultsis, and A. G. Dimitriou, "Trajectory planning of a moving robot empowers 3D localization of RFID tags with a single antenna," *IEEE Journal of Radio Frequency Identification*, vol. 4, no. 4, pp. 283–299, 2020.
[32] H. Liu, Q. Chen, N. Pan, Y. Sun, Y. An, and D. Pan, "UAV stocktaking task-planning for industrial warehouses based on the improved hybrid differential evolution algorithm," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 1, pp. 582–591, 2022.
[33] J. Xu, H. Sato, M. Motoyoshi, N. Suematsu, K. Yasui, and Q. Chen, "A low-loss and compact UHF RFID tag antenna for implanted denture," *IEEE Journal of Radio Frequency Identification*, vol. 6, pp. 1–7, 2022.
[34] "The radio frequency identification system architecture," http://http://smartt-tags.com/#what-is-rfid?, accessed: 2022-01-01.
[35] C. Bredendiek, D. A. Funke, J. Schöpfel, V. Kloubert, B. Welp, K. Aufinger, and N. Pohl, "A 61-GHz SiGe transceiver frontend for energy and data transmission of passive RFID single-chip tags with integrated antennas," *IEEE Journal of Solid-State Circuits*, vol. 53, no. 9, pp. 2441–2453, 2018.
[36] J. Zhu, C. Jin, and H. Liu, "Mutual inductance modeling of two coaxial solenoid antennas with large ferrite core for underground RFID applications," *IEEE Transactions on Magnetics*, vol. 57, no. 8, pp. 1–4, 2021.
[37] G. M. Bianco, S. Amendola, and G. Marrocco, "Near-field constrained design for self-tuning UHF-RFID antennas," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 10, pp. 6906–6911, 2020.
[38] S. Ahmed, D. Le, L. Sydänheimo, L. Ukkonen, and T. Björninen, "Wearable metasurface-enabled quasi-yagi antenna for UHF RFID reader with end-fire radiation along the forearm," *IEEE Access*, vol. 9, pp. 77 229–77 238, 2021.
[39] Y. Chen, C. Hua, and Z. Shen, "Circularly polarized UHF RFID tag antenna for wireless sensing of complex permittivity of liquids," *IEEE Sensors Journal*, vol. 21, no. 23, pp. 26 746–26 754, 2021.
[40] S. Khaledian, F. Farzami, D. Erricolo, and B. Smida, "A full-duplex bidirectional amplifier with low DC power consumption using tunnel diodes," *IEEE Microwave and Wireless Components Letters*, vol. 27, no. 12, pp. 1125–1127, 2017.
[41] D. Zouache, Y. Ould Arby, F. Nouioua, and F. Ben Abdelaziz, "Multi-objective chicken swarm optimization: A novel algorithm for solving multi-objective optimization problems," *Computers Industrial Engineering*, vol. 129, pp. 377–391, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0360835219300725
[42] W. Shi, W. Wang, Y. Yu, S. Zhang, Y. Cao, S. Yan, and J. Gao, "Optimal deployment of phased array antennas for RFID network planning based on an improved chicken swarm optimization," *IEEE Internet of Things Journal*, vol. 8, no. 19, pp. 14 572–14 588, 2021.
[43] S. Cheng, Y. Shi, and Q. Qin, *Population Diversity of Particle Swarm Optimization Algorithm on Solving Single and Multi-Objective Problems*, ser. Handbook of Research on Advancements of Swarm Intelligence Algorithms for Solving Real-World Problems. Hershey, PA, USA: IGI Global, 2020, pp. 312–344. [Online]. Available: https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-7998-3222-5.ch014
[44] B. Cao, Y. Gu, Z. Lv, S. Yang, J. Zhao, and Y. Li, "RFID reader anticollision based on distributed parallel particle swarm optimization," *IEEE Internet of Things Journal*, vol. 8, no. 5, pp. 3099–3107, 2021.
[45] F. Passos, E. Roca, J. Sieiro, R. Fiorelli, R. Castro-López, J. M. López-Villegas, and F. V. Fernández, "A multilevel bottom-up optimization methodology for the automated synthesis of RF systems," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 39, no. 3, pp. 560–571, 2020.
[46] L. Kouhalvandi, O. Ceylan, and S. Ozoguz, "Automated matching network modeling and optimization for power amplifier designs," in *2019 11th International Conference on Electrical and Electronics Engineering (ELECO)*, 2019, pp. 510–513.
[47] F. Mir, L. Kouhalvandi, L. Matekovits, and E. O. Gunes, "Electromagnetic bottom-up optimization for automated antenna designs," in *2020 IEEE Asia-Pacific Microwave Conference (APMC)*, 2020, pp. 792–794.
[48] F. Mir, L. Matekovits, L. Kouhalvandi, and E. O. Gunes, "Optimization for wideband linear array antenna through bottom-up method," in *2020 IEEE International Conference on Electrical Engineering and Photonics (EExPolytech)*, 2020, pp. 51–54.
[49] R. González-Echevarría, E. Roca, R. Castro-López, F. V. Fernández, J. Sieiro, J. M. López-Villegas, and N. Vidal, "An automated design methodology of RF circuits by using pareto-optimal fronts of EM-simulated inductors," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, vol. 36, no. 1, pp. 15–26, 2017.
[50] M. H. Bakr, J. W. Bandler, K. Madsen, and J. Søndergaard, "An introduction to the space mapping technique," *Optimization and Engineering*, vol. 2, no. 4, pp. 369–384, Dec 2001. [Online]. Available: https://doi.org/10.1023/A:1016086220943
[51] S. Fidler, M. Boben, and A. Leonardis, "A bottom-up and top-down optimization framework for learning a compositional hierarchy of object classes," in *2009 IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*, 2009, pp. 3–3.
[52] L. Kouhalvandi, O. Ceylan, and S. Ozoguz, "Automated top-down pruning optimization approach in RF power amplifier designs," *Analog Integrated Circuits and Signal Processing*, vol. 106, no. 3, pp. 525–534, Mar 2021. [Online]. Available: https://doi.org/10.1007/s10470-020-01730-w
[53] L. Kouhalvandi, L. Matekovits, and I. Peter, "Deep learning assisted automatic methodology for implanted MIMO antenna designs on large ground plane," *Electronics*, vol. 11, no. 1, 2022. [Online]. Available: https://www.mdpi.com/2079-9292/11/1/47
[54] S. M. Aslam and S. Samreen, "Gesture recognition algorithm for visually blind touch interaction optimization using crow search method," *IEEE Access*, vol. 8, pp. 127 560–127 568, 2020.
[55] M. Hussein and F. Özyurt, "A new technique for sentiment analysis system based on deep learning using Chi-Square feature selection methods," *Balkan Journal of Electrical and Computer Engineering*, vol. 9, no. 4, pp. 320–326, 2021.
[56] H. Yin, J. Zhai, P. Chen, and C. Yu, "Directed graph navigated digital predistortion of mmWave power amplifiers for 6G hopping applications," *IEEE Microwave and Wireless Components Letters*, vol. 31, no. 11, pp. 1235–1238, 2021.
[57] N. L. K. Nguyen, N. S. Killeen, D. P. Nguyen, A. N. Stameroff, and A.-V. Pham, "A wideband gain-enhancement technique for distributed amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 9, pp. 3697–3708, 2020.
[58] L. Kouhalvandi, M. Pirola, and S. Ozoguz, "Automated two-step power amplifier design with pre-constructed artificial neural network," in *2020 43rd International Conference on Telecommunications and Signal Processing (TSP)*, 2020, pp. 617–620.
[59] S. Yarman, "Design of ultra wideband power transfer networks," *New York, NY, USA: Wiley*, 2010.
[60] F. Mir, L. Kouhalvandi, L. Matekovits, and E. O. Gunes, "Automated optimization for broadband flat-gain antenna designs with artificial neural network," *IET Microwaves, Antennas & Propagation*, vol. 15, no. 12, pp. 1537–1544, 2021. [Online]. Available: https://ietresearch.onlinelibrary.wiley.com/doi/abs/10.1049/mia2.12137
[61] J. Nan, H. Xie, M. Gao, Y. Song, and W. Yang, "Design of UWB antenna based on improved deep belief network and extreme learning machine surrogate models," *IEEE Access*, vol. 9, pp. 126 541–126 549, 2021.

[62] J. Gao, Y. Tian, and X. Chen, "Antenna optimization based on co-training algorithm of gaussian process and support vector machine," *IEEE Access*, vol. 8, pp. 211 380–211 390, 2020.
[63] W. Su, J. Zhu, H. Liao, and M. M. Tentzeris, "Wearable antennas for cross-body communication and human activity recognition," *IEEE Access*, vol. 8, pp. 58 575–58 584, 2020.
[64] L. Kouhalvandi, O. Ceylan, and S. Ozoguz, "Automated RF power amplifier optimization and design: From lumped elements to distributed elements," in *2019 27th Telecommunications Forum (TELFOR)*, 2019, pp. 1–4.
[65] J. Jin, C. Zhang, F. Feng, W. Na, J. Ma, and Q. Zhang, "Deep neural network technique for high-dimensional microwave modeling and applications to parameter extraction of microwave filters," *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 10, pp. 4140–4155, 2019.
[66] Y. LeCun, Y. Bengio, and G. Hinton, "Deep learning," *Nature*, vol. 521, pp. 436–44, 05 2015.
[67] L. Li, X. Yu, Z. Liu, Z. Zhao, K. Zhang, and S. Zhou, "RFID dynamic performance measurement system embedded in multiscale deep learning," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–12, 2021.
[68] L. Kouhalvandi, O. Ceylan, and S. Ozoguz, "Automated deep neural learning-based optimization for high performance high power amplifier designs," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 67, no. 12, pp. 4420–4433, 2020.
[69] ——, "Multi-objective efficiency and phase distortion optimizations for automated design of power amplifiers through deep neural networks," in *2021 IEEE MTT-S International Microwave Symposium (IMS)*, 2021, pp. 233–236.
[70] P. Yan, S. Choudhury, and R. Wei, "A machine learning auxiliary approach for the distributed dense RFID readers arrangement algorithm," *IEEE Access*, vol. 8, pp. 42 270–42 284, 2020.
[71] C. Peng, H. Jiang, and L. Qu, "Deep convolutional neural network for passive RFID tag localization via joint RSSI and PDOA fingerprint features," *IEEE Access*, vol. 9, pp. 15 441–15 451, 2021.
[72] X. Li, Y. Zhang, I. Marsic, A. Sarcevic, and R. Burd, "Deep learning for RFID-based activity recognition," vol. 2016, 11 2016.

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