Proceedings of the Third International Conference on Intelligent Sustainable Systems [ICISS 2020]
IEEE Xplore Part Number: CFP20M19-ART; ISBN: 978-1-7281-7089-3

2020 3rd International Conference on Intelligent Sustainable Systems (ICISS) | 978-1-7281-7089-3/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICISS49785.2020.9316105

# *Design of Circularly Polarized Patch Antenna using Genetic Algorithm for Energy Harvesting*

Dhakshinamoorthi M K, Denesh Kumar M, Gokulakkrizhna S, Subha M, Mekaladevi V
Department of Electronics and Communication Engineering
Amrita School of Engineering, Coimbatore
Amrita Vishwa Vidyapeetham, India
kdhakshna07@gmail.com, v_mekaladevi@cb.amrita.edu

*Abstract*— **This paper presents a design of single-fed circularly polarized patch antenna at 2.4 GHz-band for RF energy harvesting application. The irregular shaped patch is obtained by genetic algorithm optimization technique. The fitness function for circular polarization and return loss has reliably conflated in the genetic algorithm. The optimized irregular shaped single-fed microstrip patch antenna is designed using Matlab and HFSS software and the simulated result shows a return loss of -15.498 dB and the axial ratio of 2.09 dB at 2.41 GHz resonating frequency.**

*Keywords—Microstrip patch antenna, single feed, circular polarization, Genetic algorithm, energy harvesting.*

## I. INTRODUCTION

Since the 19th century, there was a huge requirement for the development of the communication system. This has led to a drastic boom in communication devices. The communication devices include everything from cellular phones to the latest Li-Fi technology. It also includes Bluetooth, GPS, wireless LAN, Wi-Fi that are utilized in our daily lives. Currently, the most commonly used WLAN is the IEEE 802.11b system [1], with a throughput of 11 Mbps. These communication systems now are trying to achieve a larger throughput, with high bandwidth and gain that completely relies on the performance of the antenna.

It is already known that, our major source of the power supply is limited, and so the need for alternate energy sources has become more essential. But a large quantity of energy is also getting wasted. These energies could be harvested (to harvest energy from vibrations and unused EM waves) and reused to power up some electronic devices. The abundant radio frequency (RF) energy can be harvested from sources like mobile phone, wireless LANs, Wi-Fi, or FM/AM radio signals and broadcast signals are captured by an antenna and rectified into usable DC voltage at receiving end [2]. For the practical approach of harvesting energy, the beamwidth of the antenna should be high. The classical method of the power supply is a battery which limits the life of electronic devices, but by energy harvesting, there will be a source of energy for a long time.

A receiver should be highly versatile to both operating frequency and RF power range to attain RF energy harvesting. The harvested amount is dependent on the environment, transmitted power, source type, path loss exponents, and the distance between them [3].

In the past few years, various antenna have been proposed for energy harvesting like loop antenna, a monopole antenna, dipole antenna, Yagi-Uda antenna, microstrip patch antenna (MPA) but RF energy harvesting design is commonly done in MPA due to its low profile, lightweight, and planar structure [4]. In [5], low cost cement substrate is used to construct patch antenna to attain low cost device.

To manage the problem of unknown location and orientation of the RF source, an antenna is designed with circular polarization (CP) property with large beamwidth. A rectenna with a wide operating input power range has been achieved in [6] to deal with the input power of varying levels.

According to [7], the primary requirement of antenna design for energy harvesting would be CP and wide beamwidth to maximize the received power. The requirement of devices with low power consumption is recovered by using this energy harvesting technique and also replacing limited energy sources like batteries.

CP radiates the field in both vertical and horizontal directions. CP can be achieved in MPA by making an asymmetric shape on the patch. [8-9] proves that it has achieved CP by making slits of different shapes on the antenna. [10] has achieved CP by adding a circular patch of different radii on each corner of the patch. CP can also be achieved by making slots on the ground plane (DGS) of the MPA. [11] explains CP can also be achieved by making slots on the ground plane (DGS) of the MPA by reducing cross polarization. [12] has achieved CP by making Y structure slot on the ground of MPA.

The structure of the patch plays an important role in defining the property of the antenna. So, to figure out the best patch structure that has incorporated an evolutionary algorithm with certain conditions on the patch.

A genetic algorithm (GA) is a search technique used to find the solutions for that are approximate to optimization and search problems. GA is the process which has a larger search space when compared to other optimization technique. The solution obtained from the GA will be a global optimum. GA optimization's been widely used in the areas of electromagnetics such as antennas, antenna arrays, radar, etc. This evolutionary algorithm uses techniques such as selection, mutation, and crossover for optimization. [13] has explained evolutionary algorithm optimization on MPA. The main reason for GA on the antenna is that to divide the rectangular MPA into a grid of symmetrical rectangles and evaluate all the possible structures and derive the best structure with the help of the fitness function.

When the beamwidth of the antenna is wide, more number of EM waves within the range can be converted to a voltage. The efficiency of the antenna is directly proportional to the Gain and directivity of the antenna design. This value should be high to increase the magnitude of the output voltage. From a literature survey designing a circularly polarized, microstrip patch fed by single microstrip line using the genetic algorithm was not attempted by any scholars. An energy harvesting antenna should be contemptible with the transmitter in its surrounding; hence it should be circularly polarized. Since the antenna has only single feed the circular polarization is achieved only by GA. And if circular polarization can be achieved through basic optimization technique like genetic algorithm, then it is evident that it is possible for more advanced evolutionary algorithms. Hence, the genetic algorithm is chosen to achieve our objective. Based on the literature survey, the antenna with a single substrate for RF energy harvesting has achieved an efficiency of 30-40 percent.

The objective of this paper is to achieve circular polarization by applying GA on linearly polarized MPA resonating at a different frequency.

## II. Design Procedure

The genetic algorithm involves both computational and conventional designs for which the MATLAB and Ansys HFSS software tools are used respectively. The objective of the GA design is to achieve circular polarization at the desired frequency which is converted into a set of protocols and constraints that defines GA in MATLAB.

The first and basic step of the GA simulation is to determine the parameters such as population size, the maximum number of generations, the chromosome length, crossover rate, mutation rate, maximum mutation percentage of an individual, fitness function, and termination criteria. Once the parameters have set, the initial set of chromosomes is randomly created concerning population size. The individuals in this set of chromosomes will be modeled in HFSS and the solved results will return to MATLAB. If any of these values satisfy the termination criteria, then the iteration will be terminated while the terminated chromosome becomes the best. If not, then it will move onto operations such as selection, crossover, mutation, and elitism. These operations will repeat until the simulation reaches the maximum number of generations or meets the termination criteria in upcoming generations.

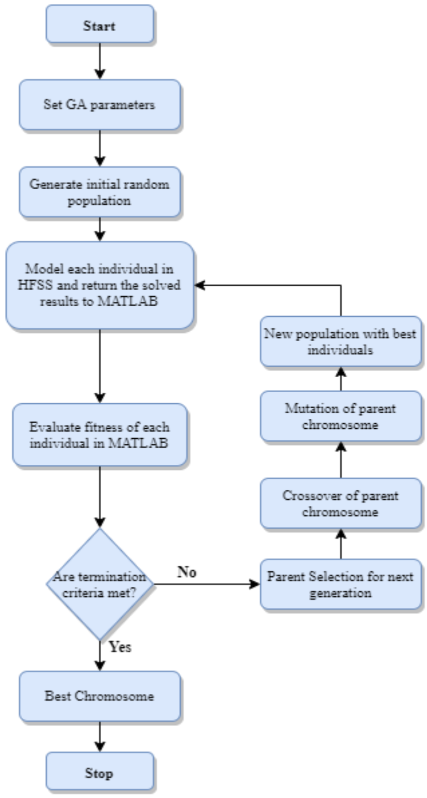


Fig 1. Flowchart of proposed GA

The patch is divided into n x m rectangular cells. Binary coded GA with 1 being no slot and 0 being slot is implemented. 2D chromosome is imposed for each individual. The chromosomes undergo crossover and mutation, which produces new chromosomes. Crossover means more than one parent is selected to produce one or more off-springs by exchanging the set of cells between the parents. Mutation means flipping of variable values because every variable has only two states that may lead to a better chromosome. The newly produced chromosome can either be best or worst. Each chromosome is given a value for fitness based on the required characteristics. So the chromosome with the highest fitness value will be the best. In each generation, the individuals with the worst fitness values are discarded.

The key role in yielding the best result at the end of GA optimization is to define a fitness function that accounts for all variables in the objective. For any GA optimization, the final result will consist of a set of better individuals but each with different characteristics. To achieve the best and optimized individual, the fitness function assigns a fitness value for each design depending on how close they meet the objective. The goal is to define a fitness function that achieves circular polarisation at the desired frequency without changing the resonant frequency. The GA optimization will be converged depending on the pressure kept on the individual by the fitness function.

For achieving circular polarization, the axial ratio of the antenna should be below 3dB. Axial ratio is the ratio between the minor and major axis of the polarization ellipse. The fitness function is defined considering this parameter as a variable in the objective function. Fitness function is defined such that to minimize the axial ratio at the desired frequency. Based on this fitness function and the parameters obtained from the literature survey, we ran the simulation. We observed that minimizing the axial ratio affected the resonant frequency. So we defined a fitness function that accounts for both axial ratio and return loss. We referred to the fitness function defined in [14] for minimizing the return loss. The fitness function is as defined in eq. (1) – (5).

$$L1(fi) = \begin{cases} |\mathrm{s11}(fi)|, \mathrm{s11}(fi) \geq -11\mathrm{dB} \\ 11, \text{otherwise} \end{cases} \quad (1)$$

$$L2(fi) = \begin{cases} \mathrm{ar}(fi), \mathrm{ar}(fi) > 3\mathrm{dB} \\ 3, \text{otherwise} \end{cases} \quad (2)$$

$$F1 = \begin{cases} \frac{\sum_N L1(fi)}{N}, \mathrm{s11min} > -9\mathrm{dB(or)armin} > 6.5\mathrm{dB}, \\ \frac{\sum_N L1(fi)}{(N|frl - fd|)}, otherwise \end{cases} \quad (3)$$

$$F2 = \begin{cases} \frac{\sum_N L2\,(fi)}{N}, \mathrm{s11min} > -9\mathrm{dB}\ (\mathrm{or})\ \mathrm{armin} > 2.5\mathrm{dB} \\ \left(\sum_N L2\,(fi)\right)(N|far - fd|), otherwise \end{cases} \quad (4)$$

$$F = \begin{cases} \frac{\mathrm{F1}}{\mathrm{F2}}, \mathrm{s11min} > -10.5\mathrm{dB}\ (\mathrm{or})\ \mathrm{armin} > 2.8\mathrm{dB} \\ \frac{\mathrm{F1}}{\mathrm{F2}|frl - far|}, \text{otherwise} \end{cases} \quad (5)$$

Where $f_i$: Frequency of each sample

$N$: Total no. of samples under consideration (500)

$f_d$: Frequency required (2.4 GHz)

$f_{rl}$: The individual resonance frequency

$s11_{min}$: The s11(dB) at resonating frequency.

$ar_{min}$: The min axial ratio

$f_{ar}$: Frequency at min axial ratio

This fitness function aims to maximize the negative of return loss and minimize the axial ratio at a particular frequency. With this fitness function, we ran the simulation. But the results weren't quite promising. From the results, we observed that frequency at the axial ratio minimum and s11 minimum were far apart. The parameters like population size, mutation rate, mutation percentage, crossover rate, selection type were changed to improve the results. The results improved but not significantly. The algorithm was modified to improve the output of the simulation.

In each generation, due to crossover and mutation, new offsprings are produced from the parents. These offspring may be good or bad. So based on the fitness values, these are arranged from better to worse. The worst 25% of the population was discarded in each generation to improve the algorithm and thereby convergence rate. Since the population size reduces in each generation, the solution space reduced while making the simulation stagnant at a solution.

Symmetric structure constraint was added to the GA algorithm to observe improvement in results. Since this population is a subset of larger search space, the results did not converge. Besides, we observed the worst outcome after the optimization. The results of this simulation satisfied only one of the objectives either return loss or axial ratio.

MATLAB considers values above a certain threshold as infinity. This becomes the limitation of the algorithm, as the first individual to attain infinity will be the best chromosome leaving the better individuals in upcoming generations neglected. Also, individuals with closer fitness values are not differentiated enough. Logarithmic functions are included in the fitness function to scale down the fitness value and to differentiate the individuals with closer fitness values. The improved fitness function is given below in eq. 6 – 10 and the corresponding termination criteria in eq. 11.

$$L1(fi) = \begin{cases} |s11(fi)|, s11(fi) \geq -13dB \\ 13, otherwise \end{cases} \quad (6)$$

$$L2(fi) = \begin{cases} ar(fi), ar(fi) > 2dB \\ 2, otherwise \end{cases} \quad (7)$$

$$F1 = \begin{cases} log\left(\frac{\sum_N L1(fi)}{N}\right) s11min > -11dB\,(or) armin > 5.5dB \\ log\left(\frac{\sum_N L1(fi)}{(N|frl - fd|)}\right), otherwise \end{cases} \quad (8)$$

$$F2 = \begin{cases} log\left(\frac{\sum_N L2(fi)}{N}\right) s11min > 9dB\,(or) armin > 2.5dB \\ log\left(\frac{\sum_N L2(fi)}{N} \|far - fd\|\right), otherwise \end{cases} \quad (9)$$

$$F = \begin{cases} F1 - F2, s11min > -12dB \ (or) \ armin > 2.2dB \\ F1 - F2 - \log(|frl - far|), \ otherwise \end{cases} \quad (10)$$

$$2.37 > frl < 2.43 \ \&\& \ 2.365 > far < 2.425 \ \&\& \ s11 < -13.5 \ \&\& \ ar < 2 \ \&\& \ ||far - frl|| < 0.05 \quad (11)$$

Where $f_i$: Frequency of each sample

$N$: Total no. of samples under consideration (500)

$f_d$: Frequency required (2.4 GHz)

$f_{rl}$: The individual resonance frequency

$s11_{min}$: The s11(dB) at resonating frequency.

$ar_{min}$: The min axial ratio

$f_{ar}$: Frequency at min axial ratio

We understood the key role of the initial population on the convergence rate based on the results from the above simulations. The individuals in the initial population should be equally distributed for the simulation to converge, i.e. to attain global optima. So we decided to feed the initial population with the results from previous simulations. As different improvements and modifications have analyzed on GA, few best and worst results of these simulations obtained fed as the initial population to this algorithm. This will improve the diversity in search space so that the offspring produced will be in good quality. When we simulated the algorithm with these constraints, we obtained the global optimum that satisfies the required objective.

## III. RESULTS

From the above training steps, we simulated with the initial factors population size – 30, maximum generation – 30 and GA operators – Rank Selection, One, Two-point and Uniform Crossover and elitism for the final optimized result. The result converged as this GA got terminated at 26th Generation because the optimized design satisfied the termination criteria in eq. (11). The dimensions of the resultant design are shown in table I and the substrate material FR4 Epoxy with dielectric constant of 4.4 is used.

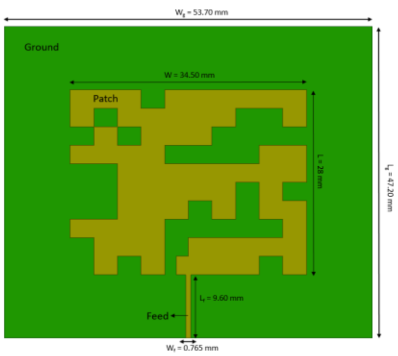


Fig 2. Optimized Design

TABLE I. ANTENNA DIMENSIONS

| Parameters | Values (mm) |
|---|---|
| Length of the patch (L) | 28 |
| Width of the patch (W) | 34.5 |
| Length of the ground ($L_g$) | 47.2 |
| Width of the patch ($W_g$) | 53.7 |
| Length of the feed ($L_f$) | 9.6 |
| Width of the feed ($W_f$) | 0.765 |
| Thickness of the substrate (h) | 1.6 |

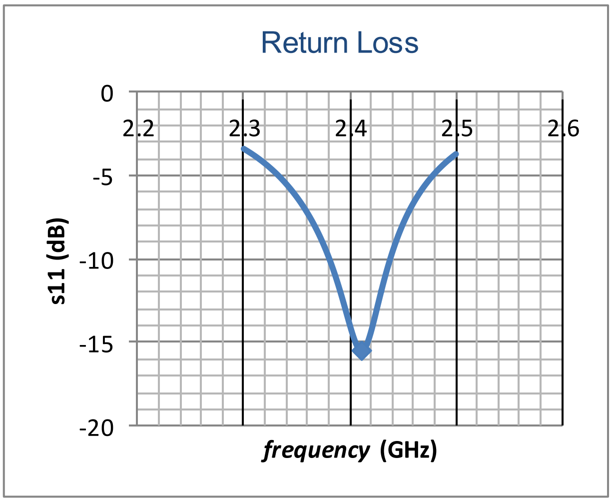


Fig 3. Return Loss

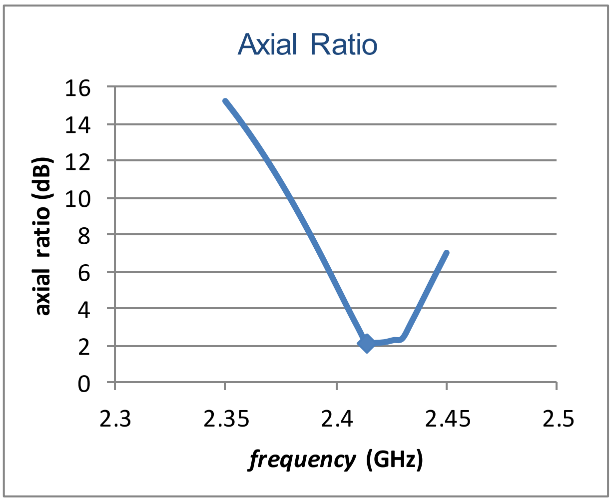


Fig 4. Axial ratio

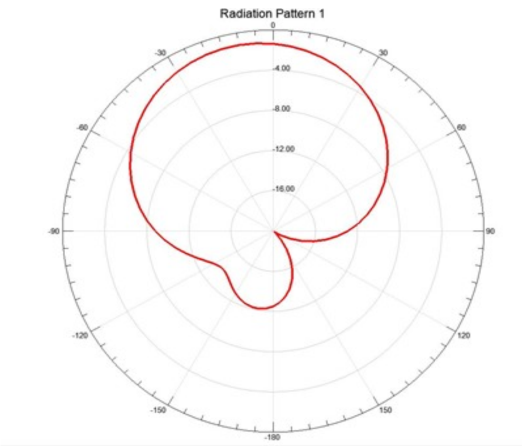


Fig 5. Radiation pattern of gain

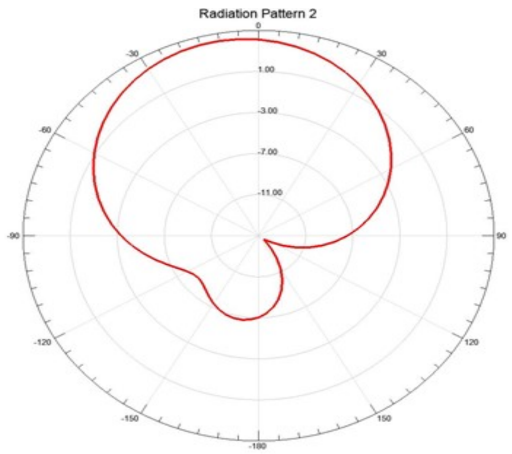


Fig 6. Radiation pattern of directivity

(a) (b)

(c) (d)

Fig 7. Vector E fields (a) at phase = $0^0$ (b) at phase = $90^0$ (c) at phase = $180^0$ (d) at phase = $270^0$

Fig 2 show the design of the GA modified patch and fig 3 shows that this antenna resonates at 2.41 GHz with a return loss of -15.498 dB. This antenna has an axial ratio of 2.09 dB at 2.41 GHz as shown in fig 4. The gain and directivity of the optimized is shown in fig 5 and fig 6 respectively. The electric field distribution on patch is shown in fig 7.

## IV. CONCLUSION

We obtained the results by researching a wide range of solution space and narrowing it down to global optima. We defined a fitness function to achieve axial ratio 3dB while maintaining return loss below -13.5dB. The final optimized antenna resonates at 2.41 GHz with a return loss of -15.498 dB and obtained circular polarization with an axial ratio of 2.09 dB and a beamwidth of $82^0$. The proposed antenna is suitable for energy harvesting as it satisfies the fundamental requirements of circular polarization and wide beamwidth. However, the efficiency of the antenna is 27.71%. The efficiency is low due to the FR4 substrate. This efficiency can be improved with a lossless substrate and thereby increasing the gain of the antenna.

## V. FUTURE SCOPE

The genetic algorithm has been used in this antenna design to achieve circular polarization. This energy harvesting designs efficient can be improved by considering gain as one of the parameters in the constraint of GA fitness function and also by having a lossless substrate. This work can further be extended to a multi-band antenna to improve the magnitude of voltage.

## REFERENCES


[1] Wong, W. W. L., V. C. M. Leung, and R. W. Donaldson. "Call transport alternatives for interconnected wireless communication networks based on IEEE 802.6 MAN." In IEEE Pacific Rim Conference on Communications, Computers, and Signal Processing. Proceedings, pp. 235-240. IEEE, 1995.

[2] Keyrouz, S., H. J. Visser, and A. G. Tijhuis. "Multi-band simultaneous radio frequency energy harvesting." In 2013 7th European Conference on Antennas and Propagation (EuCAP), pp. 3058-3061. IEEE, 2013.

[3] Soyata, Tolga, Lucian Copeland, and Wendi Heinzelman. "RF energy harvesting for embedded systems: A survey of tradeoffs and methodology." IEEE Circuits and Systems Magazine 16, no. 1 (2016): 22-57.

[4] Shrestha, Sika, Sun-Kuk Noh, and Dong-You Choi. "Comparative study of antenna designs for RF energy harvesting." International Journal of Antennas and Propagation 2013 (2013).

[5] M. V. Amrutha and B. S. Narayanan, "Low profile patch antenna on cement substrate for indoor applications," 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, 2017, pp. 2508-2511, doi: 10.1109/WiSPNET.2017.8300213.

[6] Liu, Zhongtao, Zheng Zhong, and Yong-Xin Guo. "Enhanced dual-band ambient RF energy harvesting with ultra-wide power range." IEEE microwave and wireless components letters 25, no. 9 (2015): 630-632.

[7] Barcak, J. Michael, and Hakan P. Partal. "Efficient RF energy harvesting by using multiband microstrip antenna arrays with multistage rectifiers." In 2012 IEEE Subthreshold Microelectronics Conference (SubVT), pp. 1-3. IEEE, 2012.

[8] Yang, Kai-Ping, and Kin-Lu Wong. "Dual-band circularly-polarized square microstrip antenna." IEEE Transactions on Antennas and Propagation 49, no. 3 (2001): 377-382.

[9] Kovitz, Joshua M., Harish Rajagopalan, and Yahya Rahmat-Samii. "Circularly polarised half E-shaped patch antenna: a compact and fabrication-friendly design." IET Microwaves, Antennas & Propagation 10, no. 9 (2016): 932-938.

[10] Anjani, Y. S., and Arokiaswami Alphones. "A wide-beam circularly polarized asymmetric-microstrip antenna." IEEE Transactions on Antennas and Propagation 63, no. 8 (2015): 3764-3768.

[11] Pavithra, S., A. Sivapradhayni, and V. Mekaladevi. "Suppression of Cross Polarization with Various Geometries of DGS in the Design of Microstrip Patch Antenna." In 2019 International Conference on Communication and Electronics Systems (ICCES), pp. 464-467. IEEE, 2019.

[12] Wei, Kun, J. Y. Li, L. Wang, R. Xu, and Z. J. Xing. "A new technique to design circularly polarized microstrip antenna by fractal defected ground structure." IEEE Transactions on Antennas and Propagation 65, no. 7 (2017): 3721-3725.

[13] Sudhakaran, Gopika, Bindu Kandipati, G. Bhuvan Surya, V. Karthikhaa Shree, M. Sivaprasad, and M. Jayakumar. "Evolutionary algorithm based structural optimization for patch antenna design and its performance analysis." In 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI), pp. 2189-2192. IEEE, 2017.

[14] Dhakshinamoorthi, M. K., S. Gokulakkrizhna, M. Subha, and V. Mekaladevi. "Rectangular Microstrip Patch Antenna Miniaturization using improvised Genetic Algorithm." In 2020 4th International Conference on Trends in Electronics and Informatics (ICOEI)(48184), pp. 894-898. IEEE, 2020.