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A simple design and fabrication of polarization reconfigurable antenna for industrial scientific and medical-band applications

Md. Azad Hossain[1], Muhammad Asad Rahman[2], Abu Hena Murshed[1], Eisuke Nishiyama[3], Ichihiko Toyoda[3]
[1]Department of Electronics and Telecommunication Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh
[2]Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh
[3]Department of Electrical and Electronic Engineering, Saga University, Saga, Japan

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ABSTRACT

This paper proposes a simple microstrip patch antenna (MPA) that can reconfigure its polarization states from linear to circular polarization in real-time by means of a PIN diode. An antenna is fed by a 50 Ω coaxial cable through the substrate of Teflon with relative permittivity of 2.15. The proposed antenna possesses a simple patch with a one-sided corner truncated to achieve polarization reconfigurability. A PIN diode is loaded to connect the main patch with a truncated corner and further maintain dual polarization states such as linear polarization (LP) and circular polarization (CP). Advanced design system (ADS) was used as a simulator to simulate the antenna, and a good understanding was obtained between simulated and measured results. Measured results showed a good agreement with simulated results at all working frequencies of interest. It shows minimum reflection coefficient gain with -10 dB scattering bandwidth 100 MHz for LP states and 170 MHz for CP states. It also shows an axial ratio of 1.56 dB for CP, and the cross-polarization level is also in a satisfying range.

Corresponding Author:

Md. Azad Hossain
Department of Electronics and Telecommunication Engineering, Chittagong University of Engineering and Technology
Chittagong, Bangladesh
Email: azad@cuet.ac.bd

1. INTRODUCTION

Nowadays, this modern period has witnessed a rapid development of communication technicality where microstrip [1]–[40] and reconfigurable antenna [4], [5], [7], [11], [13], [15], [16] possess a key role. Such types of antennas can change their behavior in real-time by means of an intermediate device that helps to increase system capacity by means of reusing frequency [8] and multipath fading [9] and dispels the possibility of polarization mismatch [10]. There exist various types of reconfigurable antenna based on their reconfigurable characteristics, such as frequency reconfigurable antenna [11], pattern reconfigurable [3] and polarization reconfigurable [13]. The circular polarization (CP) antenna has been popular as it provides extra advantages over other antennas. But the reconfigurable polarization antenna draws significant attention among them, and reconfigurability of polarization can be eventuated between linear polarizations to circular polarization modes [13].

PIN diodes are normally used extensively as they are cheap in the market, easy to implement in the antenna structure and also have low insertion loss during fabrication of the antenna. As it provides several advantages over other switching elements, and many authors have proposed this in the recent year [7].

Besides this, radio frequency (RF) micro-electro-mechanical systems (MEMS) [15], varactor diode [16], and field effect transistor (FET) switches [17], [18] also have been proposed to achieve agility of an antenna. But employing this RF MEMS could lead to a problem in controlling high voltages during operation, and the varactor diode makes the system tuning capability limited because of the non-linear characteristics of applied voltages.

Some reconfigurable polarization antenna has been presented where each antenna has several polarization states and obtains various shapes such as e-shape [19], obtain u-shape slot [20] on its patch and stair-slots on its ground plane [21]. Sometimes cutting slots may cause an uncertain current perturbation that could demean the radiation pattern. A reconfigurable feeding network is employed to achieve quad-polarization states is proposed in [22].

To achieve CP, generating two orthogonal degenerate modes is a primary need which is equal in magnitude but in phase quadrature, and to obtain this CP antenna needs to be different in shape, type and structure. Truncating corner approach has been employed by several users, and many works have been published given in [23], [24]. Truncating the corner of the patch is one of the easiest ways to generate two orthogonal degenerates' modes to obtain CP. Corner truncating of a patch to achieve CP is also used in [25] with an impedance transformer to achieve switchable polarization with the help of total of four PIN diodes. But the increasing number of PIN diodes also lessens the positive gain due to its own insertion loss. In [26], a wideband double corner truncated patch antenna is proposed, but an inverted u-shape slot degraded the radiation pattern after not making the antenna a directive one.

CP antenna can also be divided according to their structures like single-feed [27], dual feed [28] and sequential feed [29], but the single feed is the simplest of them as it does not demand any external circuitry to excite CP. A single feed could be employed either using line feed or coaxial feed. The antenna in [30] uses the coaxial feed technique to achieve CP by means of two PIN diodes and one short PIN to achieve reconfigurability which makes the antenna suitable for 5G application but using a short pin also makes fabrication difficult.

In this article, a dual-polarization reconfigurable patch antenna is proposed with both simulated and measured results. The proposed antenna has a simple mechanism behind such kinds of polarization reconfigurability. The proposed antenna demanded only one PIN diode with a one-sided corner truncated patch. An inductor is used with a quarter wavelength bias line to provide a ground circuit for the proposed antenna. Such a simple mechanism with a regular symmetrical shape provides a couple of splendid parameters that make the antenna worthy for the 5 GHz ISM-band applications. The proposed antenna has also achieved a good agreement between simulated and measured data.

2. ANTENNA STRUCTURE AND WORKING MECHANISM

The main corner truncated square shape radiator of the proposed polarization reconfigurable antenna is shown in Figure 1, which possesses a total dimension of 17×17 mm^2. Figures 1(a) and 1(b) show the geometry and equivalent circuit of the PIN diode. In Figure 1(a), a full view of the reconfigurable polarization antenna is shown with a proper dimension that possesses a total dimension of 51×51 mm^2 that is made up of three layers with a 0.8 mm layer of substrate Teflon (ϵ_r=2.15). A coaxial feed of 50 Ω impedance has been used as a feed at the bottom side of the antenna after drilling the substrate layer of the antenna.

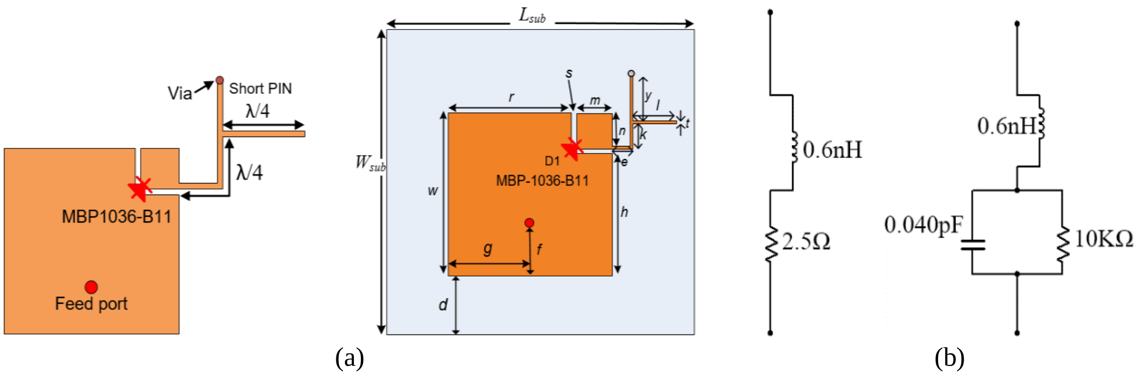
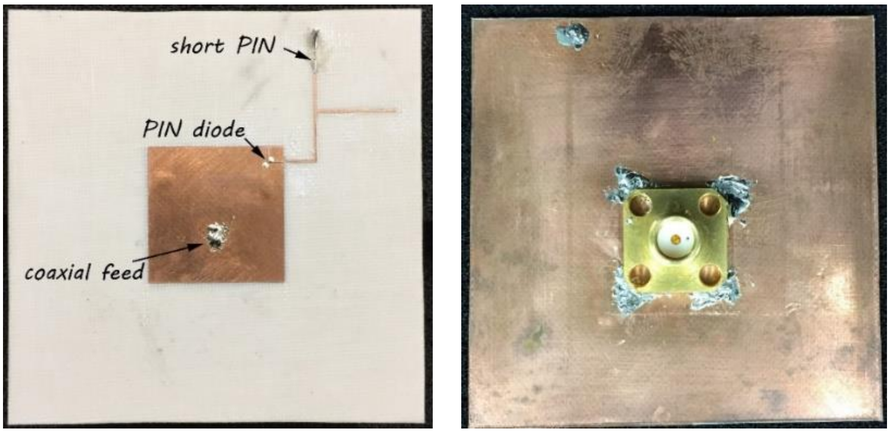


Figure 1. The proposed antenna geometry (a) Top view of proposed antenna structure where L_{sub}=51 mm, W_{sub}=51 mm, w=17 mm, d=17 mm, n=1.72 mm, y=10 mm, l=10.1 mm, r=14.88 mm, g=8.5 mm, e=4.0 mm, k=6.0 mm, f=5.5 mm, s=0.2 mm, m=1.92 mm, h =14.88 mm and t=0.2 mm and (b) the ON and OFF state equivalent circuit diagram of PIN diodes respectively

A 0.2 mm *L* shaped slot has been cut at the corner of the main patch, and an MBP-1036-B11 PIN diode is loaded to control current perturbations. Here, PIN diode works as a switch, and its ON and OFF conditions depend upon how biasing voltage is supplied to the terminal of the PIN diode with the help of an extra biasing circuit. The equivalent circuit for PIN diode is shown in Figure 1(b). It provides a path of only 2.5 Ω after applying a positive voltage of 0.7 V, during the 'ON' state shown in Figure 1(b), allowing current to flow in the detached patch corner. And it provides a high degree of resistance during 'OFF' state conditions where capacitor and resistor together block the surface current after making a parallel combination of them. When it blocks current to the truncated corner of the radiator, it produces an orthogonal degenerate mode that causes a rotating movement of current, thus obtaining CP. The rotational movement of the current also depends upon feed location that had been optimized after carrying out several simulations. The rotating movement of the current is shown later in this article which is in clockwise, indicating the antenna has right-hand circular polarization (RHCP). Similarly, when the diode is in an 'ON' state, current can flow through the detached patch and produce linear polarization (LP). A strapline of $\lambda/4$ alongside with via is provided to connect the detached patch and to make sure that circuit is closed.

3. SIMULATED AND MEASURED RESULTS

Figure 2 depicts a fabricated photograph of the proposed polarization reconfigurable antenna showing a front view in Figure 2(a) and a back view in Figure 2(b). The antenna was fabricated according to mentioned parameters to validate the polarization reconfigurable procedure. Having been fabricated the proposed antenna, further investigations on this antenna is executed in an anechoic chamber and represented in this paper in phases.



(a) (b)

Figure 2. The photograph of fabricated antenna: (a) top view and (b) bottom view

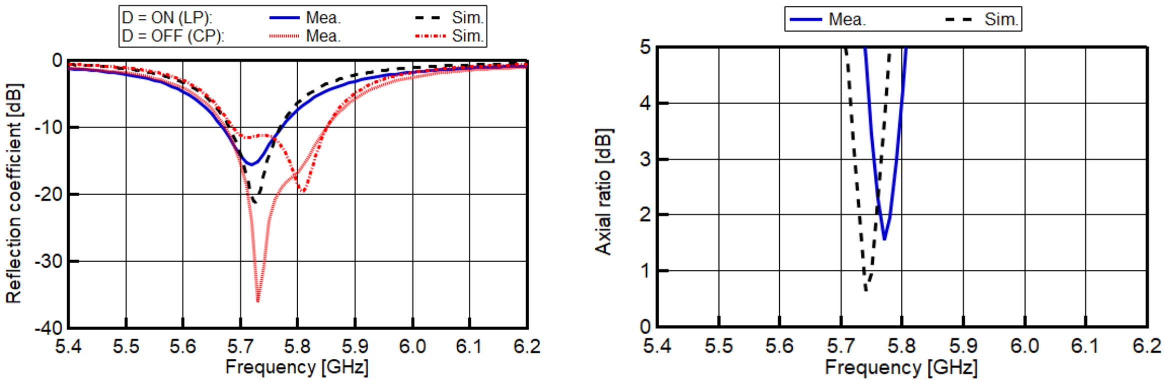
3.1. Reflection coefficient curve

Figure 3 shows the simulated and measured value of antenna parameters. Figure 3(a) shows the reflection coefficient curve of the proposed antenna with respect to operating frequency, and a satisfying agreement prevailed between these data. In LP states, a small deviation is observed between simulated and measured reflection coefficient (RC) curves value while maintaining the same operating bands. However, measured RC value is more than that of simulated value, and this causes loss that occurred during the ON state of the PIN diode in real life but was ignored while simulating. In the CP state, both simulated and measured RC curves render the same span of operating frequency, but the resonant frequency has changed due to fabrication tolerance. Operating frequency slightly goes higher as the surface current path has reduced after being applied negative potential at the PIN diode terminals.

As a result, the proposed PIN diode increase capacitance, which reduces the surface current and also a difference between ON and OFF state resistance in both the simulation and measurement process showing a difference. The proposed antenna obtains a -10 dB bandwidth of 170 MHz for CP states and 100 MHz for LP states with a VSWR ≈ 1 at operating frequency and VSWR ≤ 2 at other frequencies, which indicates perfect impedance matching with a coaxial feed network.

3.2. Axial ratio

The axial ratio is one of the important parameters to care about in the case of circular polarization antenna since it indicates the purity of polarization, and it is 0dB in the ideal case and also varies from 0 to 3dB. Both the simulated and measured results of the proposed antenna are illustrated in Figure 3(b), where the axial ratio (AR) curve is less than 3 dB, which is acceptable for CP universally, and both of these data have a similarity which gives an inkling about the incredible accuracy of simulated results. For both simulated and measured cases proposed antenna shows an AR value of less than 3 dB and 1.56 dB in the measured case, which causes the antenna to be portrayed as a circularly polarized antenna.

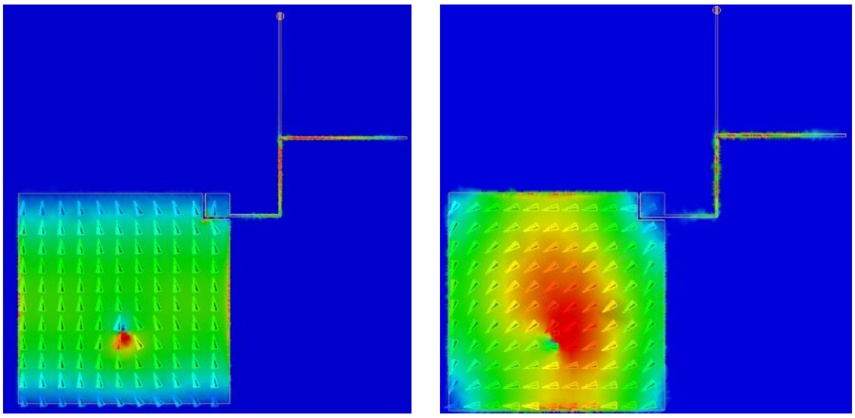


(a) (b)

Figure 3. The simulated and measured: (a) reflection coefficient curve and (b) axial ratio curve of proposed antenna

3.3. Surface current

The surface current is an important parameter in the case of microstrip patch antenna (MPA) to delve into the antenna's behavior and polarization states. To detect polarization mode, the surface current direction of the radiator is an important parameter, it gives a wide phenomenon about antenna polarization. Figure 4 depicts simulated surface currents for both LP and CP states. In LP states current direction is quite straight, which will later produce an E-field vibrating only in a single direction shown in Figure 4(a). But for CP in Figure 4(b), a surface current is rotational, which is inevitable for a rotating electromagnetic (EM) field. The rotation of surface current was made possible by truncating corners in such a way as to produce rotating surface current. A high density of current appears in the figure as red marked small arrows that are maximum always at the center of the patch. The current is maximum at the center of the patch, which means the voltage is minimum at that center of the patch. Table 1 shows the summary of the results and antenna switching configurations.



(a) (b)

Figure 4. Simulated surface current (a) for LP at 5.72 GHz and (b) for CP at 5.73 GHz

Table 1. The switching configuration of the proposed antenna related to frequency and bandwidth

States	Switches	Resonant frequency (GHz)	Frequency Bands (GHz)	Bandwidth (%)
LP	ON	5.72 GHz	5.67 to 5.77 GHz	1.75 %
CP	OFF	5.73 GHz	5.68 to 5.85 GHz	2.9 %

3.4. Radiation pattern

In the case of considering the radiation pattern of an MPA in both x-z and y-z planes conveys important information about its pattern. Figure 5 depicts the comparative gain of co-polarization and cross-polarization levels of the antenna radiation in x-z plane. In LP states, the antenna shows a neat gain of 7.27 dBi in x-z plane depicted in Figure 5(a), whereas 7.21 dBi in y-z plane is shown in Figure 5(b), where the measured value shows 6.90 and 7.21 dBi for x-z and y-z plane respectively. There is a difference between measured and simulated data, which could be a reason of not taking the fringing effect into consideration.

The main beam of the antenna is pointing at 0°(theta) of the broadside axes in both x-z and y-z plane which indicates the superior directivity of the antenna. The cross-polarization gain -13.05 dB for x-z and -13.8 dB for y-z plane respectively. The cross-polarization is orthogonal to co-polarization and undesired for any radiation. The lower the level of cross-polarization better the purity of that polarization. Both the simulated and measured results have satisfying similarities. The cross-polarization levels are below -8 dB for both simulated and measured cases. In CP states in Figure 6(a), both x-z and y-z plane gain is 7.58 dB, where the measured result is 6.69 dB and 6.37 dB, respectively. The antennas, both x-z and y-z planes, have a good directivity which is at 0°(theta) of the broadside axis, where both simulated and measured data exhibit eye-catching similarity making the antenna a prominent candidate for wireless applications. Figure 6(b) indicates the relative power between two states of CP both for simulated and measured data at their respective resonant frequency.

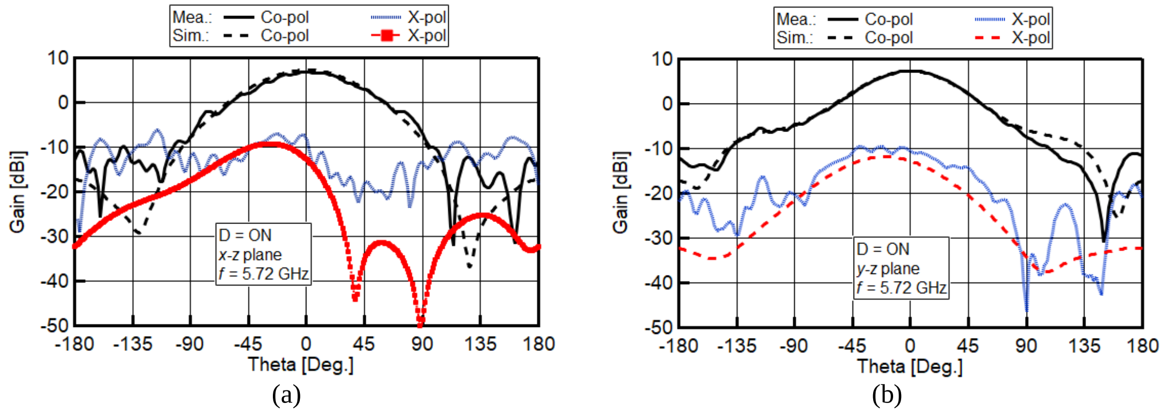


Figure 5. The simulated and measured co-pol. and cross-pol. gain of LP states (a) x-z plane and (b) y-z plane

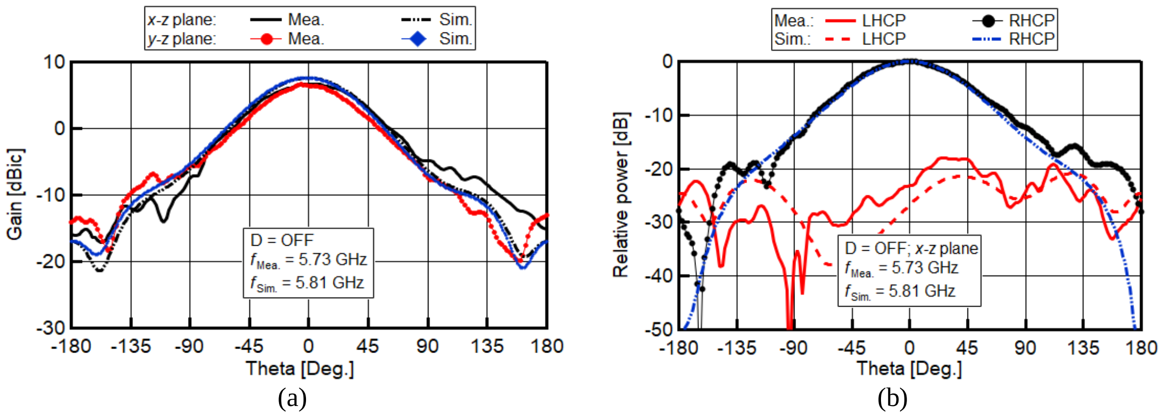


Figure 6. The simulated and measured (a) antennas circular polarization gain in both x-y and y-z plane and (b) relative power between both left-hand circular polarization (LHCP) and RHCP states

4. CONCLUSION

A novel polarization reconfigurable antenna is proposed that can reconfigure its polarization modes from LP to CP after truncating its corner and employing only a simple PIN diode on its corner which, reduces complexity in terms of fabrication and costs. It employs a simple structure with an easily applicable mechanism and provides flexibility in the wireless application making this antenna suitable for wireless applications. To validate the simulated data, the proposed antenna was fabricated, and good harmony exists between fabricated and measured results that prove its working ability in real-life applications. The antenna shows a maximum 7.58 dB gain in CP states with good directivity and maintains all other parametric requirements that led the antenna to be believed as a prominent candidate for polarimetric radar, cognitive radio and various wireless applications within the 5.8 GHz ISM-band.

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BIOGRAPHIES OF AUTHORS

Md. Azad Hossain was born in Dhaka, Bangladesh, in 1981. He received his B.Sc. degree in Electrical and Electronic Engineering from Rajshahi University of Engineering and Technology (RUET), Rajshahi, Bangladesh, in 2004. The M.Sc. degree in EEE from Saga University, Saga, Japan, in 2010; and the Ph.D. degree in Science and Advanced Technology, in 2013 from the same Institute. From 2013 to 2014, he was with Chittagong University of Engineering and Technology (CUET) as a Lecturer. Presently he is working as a professor, Head of department of ETE at CUET. His research interests include Microwave antenna design and related readout circuit simulation and experimental characterization. He can be contacted at email: azad@cuet.ac.bd.

Muhammad Asad Rahman received his B.Sc. and M.Sc. degrees in Electrical and Electronic Engineering from Chittagong University of Engineering and Technology (CUET), Bangladesh in 2009 and 2014, respectively. He pursued his Ph.D. degree in 2018 from Saga University, Japan. During his Ph.D. study, he was awarded the IEEE AP-S Japan Student of the Year 2017. Currently, he is working as an associate professor in CUET, Bangladesh. His current research interests are reconfigurable antennas, transparent antennas, active antennas, and rectenna design for wireless power transfer. He can be contacted at email: asad31@cuet.ac.bd.

Abu Hena Murshed was born in Feni, Bangladesh, in 1998. He has just received his B.Sc degree in Electronics and Telecommunication Engineering (ETE) from Chittagong University of Engineering Technology (CUET), Chittagong, in Bangladesh. He is currently working towards about Microstrip Antenna and circuit Design. He is about to spearhead a new project as research assistant at CUET. His research field of interests are metamaterial antenna, electro-bandgap (EBG) antenna, 5G antenna and its related experimental characterization. He can be contacted at email: u1508017@student.cuet.ac.bd.

Eisuke Nishiyama was born in Saga, Japan. He graduated from the Department of Electronics, Saga University, in 1987, completed the M.S. program in 1989, and became a member of the technical staff there. He was a research associate from 1997 to 2007. He has been an assistant professor since 2007. He was a visiting scholar of the UCLA from 2007 to 2008. His research interest is planar antennas, especially active antennas. He holds a Dr. Eng. degree. He was the chair of the IEEE AP-S Fukuoka Chapter from 2013 to 2014, and is a member of IEEE. He can be contacted at email: nisiyama@ceng.ec.saga-u.ac.jp.

Ichihiko Toyoda received the B.E., M.E. and the Dr. Eng. degrees in communication engineering from Osaka University, Osaka, Japan, in 1985, 1987 and 1990, respectively. From 1990 to 2011, he was engaged in research and development of the three-dimensional (3-D) and uniplanar MMICs, ultra-high-speed digital ICs, millimeter-wave high-speed wireless access systems and their applications at NTT Laboratories and NTT Electronics Corporation. He was also active in developing IEEE 802.11, 802.15 and other national standards. He was a Guest Editor of a 1998 special issue on “3D-Components and Active Circuits” of the International Journal of RF and Microwave Computer-Aided Engineering and a Guest Editor-in-Chief of a 2016 special issue on “Microwave researches in universities” of the Institute of Electronics, Information and Communication Engineers (IEICE) Transactions on Electronics. He was a Councilor, Tokyo Section and Kyushu section, IEICE and a GA member of the European Microwave Association (EuMA). He served as a Chair of IEEE AP-S Fukuoka chapter. He also served Technical Committee on Electron Devices of the Institute of Electrical Engineers of Japan (IEEJ) as a Secretary, Vice-Chair and Chair. He also served on many other technical committees of IEICE and IEEJ, Japan. He published 6 book chapters. He is now a Professor and Dean of the Faculty of Science and Engineering, Saga University. His current interests concern microwave circuits, antennas and their integration technologies. Dr. Toyoda received the 1993 Young Researcher’s Award presented by the IEICE, Japan; the Japan Microwave Prize presented at the APMC1994; the 18th Telecom System Technology Award from the Telecommunications Advancement Foundation; the 2004 Electronics Society Award from the IEICE, Japan; First Prize for Propagation and Antenna Measurements at the EuCAP2010; 2010 and 2016 Best Paper Awards from the IEICE, Japan; 2020 Best Paper Award from IEEJ and many NTT R&D awards. He was also recognized as an Excellent Educator by Saga University in 2017. He is a senior member of IEICE and a member of IEEE, EuMA and IEEJ. He can be contacted at email: toyoda@cc.saga-u.ac.jp.