Single-Beam 1 Bit Reflective Metasurface Using Prephased Unit Cells for Normally Incident Plane Waves

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Abstract—A single-beam prephased 1 bit reflective metasurface is proposed to achieve single-beam patterns under normally incident plane waves. Theoretical analysis and numerical simulations are presented to show that, under normally incident waves, single-beam patterns can be achieved by introducing a fixed prephase distribution with two values in the 1 bit metasurface. Compared with conventional 1 bit reflective metasurfaces, the proposed scheme alleviates the inherent limitation of single-beam patterns on 1 bit reflective metasurfaces under normally incident plane waves. To verify the proposed scheme, a 1 bit unit cell is designed with a $180^\circ \pm 25^\circ$ phase difference between the two states for frequencies ranging from 34.3 to 49.9 GHz, and a layer-stacking method is proposed to achieve two prephases with a $90^\circ$ phase difference. As an example, three 1 bit reflective metasurfaces comprising $20 \times 20$ unit cells with single beams pointing separately at $0^\circ$, $15^\circ$, and $30^\circ$ are designed and measured over frequencies of 37.0 to 41.0 GHz; the measured sidelobe levels are less than $-7.8$ dB. Simulated and measured results show that the proposed prephased 1 bit metasurface can achieve single-beam patterns under normally incident plane waves.

Index Terms—1 bit, normally incident waves, prephased, reflective metasurface, single-beam.

I. INTRODUCTION

THE manipulation of electromagnetic (EM) waves has recently attracted substantial attention with the development of metasurfaces as well as the increasing requirements on wireless communications [1]–[4]. One of the challenges facing the millimeter wave (mmWave) is penetration loss, which restricts the development and applications of mmWave indoor communication. Nevertheless, penetration loss can be alleviated if a surface can guide incoming plane waves from one room to another rather than let the waves penetrate through a thick wall. For example, mmWave penetration loss can be avoided or diminished if a series of reflective metasurfaces, which can manipulate incoming plane waves toward an arbitrary direction, are used to guide those waves without penetrating the concrete walls [5]. Therefore, reflective metasurfaces, which can guide incident plane waves to the desired direction, have excellent potential for indoor mmWave wireless communications.

EM waves can be guided to an arbitrary direction when there are precise phase compensations for each unit cell on the metasurfaces [6]. However, when precise phase compensations are difficult to achieve, discrete phase compensations are used as an alternative to control the radiation beams. One of the most classic discrete phase compensation techniques is based on the use of 1 bit or 2 bit unit cells, which are easily achieved using the ON- and OFF-states of p-i-n diodes. Although 2 bit or higher order bit unit cells can provide greater designed freedom than 1 bit unit cells for beamforming and beam scanning, particularly in the generation of single-beam radiation patterns for normally incident plane waves, the cell designs of higher order bit unit cells are much more complicated, especially when integrated with beam scanning control systems. Therefore, to simplify the complexity of beam-scanning systems and reduce the fabrication cost, 1 bit metasurfaces with single-beam radiation patterns are preferred.

Accordingly, as a type of reflective metasurface, several 1 bit reflectarrays were proposed for beamforming and beam scanning in [7]–[10]. A large electronically reconfigurable reflectarray was designed by a 1 bit unit cell [8]; by using a horn antenna as the feeding source to provide approximately spherical waves, this reflectarray can achieve single-beam patterns. In fact, most single-beam 1 bit reflective metasurfaces developed to date utilize horn antennas to imitate spherical waves as incident waves. The inherent reason for this is that spherical waves can introduce an intrinsic pseudorandom distribution of the phase quantization error, making single beams achievable [11]. However, regarding normally incident plane waves, 1 bit metasurfaces can hardly generate a...
single-beam radiation pattern. In [10], single-beam patterns were realized using a programmable metasurface with a 1 bit unit cell and spherical waves; however, when using normally incident waves, the patterns contained two symmetrical beams. Currently, only 2 bit or higher order bit metasurfaces can be realized using a programmable metasurface with a 1 bit unit cell and spherical waves; however, when using normally incident plane waves [12]–[14].

In this article, a single-beam prephased reflective metasurface is presented for normally incident plane waves. First, a theoretical analysis is presented to explain the reason for symmetrical radiation patterns for conventional 1 bit metasurfaces under normally incident plane waves. Next, another analysis is performed to show that the proposed 1 bit metasurface can realize single-beam patterns when the unit cells are properly prephased. Finally, as a demonstration, a broadband 1 bit unit cell is proposed, and three prephased reflective metasurfaces with different single-beam radiation patterns are designed, fabricated, and measured.

II. THEORETICAL ANALYSIS OF THE 1 BIT METASURFACE

The 1 bit reflective metasurface with \( N \times N \) unit cells is shown in Fig. 1. To realize different patterns, the states of 1 bit unit cells are switched between State 0 and State 1; a \( \pi \) phase difference can be achieved between these two states. Without loss of generality, State 0 and State 1 of the unit cells are assumed to provide 0 and \( \pi \) phase compensations, respectively. That is, the 1-bit phase compensation \( \phi_{s,k} \) for the \( k \)th column and \( s \)th row can be written as

\[
\phi_{s,k} = \begin{cases} 0, & \text{State 0} \\ \pi, & \text{State 1} \end{cases}
\]

where \( s, k = 1, 2, \ldots, N \).

We assume that the 1 bit metasurface is placed in the \( xoz \) plane and that the reflective main beam is within the \( xoz \) plane, as shown in Fig. 1. Here, \( \theta \) is the elevation angle, and the unit cells of the metasurface are uniformly distributed with a spacing \( d \). The rows of the array are parallel to the \( x \)-axis, and the columns are parallel to the \( y \)-axis.

Let the 1 bit phase compensation be \( \phi_{s,k} \) and the initial phase be \( \zeta_{s,k} \). Considering the progressive phase, the total phase \( \varphi_{s,k} \) of the unit cell in the \( s \)th row and \( k \)th column for the \( xoz \) plane is given by

\[
\varphi_{s,k} = \frac{2\pi kd}{\lambda} \sin \theta + \phi_{s,k} + \zeta_{s,k}
\]

where \( \lambda \) is the wavelength in free space. For a 1-bit reflective metasurface with uniform amplitude, using trigonometric identities, the modulus of the normalized array factor \( |\text{AF}_0(\theta)| \) for the \( xoz \) plane can be derived as [15]

\[
|\text{AF}_0(\theta)| = \frac{1}{N^2} \left| \sum_{s=1}^{N} \sum_{k=1}^{N} (\cos \varphi_{s,k} + j \sin \varphi_{s,k}) \right|
\]

\[
= \frac{1}{N^2} \left( \left( \sum_{s=1}^{N} \sum_{k=1}^{N} \cos \varphi_{s,k} \right)^2 + \left( \sum_{s=1}^{N} \sum_{k=1}^{N} \sin \varphi_{s,k} \right)^2 \right) \frac{1}{2}
\]

\[
= \frac{1}{N^2} \left( \sum_{s=1}^{N} \sum_{k=1}^{N} \sum_{a=1}^{N} \sum_{b=1}^{N} \sum_{v=1}^{N} \sum_{w=1}^{N} \cos \varphi_{a,b} \cos \varphi_{v,w} \right.
\]

\[+ \sum_{a=1}^{N} \sum_{b=1}^{N} \sum_{v=1}^{N} \sum_{w=1}^{N} \sin \varphi_{a,b} \sin \varphi_{v,w} \frac{1}{2}
\]

\[
= \frac{1}{N^2} \left( \sum_{s=1}^{N} \sum_{k=1}^{N} \sum_{a=1}^{N} \sum_{b=1}^{N} \sum_{v=1}^{N} \sum_{w=1}^{N} \cos(\varphi_{a,b} - \varphi_{v,w}) \right)
\]

\[
= \frac{1}{N^2} \left( \sum_{a=1}^{N} \sum_{b=1}^{N} \sum_{v=1}^{N} \sum_{w=1}^{N} \cos \left( \frac{2\pi (b - w)d}{\lambda} \sin \theta \right.ight.
\]

\[
\left.+ (\varphi_{a,b} - \varphi_{v,w}) + (\zeta_{a,b} - \zeta_{v,w}) \right) \frac{1}{2}
\]

(3)

where \( a \) and \( v \) represent the row index and \( b \) and \( w \) represent the column index.

Under spherical incident waves, the constant-phase surfaces are spherical surfaces, and the initial phases \( \zeta_{s,k} \) on the reflective metasurface range from 0 to \( 2\pi \). Therefore, \( -2\pi \leq \zeta_{s,k} \leq 2\pi \). In other words, spherical wavefronts introduce an intrinsic pseudorandom distribution of the phase quantization error [11], and thus, \( |\text{AF}_0(\theta)| \) is a noneven function.

Under normally incident plane waves, the constant-phase surfaces are planar, so there are a large number of identical compensated phases for the reflective metasurface, i.e., \( \phi_{1,b} = \phi_{2,b} = \cdots = \phi_{N,b} \) and \( \phi_{1,w} = \phi_{2,w} = \cdots = \phi_{N,w} \). And the initial phases on the reflective metasurface are the same, i.e., \( \zeta_{1,b} = \zeta_{1,w} = 0 \) regardless of row and column indices. Consequently, \( |\text{AF}_0(\theta)| \) can be simplified as

\[
|\text{AF}_1(\theta)| = \frac{1}{N} \left( \sum_{b=1}^{N} \sum_{w=1}^{N} \cos \left( \frac{2\pi (b - w)d}{\lambda} \sin \theta + (\phi_b - \phi_w) \right) \right) \frac{1}{2}
\]

(4)

As in (4), the value of \( (\phi_b - \phi_w) \) can be chosen only among \( -\pi, 0 \) and \( \pi \) for conventional 1 bit metasurfaces under normally incident plane waves. Therefore, \( |\text{AF}_1(\theta)| \) is an even function, that is

\[
|\text{AF}_1(\theta)| = \frac{1}{N} \left( \sum_{b=1}^{N} \sum_{w=1}^{N} (-1)^w \cos \left( \frac{2\pi (b - w)d}{\lambda} \sin \theta \right) \right) \frac{1}{2}
\]

(5)
where

\[ u = \begin{cases} 
0, & \phi_b - \phi_w = 0 \\
1, & \phi_b - \phi_w = \pm \pi \end{cases} \]

Equations (3) and (5) reveal the inherent difference between spherical incident waves and normally incident plane waves. For spherical incident waves, the intrinsic pseudorandom distribution of the phase quantization error makes (3) a noneven function, and thus, single-beam patterns can be realized. However, for normally incident plane waves, without an intrinsic pseudorandom distribution of the phase quantization error, (3) is simplified to (5). Therefore, the modulus of the array factor becomes a noneven function. This means that by adding a fixed-phase distribution to the design of a 1 bit metasurface under normally incident plane waves, the symmetrical patterns of conventional 1 bit metasurfaces can be broken and single-beam patterns can be realized.

III. NUMERICAL DESIGN AND SIMULATION OF PREPHASED 1 BIT METASURFACES

Based on the prephase concept described earlier, we regard each unit cell in the metasurface as a radiation element. Using the theory of antenna synthesis, the prephased metasurfaces with 20 × 20 unit cells for normally incident plane waves are designed and calculated. The prephase distribution \( \Psi \) on the metasurface can be obtained by the function

\[ \Psi = \frac{\pi}{2} \cdot \text{randi}([0, 1], 20, 20) \]

where randi([0, 1], 20, 20) represents a 20 × 20 matrix with a value of either 0 or 1 for each cell, and all the elements in this matrix are generated by a uniformly distributed pseudorandom function. As a demonstration, the design goals here are set to be a single beam pointing at 0°, 15°, and 30°. The prephase distribution \( \Psi \) is generated using (10) and is the same in all designs. The spacing between adjacent unit cells is approximately a half-wavelength in free space at the frequency of operation.

For the sake of comparison, the precise phase-compensated and conventional 1 bit metasurfaces are also calculated for each case under normally incident plane waves. The phase distributions for all three phase-compensated methods corresponding to a 30° beam direction are illustrated in Fig. 2, and the patterns of the array factors are shown in Fig. 3(c). The phase distribution on the reflective surface of the precise phase-compensated metasurface is generated using (10), which generates a single-beam pattern. The phase distribution on the reflective surface of conventional 1 bit metasurface is symmetrical as shown in Fig. 2(b); hence, \(|\text{AF}_0(\theta)|\) becomes an even function, and the pattern is symmetrical with two beams. By introducing pseudorandom uniformly distributed prephases, the symmetry of the phase distribution is broken, as shown in Fig. 2(c), and thus, \(|\text{AF}_0(\theta)|\) is a noneven function. Considering prephases and 1 bit compensation phases, there are four kinds of phases on the proposed reflective metasurface, namely, phases of 0°, 90°, 180°, and 270°, which represent State 0 with a 0° prephase, State 0 with a 90° prephase, State 1 with a 0° prephase, and State 1 with a 90° prephase, respectively. Each prephased unit cell can be switched between only two states, and the prephase distribution is fixed for different beam directions. Therefore, prephased 1 bit metasurfaces are quite different from conventional 2 bit metasurfaces.

Under normally incident plane waves, the calculated patterns in the xoz plane for the three metasurfaces are plotted in Fig. 3, in which the patterns for the conventional 1 bit and precise phase-compensated metasurfaces are presented for comparison. The sidelobe levels (SLLs) and beam directions...
Fig. 2. Calculated phase distributions for the three phase-compensated methods under normally incident waves, for 30° beam direction. (a) Precise phase compensation. (b) Conventional 1 bit phase compensation. (c) Prephased 1 bit phase compensation.

Fig. 3. Calculated patterns under normally incident plane waves in the xoz plane. (a) 0°. (b) 15°. (c) 30°.

| TABLE I | SIMULATED PERFORMANCE OF THE PROPOSED PREPHASED 1 BIT, CONVENTIONAL 1 BIT, AND PRECISE PHASE-COMPENSATED METASURFACES UNDER NORMALLY INCIDENT PLANE WAVES |
|---------|------------------------------------------------------------------------------------------------------|
| Direction (°) | Pre-phase | Conventional | Precise phase | SLL (dB) |
| 0/15/30 | 0/±15/±30 | 0/15/30       | 0/15/30       | -11.8/-9.4/-12.6 | -13.3/-7.5/-11.4 | -13.3/-13.2/-12.6 |

of the patterns in the xoz plane are presented in Table I. It is obvious that the undesirable symmetrical beam of the conventional 1 bit metasurface is effectively suppressed by introducing a fixed prephase distribution with only two values. Furthermore, a 1 bit metasurface with a single-beam pattern for any other directions can also be designed with the help of a fixed \( \Psi \). For a fixed prephase distribution, high SLLs may appear in some beam directions during the beam scanning design. However, to optimize and suppress the SLL, different reference phases can be introduced during each designed beam direction [9]. The proposed prephased method can also break the symmetry of the array factor under obliquely incident plane waves; consequently, single-beam patterns can also be realized under obliquely incident waves.

IV. DESIGN AND PROTOTYPE

A. 1-Bit Unit Cell

The configuration of the proposed 1 bit unit cell is illustrated in Fig. 4. For State 0, the unit cell can be regarded as a square patch with a cross-shaped slot in its center. This cross-shaped slot cuts the square patch into four small square patches that are symmetrical with respect to the center of the unit cell for State 0, as shown in Fig. 4(a). In contrast, for State 1, the four small square patches are connected by four stubs, as shown in Fig. 4(b). The difference between the two states is whether the four small patches are connected. Because the unit cell has \( 90° \) rotational symmetry with respect to its center, the proposed unit cell can respond to both vertically polarized waves and horizontally polarized waves. A Taconic TLY laminate with a dielectric constant of \( \varepsilon_r = 2.2 \) is used as the substrate. The designed frequency is in the \( Q \)-band and the period of the unit cell is chosen as approximately half the wavelength at
39.0 GHz. The simulated performance of the proposed 1 bit unit cell is plotted in Fig. 5. Furthermore, $l_2$ and $l_3$ are the same in both states; thus, this unit cell can be reconfigured by substituting the four small stubs with four p-i-n diodes.

**B. Prephase Design**

To achieve two prephases with a prephase difference of approximately 90°, as discussed in Section II, the unit cells are placed on different layers of two stacked substrates, as shown in Fig. 6. The path difference for the incident and reflected waves will produce a prephase difference of approximately 90° if the thickness of substrate 1 is one-eighth of a wavelength in the substrate. Considering the limit on the thickness of a printed circuit board (PCB), the thickness of the substrate is chosen as 0.762 mm. The reflection phases of the unit cells with the prephases are shown in Fig. 6, which demonstrates that a 90° reflection phase difference can be achieved for the same state and different prephases, whereas a 180° reflection phase can be achieved for different states and the same prephase.

However, the abovementioned layer-stacking method will increase the complexity of the reconfigurable design, so the bias circuit should be carefully designed for reconfigurable prephased metasurfaces.

**C. 20 × 20 Prephased Metasurface**

Based on the proposed 1 bit unit cell and prephase design, three 20 × 20 prephased 1 bit reflective metasurfaces with single beams pointing at 0°, 15°, and 30° are designed with a center frequency of 39.0 GHz. The prephase distribution shown in Fig. 2(c), which is generated by a pseudorandom uniformly distributed function, is utilized for all designed beam directions in this article. After the prephase is introduced to the unit cell, the state of each unit cell can be determined by the required phase compensation for the specific beam direction. If the required phase compensation lies in the range from $-90°$ to $90°$, State 0 is selected; if the required phase compensation ranges from $90°$ to $270°$, State 1 is selected.

For the 30° reflective metasurface, the phase compensations of the unit cells with the prephases are shown in Fig. 2(c). The geometry of the metasurface and the pattern are shown in Fig. 7; the metasurface includes two substrates and three copper layers. The Taconic TLY laminate is used for the metasurface design. A single beam with a suppressed SLL is achieved in the 3-D space. The performance of the designed metasurfaces is presented in Table II and their radiation patterns will be given in Section V. The patterns are degraded...
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Fig. 9. Simulated and measured patterns of the proposed 1 bit prephased metasurface in the $xoz$ plane under normally incident plane waves (vertical polarization). (a) 0°. (b) 15°. (c) 30°.

TABLE II
Simulated Performance of Three Prephased 1 Bit Metasurfaces (0°/15°/30°) Under Normally Incident Plane Waves (Vertical Polarization)

| Frequency (GHz) | Beam Direction (°) | SLL (dB) ($xoz$ plane) | 3-dB Beamwidth (°) | Normalized Max. RCS (dB) |
|-----------------|--------------------|------------------------|-------------------|--------------------------|
| 37.0            | 0/15/22.0          | -13.2/-12.2/9.8        | 5.1/5.8/5.0       | -1.3/4.1/5.9             |
| 39.0            | 0/14.6/30.0        | -12.3/-12.0/-11.2     | 4.6/5.2/5.3       | -2.1/-4.2/5.5            |
| 41.0            | 0/14.0/28.5        | -11.8/-10.0/-11.2     | 4.6/4.9/5.9       | -2.2/-4.5/5.4            |
| PEC@39.0        |                    |                        |                   | 0                        |

TABLE III
RCSs at 39.0 GHz Under Normally Incident Plane Waves

| Sample | PEC 0-degree | 15-degree | 30-degree |
|--------|--------------|-----------|-----------|
| Sim. (dB) | 0          | -2.1      | -4.2      | -5.5      |
| Mea. (dB)  | 0          | -2.1      | -4.5      | -5.6      |
| |Sim.-Mea.| (dB)      | 0         | 0.3        | 0.1        |

at the sideband frequencies because the target frequency is 39.0 GHz. Fortunately, some methods can be used to alleviate this degradation for further optimization [16], [17].

V. RESULTS AND DISCUSSION

A. Measured Results

To verify the performance of the proposed 1 bit prephased metasurface under normally incident plane waves, three reflective metasurfaces with single beams pointing separately at 0°, 15°, and 30° are fabricated. The 1 bit metasurface includes three copper layers and two substrate layers. The two substrate layers with their respective copper layers are separately fabricated using PCB technology and assembled using plastic screws. The measurement setup is presented in Fig. 8. The Tx horn antenna is fixed, and the aperture of the Tx horn is parallel to the aperture of the sample to provide approximate incident plane waves. The Rx horn antenna is aimed at the center of the sample and is fixed on the motorized rotating stage, which can rotate around the sample; furthermore, a vector network analyzer (VNA) is employed to record the electric field level of the Rx horn from −60° to 60° in the horizontal plane. To reduce the shielding effect during the 0° test, the Tx horn is slightly higher than the Rx horn. A control PC is utilized to operate the motion controller and obtain the data from the VNA.

A copper plate of the same size was also measured as a reference; accordingly, the radar cross sections (RCSs) of the three metasurfaces are given in Table III in comparison with the RCS of the copper plate. Moreover, the simulated and measured patterns in the $xoz$ plane under normally incident waves are shown in Fig. 9. Single beams can also be obtained under horizontal polarization because the structure of the proposed unit cell is symmetrical. The measured beam directions of the 1 bit prephased metasurfaces agree with the designed directions, and the measured SLLs in the $xoz$ plane are suppressed below −7.8 dB. In addition, the simulated and measured results of the 3 dB beamwidth also agree well.

B. Comparison and Discussion

The reported performance of the 1 bit and 2 bit reflective metasurfaces is summarized in Table IV. The supported polarizations in the table indicate the polarization of the incident waves. Kamoda et al. [8] and Yang et al. [9] designed a 1 bit reflective metasurface with single-beam patterns by using a horn antenna to provide spherical waves. References [4], [10], [18] designed a 1 bit reflective metasurface with symmetrical patterns under approximate plane waves. Because symmetrical patterns introduce two symmetrical beams, Cui et al. [12], [14] employed 2 bit or
higher order bit metasurfaces to achieve single-beam patterns under normally incident plane waves. Compared with the 2 bit metasurface, the 1 bit prephased metasurface has a lower gain because of the larger phase quantization error but features a lower complexity, especially regarding the reconfigurable beam design. The prephased method proposed in this article alleviates the inherent limitation of existing 1 bit reflective metasurfaces, which achieves single-beam patterns under normally incident plane waves. Moreover, the proposed method is simple, and the proposed metasurface has low complexity and a low-cost fabrication process.

A prephased 1 bit reflective metasurface has been proposed to achieve single-beam patterns under normally incident plane waves. The proposed scheme alleviates the inherent limitation of existing 1 bit reflective metasurfaces under normally incident plane waves, and a pseudorandom uniformly distributed prephase is added to the metasurface to break the symmetry of the array factor. A numerical simulation has illustrated that under plane incident waves, single-beam patterns can be achieved by a 1 bit prephased metasurface. To design and realize the prephased 1 bit metasurface, a broadband 1 bit unit cell has been proposed, and a prephased method has been presented to realize two prephases with a 90° phase difference. To verify the proposed approach, three prephased 1 bit metasurfaces under normally incident plane waves with different beam directions have been designed and fabricated via the PCB process. The simulated and measured results have revealed that the proposed 1 bit prephased reflective metasurface can achieve single-beam patterns under normally incident plane waves. For further beam scanning and reconfigurable design purposes, the basic circuit should be carefully designed because of the multilayer prephased metasurface. Ultimately, the proposed prephased method has the potential to achieve beamforming and beam scanning for mmWave indoor communications.

VI. CONCLUSION

A prephased 1 bit reflective metasurface has been proposed to achieve single-beam patterns under normally incident plane waves. The proposed scheme alleviates the inherent limitation of existing 1 bit reflective metasurfaces under normally incident plane waves, and a pseudorandom uniformly distributed prephase is added to the metasurface to break the symmetry of the array factor. A numerical simulation has illustrated that under plane incident waves, single-beam patterns can be achieved by a 1 bit prephased metasurface. To design and realize the prephased 1 bit metasurface, a broadband 1 bit unit cell has been proposed, and a prephased method has been presented to realize two prephases with a 90° phase difference. To verify the proposed approach, three prephased 1 bit metasurfaces under normally incident plane waves with different beam directions have been designed and fabricated via the PCB process. The simulated and measured results have revealed that the proposed 1 bit prephased reflective metasurface can achieve single-beam patterns under normally incident plane waves. For further beam scanning and reconfigurable design purposes, the basic circuit should be carefully designed because of the multilayer prephased metasurface. Ultimately, the proposed prephased method has the potential to achieve beamforming and beam scanning for mmWave indoor communications.

ACKNOWLEDGMENT

The authors would like to thank the editors and the anonymous reviewers for their valuable comments and discussion. They would also like to thank their colleagues in the State Key Laboratory of Millimeter Waves, Southeast University, Nanjing, China, for their valuable discussions and support in measurements.

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He holds 32 granted/filed patents and completed more than 38 technology licensed deals with industry. He is pioneering in developing small and broadband antennas, wearable/implemented medical antennas, package antennas, near-field antennas/coils, 3-D integrated LTCC arrays, microwave lens antennas, and microwave metamaterial-metasurface antennas for communications, sensing, and imaging systems. He is more interested in the translational research of metasurfaces into antenna engineering. He has published more than 650 academic articles and five books entitled Broadband Planar Antennas (Wiley, 2005), UWB Wireless Communication (Wiley, 2006), Antennas for Portable Devices (Wiley, 2007), Antennas for Base Stations in Wireless Communications (McGraw-Hill, 2009), and Handbook of Antenna Technologies with 76 chapters (by Springer References in 2016 as an Editor-in-Chief). He has also contributed the chapters to the books entitled Developments in Antenna Analysis and Design (IET, 2018), UWB Antennas and Propagation for Communications, Radar, and Imaging (Wiley, 2006), Antenna Engineering Handbook (McGraw-Hill, 2007), Microstrip and Printed Antennas (Wiley, 2010), and Electromagnetics of Body Area Networks (Wiley, 2016).

Dr. Chen was elevated to the fellow of Academy of Engineering, Singapore, in 2019, and a fellow of the IEEE for the contribution to small and broadband antennas for wireless applications in 2007. He was a recipient of the Internation Symposium on Antennas and Propagation Best Paper Award in 2010, the CST University Publication Awards in 2008 and 2015, the IEEE Outstanding Engineering Achievement Award in 2013, the Institution of Engineers Singapore Prestigious Engineering Achievement Awards in 2006, 2013 (two awards), and 2014, the I2R Quarterly Best Paper Award in 2004, the IEEE iWAT Best Poster Award in 2005, several technology achievement awards from China during 1990 to 1997, and more than 21 academic awards by the students under his supervision. He has served as a member of the IEEE Council on RFID, where he has been serving as a Distinguished Lecturer since 2015. He is the founding General Chair of the International
Workshop on Antenna Technology (iWAT 2005), the International Symposium on InfoComm and Mechatronics Technology in Bio-Medical and Healthcare Application (IS 3Tin3A 2010), the International Microwave Forum (IMWF 2010), and the Asia–Pacific Conference on Antennas and Propagation (APCAP 2012). He has also been involved in many international events as the general chair, the chair, and a member for technical program committees and international advisory committees. He has been invited to deliver more than 90 keynote/plenary/invited speeches at international academic and industry events. He has served as an Associate Editor of the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION and a Distinguished Lecturer for the IEEE Antennas and Propagation Society.

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Dr. Hong was thrice awarded the First-Class Science and Technology Progress Prizes issued by the Ministry of Education of China and the Jiangsu Province Government, China, and the Foundations for China Distinguished Young Investigators and for “Innovation Group” issued by the NSF of China. He currently serves as the Vice-President of the Microwave Society and Antenna Society of the CIE, the Chair of the IEEE MTT/AP/EMC Joint Nanjing Chapter, and an AdCom Member of the IEEE Microwave Theory and Techniques Society. He served as an Associate Editor for the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES from 2007 to 2010.