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Review Article

Some Recent Developments of Microstrip Antenna

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Although the microstrip antenna has been extensively studied in the past few decades as one of the standard planar antennas, it still has a huge potential for further developments. The paper suggests three areas for further research based on our previous works on microstrip antenna elements and arrays. One is exploring the variety of microstrip antenna topologies to meet the desired requirement such as ultrawide band (UWB), high gain, miniaturization, circular polarization, multipolarized, and so on. Another is to apply microstrip antenna to form composite antenna which is more potent than the individual antenna. The last is growing towards highly integration of antenna/array and feeding network or operating at relatively high frequencies, like sub-millimeter wave or terahertz (THz) wave regime, by using the advanced machining techniques. To support our points of view, some examples of antennas developed in our group are presented and discussed.

1. Introduction

The concept of microstrip antenna was first introduced in the 1950s [1]. However, this idea had to wait nearly 20 years to be realized after the development of the printed circuit board (PCB) technology in the 1970s [2, 3]. Since then, microstrip antennas are considered as the most common types of antennas due to their obvious advantages of light weight, low cost, low profile, planar configuration, easy of conformal, superior portability, suitable for arrays, easy for fabrication, and easy integration with microwave monolithic integrate circuits (MMICs) [4–7]. They have been widely employed for the civilian and military applications such as television, broadcast radio, mobile systems, global positioning system (GPS), radio-frequency identification (RFID), multiple-input multiple-output (MIMO) systems, vehicle collision avoidance system, satellite communications, surveillance systems, direction founding, radar systems, remote sensing, biological imaging, missile guidance, and so on [8].

Despite the many advantages of typical microstrip antennas, they also have three basic disadvantages: narrow bandwidth, low gain, and relatively large size. The narrow bandwidth is one of the main drawbacks of these types of antennas. A straightforward method of improving the bandwidth is increasing the substrate thickness. However, surface wave power increases and radiation power decreases with the increasing substrate thickness [7], which leads to poor radiation efficiency. Thus, various other techniques are presented to provide wide-impedance bandwidths of microstrip antennas, including impedance matching networks using stub [9, 10] and negative capacitor/inductor [11], microstrip slot antennas using the U, L, T, and inverted T slots in the ground plane (sometimes termed defected ground structures (DGSs)) [12, 13], surface wave suppressing using magneto-dielectric substrate [14] and electromagnetic bandgap (EBG) structures [15], and composite-resonator microstrip antennas using metamaterial resonators [16, 17]. Another problem to be solved is the low gain for conventional microstrip antenna element. Cavity backing has been used to eliminate the bidirectional radiation, thereby providing higher gain compared with conventional microstrip antenna [18]. Lens covering is an alternative way to achieve gain enhancement. The lens with canonical profile, like elliptical, hemielliptical, hyper-hemispherical, extended hemispherical, used to focus the radiation beam from the radiator elements. The integrated lens microstrip antenna can be treated as composite antenna combined by microstrip radiator elements and dielectric lens, which is very useful for high frequencies (mm, sub-mm, terahertz (THz), and optical waves) applications

[19]. It is also well known that antenna array is an effective means for improving the gain [20–25].

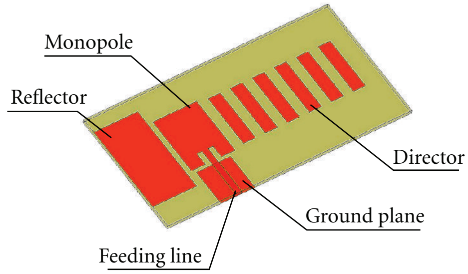
The last limitation of conventional microstrip antennas is the relatively large size, particularly at lower microwave frequencies, since their operation frequencies are related to the electrical size of antenna. In general, the size of the rectangular microstrip antenna should be of order of a half-guided wavelength. This limitation was mathematically studied by Wheeler [26] and Chu [27]. There have been numerous efforts to minimize the antenna size and obtain the electrically small microstrip antenna with the raised demand towards smaller and smaller wireless devices. Inductive or capacitive loading are effective ways to reduce the size of microstrip antennas [28]. In the former work, we demonstrated that the size of microstrip antenna can be miniaturized using composite metamaterial resonators [16, 17]. Magneto-dielectric substrates have been widely used to miniaturize microstrip antennas due to magnetic substrates and could provide wider bandwidths than dielectric substrates [29–32]. Fractal geometries, which are composed by self-similar structures, have opened an alternative way for antenna miniaturization [33].

From the above discussions, we see that many methods and materials are used to improve the properties of microstrip antennas. However, there should be a relationship among bandwidth, gain, and size of the microstrip antennas. Antenna engineers have recognized that the improvement in one antenna property is frequently accompanied by decline in its other performances. For example, the antenna size is reduced usually at the expense of its bandwidth and gain. Therefore, a more comprehensive consideration must be given on further developments of microstrip antennas.

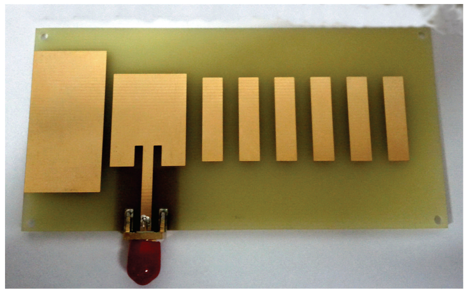
In this paper, we will suggest three areas for further research based on our previous works on microstrip antenna elements and arrays [16–25, 34–41]. We first note that novel microstrip antenna topologies are proposed to meet the desired requirement of variety of potential wireless applications, such as ultrawide band (UWB), high gain, miniaturization, circular polarization, multipolarized, and so on. Next, we discuss the composite antennas based on microstrip antennas which have more potent than each individual antenna. Finally, with the development of micro-/nano-machining techniques, antennas/arrays with highly integration and with highly operating frequencies are discussed. We present some examples of antennas developed in our group to support our points of view.

2. Variety of Microstrip Antenna Topologies

Microstrip antennas have extensively used in commercial and military applications due to their attractive advantages. However, the traditional microstrip antennas have the impedance bandwidth of only a few percent and radiation pattern with omnidirection, which obviously does not meet the requirements of various wireless applications. To this end, a wide variety of microstrip antenna topologies, including different microstrip antenna element structures and different microstrip array arrangements, have been studied to meet the desired requirement such as ultrawide band (UWB), high gain, miniaturization, circular polarization, multipolarized, and so forth.



(a) The structure of the quasi-Yagi antenna



(b) The photograph of the quasi-Yagi antenna

Figure 1: Compact broad-band quasi-Yagi antenna.

As we know, microstrip antennas inherently have narrower bandwidth and lower gain compared to conventional bulky antennas. Some microstrip antennas with special topologies, like quasi-Yagi, planar reflector antenna, are proposed to replace the conventional bulky antennas. Here, we will take a quai-Yagi antenna as an example to show how to design a planar microstrip antenna with Yagi-Uda end-fire radiation pattern. In addition, a microstrip array with special array topology is designed to get dual-polarized property.

2.1. Compact Broad-Band Quasi-Yagi Antenna. A novel S-band compact quasi-Yagi antenna has been designed, fabricated and measured by our group, as shown in Figure 1. This antenna is composed of a printed monopole-driven element, a printed reflector element, and six printed director elements.

To explain the end-fire radiation behavior of the quasi-Yagi antenna, a comparison of radiation patterns, among (1) microstrip monopole only, (2) microstrip monopole and a reflector, (3) microstrip monopole and a director, (4) microstrip monopole and a reflector with one director, and (5) microstrip monopole and a reflector with six director, is shown in Figure 2. We can observe that both the reflector and the director can increase the end-fire radiation, and it could be substantially improved by increasing the number of directors.

The measured VSWR results are shown in Table 1. A bandwidth of 14% for VSWR less than 1.5 is achieved. The gain of the antenna is above 7.5 dBi, as shown in Table 2. In this design, we see that the microstrip antenna with special topology could be conveniently used to replace the bulky Yagi-Uda antenna.

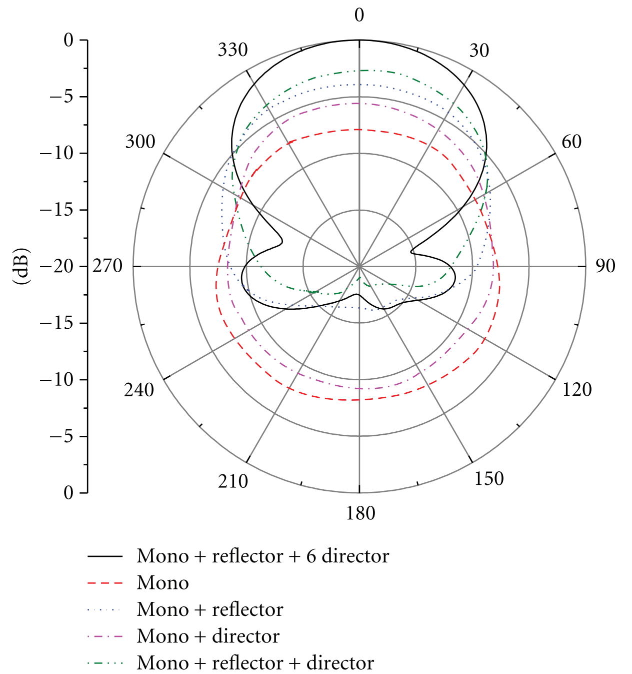
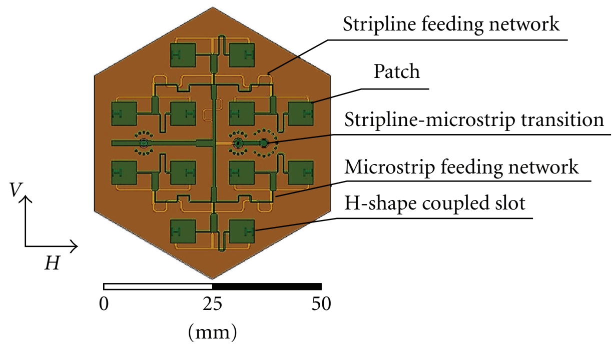
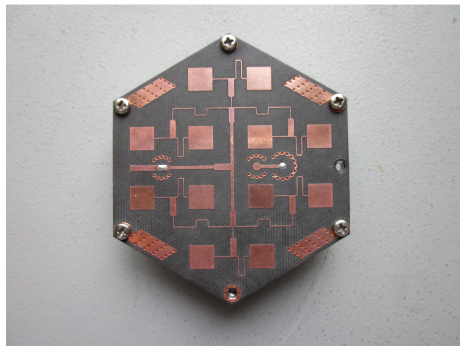


Figure 2: Radiation patterns of microstrip monopole only, microstrip monopole and a reflector, microstrip monopole and a director, microstrip monopole and a reflector with one director, and microstrip monopole and a reflector with six director.



(a) The structure of the dual-polarized microstrip antenna array



(b) The photograph of the dual-polarized microstrip antenna array

Figure 3: Dual-polarized microstrip antenna array.

Table 1: The measured VSWR of the quasi-Yagi antenna.

No.	Frequency (GHz)			
	3.25	3.5	3.75	Inband
1	1.36	1.34	1.47	<1.5
2	1.37	1.26	1.49	<1.5
3	1.36	1.25	1.48	<1.5

Table 2: The measured gain of the quasi-Yagi antenna (unit: dBi).

No.	Frequency (GHz)		
	3.25	3.5	3.75
1	7.57	8.73	8.35
2	7.58	8.55	8.37
3	7.56	8.77	8.51

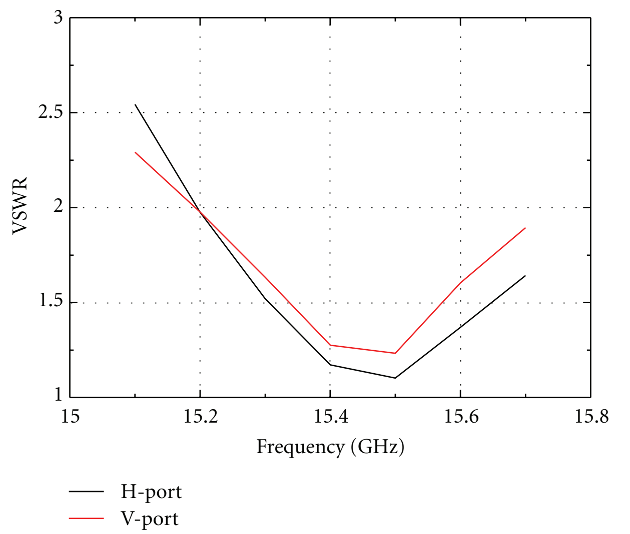


Figure 4: The VSWR of the dual-polarized microstrip antenna array.

2.2. Dual-Polarized Microstrip Antenna Array. The dual-polarized antenna is highly required for the radar, electronic countermeasure, and aerospace systems. It is known that the microstrip antenna can easily be integrated with microwave circuits and feeding network. Here, a novel Ku-band dual-polarization microstrip antenna array with a mixed feeding network, that is, the slot coupled feeding (V-port) and the coplane feeding (H-port), is designed by our group, as shown in Figure 3. It is a three layers structure: top microstrip patch layer, middle stripline feeding network layer, and bottom coplane microstrip feeding network layer. Through proper array arrangement, very good isolation can be obtained.

The VSWR, radiation patterns, and the isolation between two polarizations of the proposed dual-polarized microstrip antenna array are shown in Figures 4, 5, and 6, respectively. The results indicate that this microstrip antenna array has a good impedance matching, good radiation performance, as well as very high isolation (less than −25 dB), which can be an idea candidate for the dual-polarized wireless systems.

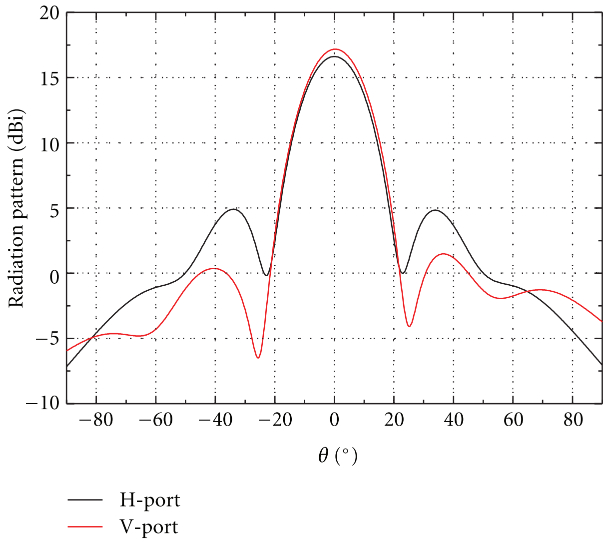


FIGURE 5: The radiation patterns of the dual-polarized microstrip antenna array at the center frequency.

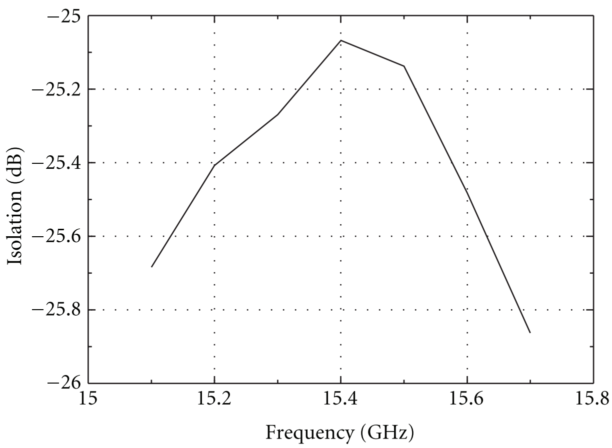


FIGURE 6: The isolation of the dual-polarized microstrip antenna array.

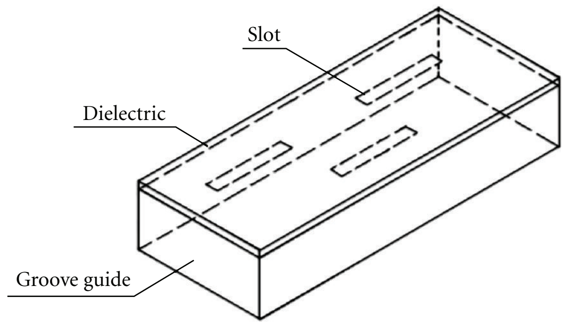


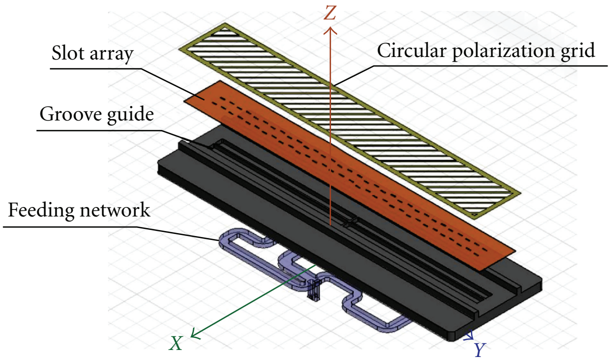
FIGURE 7: The structure of the DCWS.

3. Microstrip-Antenna-Based Composite Antenna

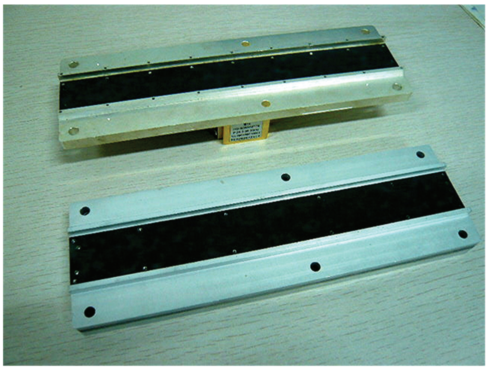
As many antenna designers have found, it is not easy to design an antenna to meet the user-defined stringent performance requirements demanded by special wireless applications like military radars, surveillances, and missile guidance, if only one type of antenna is considered. This difficulty may require the use of two more different types or structures of antenna elements with different characteristics. Composite antenna formed by two more types or structures of antennas is particularly suitable for these applications due to more advantages offered by different types or structures of antennas. For example, it is a challenging task to use single type of antenna to design a dual-band dual-polarization antenna for satellite digital multimedia broadcast (S-DMB) application [36]. A composite antenna composed with a left-handed circularly polarized (LHCP) microstrip antenna and a linear polarized omnidirectional biconical antenna is proposed by our group to meet this requirement [36]. Another example of composite antenna is comprised of a dielectric lens and microstrip log-period antenna, which has been widely applied to THz systems (this type of antenna will be further discussed in Section 4.2). Here, we will give an example of composite antenna with "structure composite" method.

3.1. Monopulse Circular-Polarized Dielectric Complex Waveguide Slot Antenna Array. Waveguide slot antenna array has been widely used for wireless system, due to its advantages of high radiation efficiency, high power capacity, and high reliability. However, it is hard to overcome the disadvantage of high cost of fabrication.

One composite antenna with waveguide slot antenna array property, termed dielectric complex waveguide slot (DCWS), is composed with slot microstrip line and groove guide, as shown in Figure 7. The slot microstrip line is formed by a metal clad dielectric substrate and slots etched in the metal. This composite antenna not only maintains the advantages of the traditional waveguide slot antenna array but also has the characteristics of high consistence, easy for fabrication, and low cost.



(a) The structure of the monopulse circular-polarized DCWS antenna array (separating view)



(b) The photograph of the monopulse circular-polarized DCWS antenna array.

FIGURE 8: Ka-band monopulse circular-polarized dielectric complex waveguide slot (DCWS) antenna array.

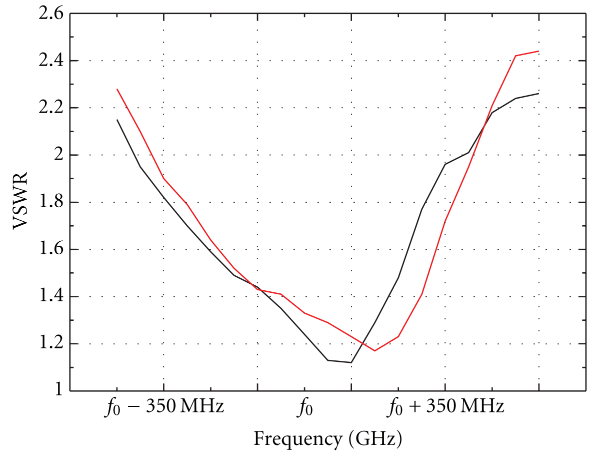


FIGURE 9: The VSWR of sum and difference port of the monopulse circular-polarized DCWS antenna array.

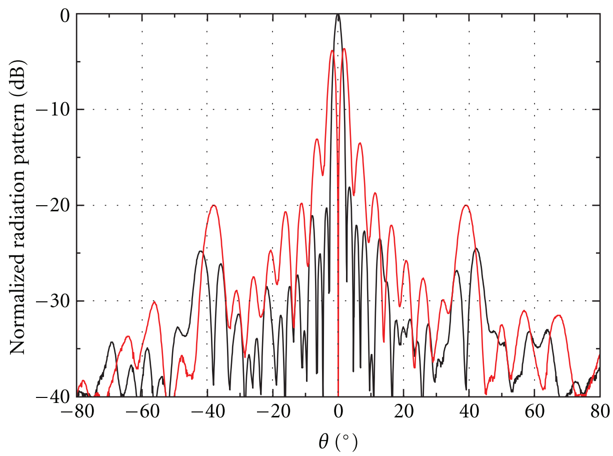
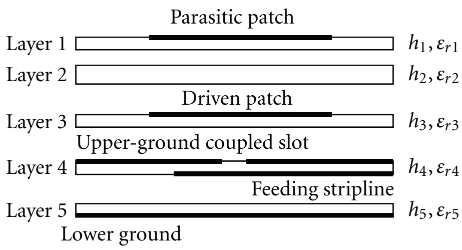


FIGURE 10: The radiation pattern of the monopulse circular-polarized DCWS antenna array at the center frequency.

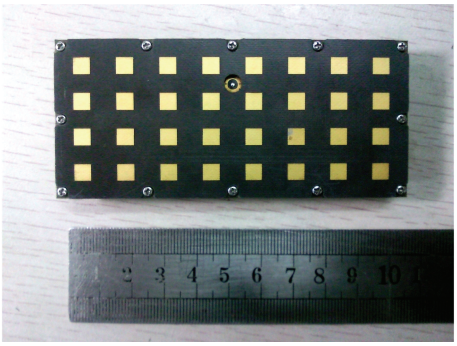
A Ka-band monopulse circular-polarized dielectric complex waveguide slot (DCWS) antenna array is designed, fabricated, and measured by our group, as shown in Figure 8. It consists of a circular polarization grid, a slot microstrip array, and a groove guide and feeding network. The slot microstrip array is fabricated on a Rogers 5880 film with dielectric constant of 2.2 and the thickness of 0.254 mm. The measured results of VSWR of sum and different port are shown in Figure 9. Figure 10 shows the measured radiation pattern at the center frequency. Some important array performance parameters such as gain, null depth and axial ratio (AR) are also given in Table 3. As shown in the measured results, very good performance can be obtained with the DCWS antenna array. The radiating efficiency of the DCWS antenna array is 80%, which is almost the same as the traditional waveguide slot antenna array. Moreover, the DCWS antenna array has 40% larger bandwidth than the traditional waveguide slot antenna array.

4. Highly Integration and Highly Operating Frequency Antennas Based on Advanced Machining Techniques

It is known that the microstrip antenna was first fabricated using PCB technology in 1970s, nearly 20 years after its concept was first presented in 1950s [1–3]. Clearly, the development of microstrip antennas is closely related with the machining techniques. Recently, various machining techniques, including multilayer printed circuit board (MPCB), complementary metal oxide semiconductor (CMOS), low-temperature cofired ceramics (LTCC), and micro-electro-mechanical systems (MEMS), are highly developed, opening opportunities for innovative antennas, such as active antennas, reconfigurable antennas, metamaterial-based antennas, THz antennas, and so forth. With the availability of high-precision and high-speed advanced machining techniques, microstrip antennas are growing towards highly integration of antenna/array and feed network and operating at relatively high frequencies. Since they are all based on the advanced



(a) Schematic side view of the structure of the high integrate broadband microstrip antenna array



(b) The photograph of the high integrate broadband microstrip antenna array

Figure 11: Ku-band high integrate broadband microstrip antenna array using MPCB technology.

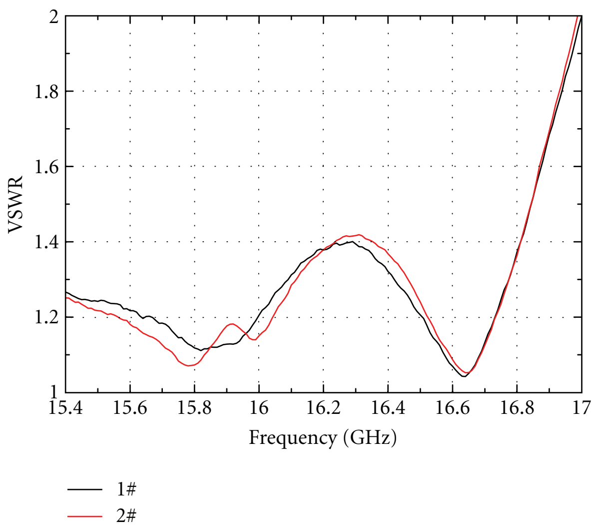


Figure 12: The VSWR of the high integrate broad-band microstrip antenna array using MPCB technology.

machining techniques, we suggest that a third research area of microstrip antennas is constantly introducing novel advanced machining techniques. In the following, two examples will be presented to show how important the advanced machining technique is to fabricate microstrip antennas. One is the highly integrate broad-band microstrip antenna array fabricated using MPCB technology. Another is THz wave planar integrated active microstrip antenna using MEMS technology.

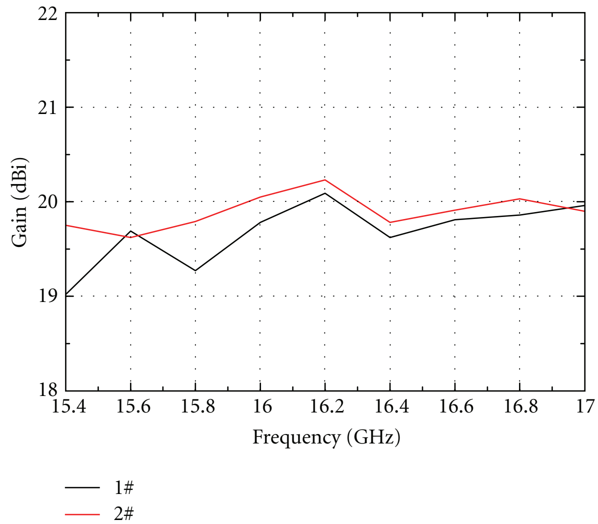


Figure 13: The gain of the high integrate broad-band microstrip antenna array using MPCB technology.

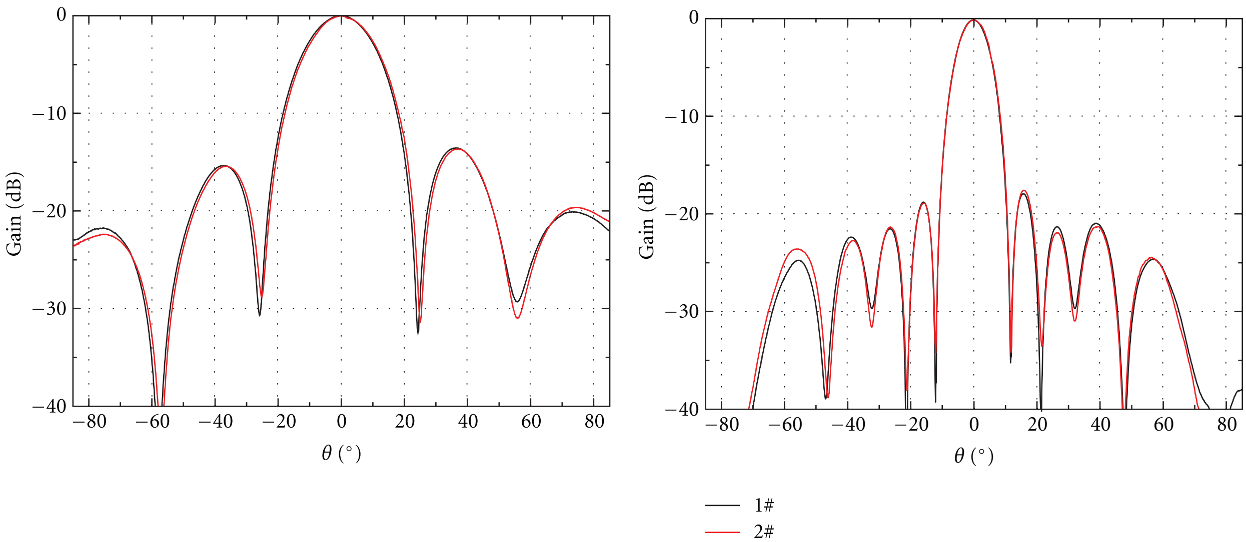
Table 3: The measured data of the monopulse circular-polarized DCWS antenna array.

Fre. (GHz)	Gain (dBi)	Null depth (dB)	AR (dB)
$f_0 - 0.2$	22.8	−37.3	3.8
f_0	21.9	−29.9	2.9
$f_0 + 0.2$	22.1	−26	4.1

4.1. High Integrate Broad-Band Microstrip Antenna Array Using Multilayer Printed Circuit Board (MPCB) Technology. Recently, with the development of the multilayer printed circuit board (MPCB) technology, the microstrip antennas can be designed and fabricated from one-dimensional (1D) to 2D and even 3D structures.

Based on the MPCB technology, a high integrated broadband Ku-band microstrip antenna array is designed, fabricated, and measured by our group, as shown in Figure 11. This antenna consists of a parasitic patch, a driven patch, a stripline feeding network, a broad-band coaxial line to stripline transition, some buried screw holes, and some via holes. The feeding network is integrated in the bottom of the substrate of the antenna. As all of the structures fabricated at once, the accuracy and the uniformity can be assured. Two antennas of this type are measured. The measured VSWR, gain, and radiation pattern at the center frequency are shown in Figures 12, 13, and 14, respectively. The measured results show that this antenna maintains good radiation and matching performances with relative bandwidth of 13%. They have also shown good uniformity by using MPCB technology.

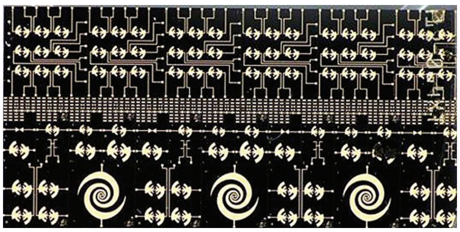
4.2. THz Wave Planar Integrated Active Microstrip Antenna Using Micro-Electromechanical Systems (MEMSs) Technology. THz waves typically include frequencies between 0.1 THz and 10 THz. THz technology is now becoming a promising technology which has potential applications in many fields, such as short-range communication, biosensor, imaging,



(a) E-plane

(b) H-plane

Figure 14: The radiation pattern of the high integrate broad-band microstrip antenna array using MPCB technology at the center frequency.



(a) The photograph of the THz monolithic antenna

(b) The photograph of the THz monolithic antenna covered by a dielectric lens

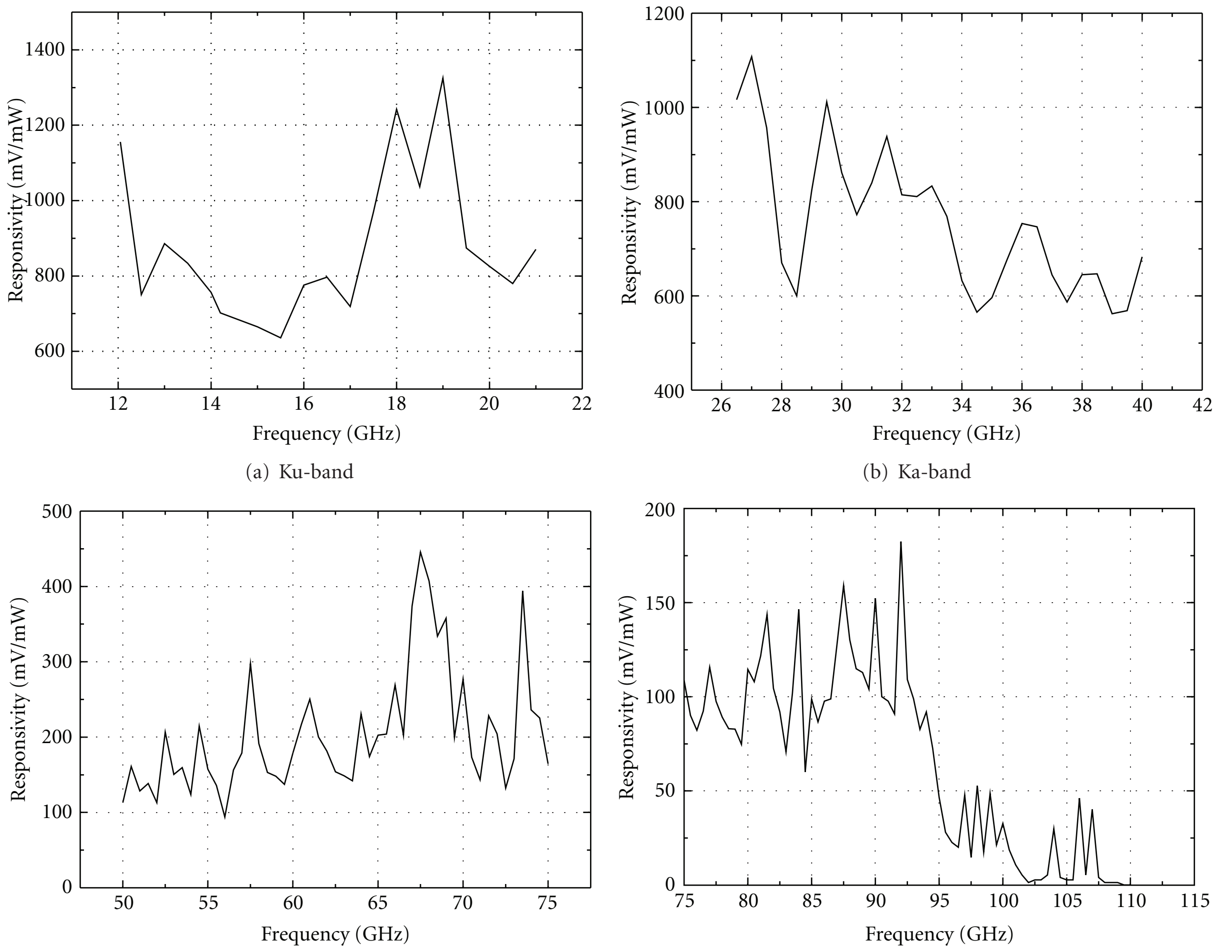
Figure 15: THz wave planar integrated active microstrip antenna using micro-electromechanical systems (MEMSs).

national security, space exploration and communication, and so forth [39–46]. To realize THz transceiver system, antenna is an essential component. We often use horn antenna, lens antenna, and dielectric parabolic antenna, for THz systems. However, they are not easy to integrate with monolithic integrate circuits. Although the microstrip antenna has the merits of small volume, light weight, and easy integration with circuit, it is difficult to be processed in such high-frequency regions. MEMS technology opens the way to design of THz antennas, circuits, and systems. THz monolithic antenna fabricated using MEMS technology and covered by a dielectric lens, which can be considered a composite antenna, are designed, fabricated, and measured by our group, as shown in Figure 15.

Diodes have the functions of mixing and/or modulating the carrier-wave signal. It is an effective way to reduce the propagation path for detectors application by integrating the diode and microstrip antenna. The extended hyper-hemispherical dielectric lens is used to increase the gain of the microstrip antenna. An antenna-coupled detector integrated with a dielectric lens is designed and fabricated up to THz range by our group. The planar microstrip log-spiral antenna and log-period antenna have been fabricated using micro-electromechanical systems (MEMSs) technology. The photographs of the antennas are demonstrated in Figure 15. The measured responses of the antenna-coupled detector working at different frequency bands are shown in Figure 16, which can be considered to determine the effective operating frequencies [19, 40]. This detector gave a valid response from 12 GHz to 110 GHz frequencies. The results prove the validity and feasibility of the THz antenna designed using micro-electromechanical systems (MEMSs) technology.

5. Conclusion

The advantages and disadvantages of microstrip antennas are discussed in this paper. In particular, three areas for further development of microstrip antennas are presented based on our previous works on microstrip antenna elements and arrays. Variety of microstrip antenna topologies and microstrip-antenna-based composite antenna are discussed, and



(c) V-band

(d) W-band

Figure 16: Frequency responses test results of the THz wave planar integrated active microstrip antenna covered by a dielectric lens.

the advanced machining techniques pushing the microstrip antennas towards the highly integration of antenna/array and feeding network and the highly operating frequencies are described. To demonstrate the distinctive features of novel microstrip antennas, various antenna elements and arrays for different applications are presented. This paper has shown that the microstrip antennas are still very promising paradigm for civilian and military wireless applications.

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