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An UWB Top-Loaded Monocone Antenna for Multiservice Wireless Applications

Xia Bai*, Ming Su, Zhaodong Gao, and Yuanan Liu

Abstract—A compact ultra-wideband (UWB) top-loaded antenna for multiservice wireless applications is presented. It consists of a metal cone radiator, a small ground plane, four shorting poles and a top-cross plate, among which the top-cross plate with two slots shorted to the ground planet is important to broaden the low frequency bandwidth. The measured result shows that an improved impedance bandwidth of 185% from 1.17 to 30 GHz is achieved. The omnidirectional stable radiation pattern in the horizontal plane is also obtained. The volume of proposed design is approximately $0.0173\lambda^3$ at 1.17 GHz. With the small volume and UWB characteristic, the design of the proposed antenna is very suitable for many wireless standards such as Softbank (1427–1500 MHz), DCS1800, PCS1900, UMTS, IMT2000, Wi-Fi (2.4 GHz), WiMAX (2.2–5.5 GHz), UWB (3.1–10.6 GHz), and satellite communication (X band, Ku band and Ka band).

1. INTRODUCTION

With the rapid developments in the modern wireless communication, broadband antennas are required for high speed data exchange in wireless network. The broadband technology has appeared as an attractive solution for multiservice wireless applications its many advantages such as transmitting signals with an inherent noise-like behavior (due to low EIRP level), reduced probability of detection and intercept, robustness against multipath, and potentially high data rates over short distances [1]. The monopole antennas with broadband, and omnidirectional radiation characteristic have aroused great concern in the mobile radio communication. Now most of the reported monopole antennas are applied in LTE band or UWB band. In order to meet different needs of communication services, antenna covering multiband is required, which will further improve data rate and multiple access capability.

Recently, several relevant structures of the monopole antennas have been designed in the literature. The disadvantages of the traditional monopole antennas are large size and high profile. Using a ring patch shorted to ground plane, the antenna achieved a -10 dB return loss bandwidth of 121.1% from 2.8 to 11.4 GHz in [2]. The diameter of ground plane is 200 mm. A monopole antenna covering from 0.8 to 2.4 GHz with omnidirectional radiation pattern in H-plane, was investigated in [3]. The profile of the design was $0.08\lambda_0$ at the low operating frequency. In [4], the monocone antenna with the loaded top hat cutting two slots had been presented, which achieved a broad bandwidth of 98%. The antenna profile is about 0.15 λ_0. In [5], the circular sleeve structure was used to effectively improve the matching of the upper operating frequency edge. The antenna achieved impedance bandwidth of about 112%. The antenna consisted of three top loaded coupling patches over the top of the radiation patches and a circular sleeve on the ground plane. The profile of the broadband omnidirectional antenna was $0.23\lambda_0$ with an impedance bandwidth of 152% ranging from 0.97 to 7.09 GHz in [6]. In [7], A low-profile monopole-type antenna operating over 148% impendence bandwidth was proposed. A conical

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* Corresponding author: Xia Bai (2521583475@qq.com).
The authors are with Beijing Key Laboratory of Work Safety Intelligent Monitoring, School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China.

monopole antenna consisting of two mechanical parts achieved an impedance bandwidth of 159% in [8]. The design was approximately $0.24\lambda_0$ in length with respect to the lower frequency of 2.4 GHz. Vehicle and helmet antennas operated in a wide frequency range from about 800 to 2300 MHz in [9], whose curved ground plane was utilized to improve the radiation patterns at broadside and further reduce the antenna height. In general, the super large ground plane can help to broaden the lower frequency edge of the cone antenna, while it restricts application and also increases the manufacture cost. In [10], a monocone antenna using dielectric loading to reduce the diameter of the ground plane was presented, which had an impedance bandwidth of 106.3%. However, the monpole antenna mentioned above does not have a wide enough impedance bandwidth to cover the operating frequency bands of the multi-band wireless communication system.

In this letter, a UWB monocone antenna with small volume is presented. The top-cross plate with two slots to effectively improve the matching condition of the low operating frequency is introduced. The proposed antenna achieves an impedance bandwidth of 185% with $|S_{11}| < -10$ dB from 1.17 to 30 GHz. So the small volume and low profile of the antenna are realized by a top-loading patch and four shorting pins. The radiation pattern is omnidirectional and the cross-polarization level is low. With the small volume and UWB characteristics, the design of the proposed antenna is very suitable for many wireless standards.

2. ANTENNA DESIGN

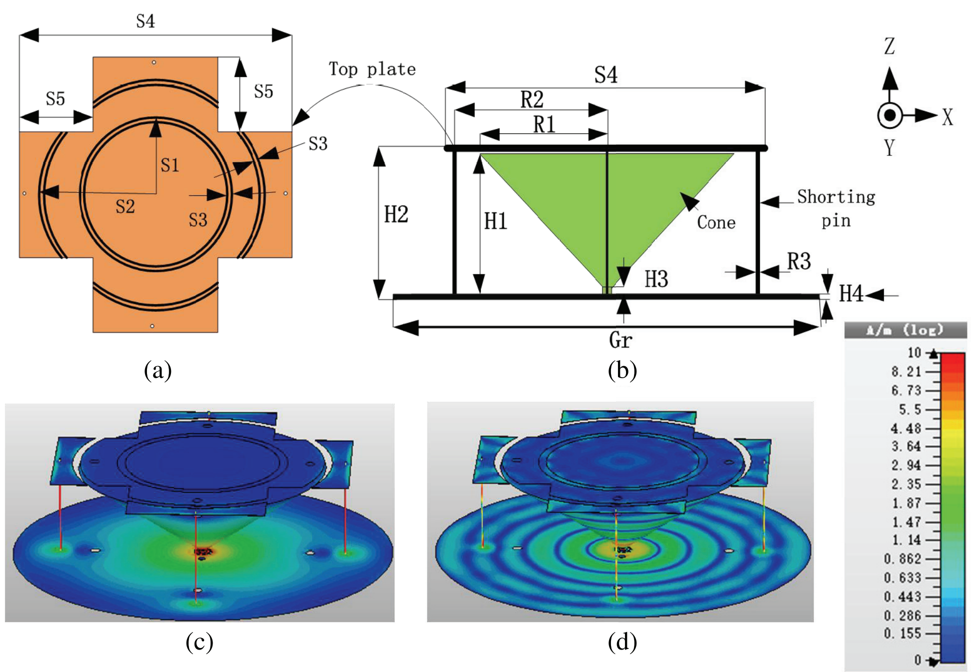


Figure 1. Structure diagrams (a) the top plane of the proposed design. (b) The side view of the proposed cone antenna. (c) Current distribution at 2 GHz. (d) Current distribution at 15 GHz.

2.1. Antenna Design

Figures 1(a) and (b) show diagrams of the top-cross plate and proposed cone antenna, respectively. As seen in Fig. 1(b), the antenna mainly includes a top-cross plane, a metallic cone, four shorting pins and a circular ground plane. The top-cross plane is shorted to ground plane by four shorting pins to obtain low profile. The cone antenna is fed by a coaxial probe, of which feed distance $H3$ between the metallic cone and the ground plane is chosen as 0.5 mm. Four shorting pins are symmetrical on the horizontal

Table 1. Final optimal dimension values of the proposed antenna.

Dimension	Value (mm)	Dimension	Value (mm)
$S1$	26.8	$R2$	44.6
$S2$	40.9	$R3$	0.7
$S3$	2.5	$H1$	28.2
$S4$	93.2	$H2$	31.2
$S5$	25	H3	0.5
$R1$	38.9	$H4$	0.762

plane of the monopole antenna. The top plane is utilized to reduce the antenna height and the effective area of antenna radiation, which increases the reactive energy stored within the antenna and reduces the Q value [5]. The detailed parameters of the top plane are described in Fig. 1(a). The top plane with chamfer and slot is designed to match the impedance bandwidth. Figs. 1(c) and (d) show the current distribution of the cone antenna at 2 GHz and 15 GHz, respectively. It can be seen that the current distributions of antenna are concentrated on the poles, feed position and the edge of top plane at 2 GHz. The current distribution is spread out in a circle at 15 GHz, which proves the traveling wave characteristics of the antenna and explains the nature of ultra wideband. In order to fix and install, Rogers 4350b with a dielectric constant of 3.48 and thickness of 0.762 mm is used as the substrate of the top plane and ground plane. The final optimized parameters of the proposed monopole antenna are listed in Table 1.

2.2. Effects of Key Parameters

In this section, key parameters of the proposed antenna are analyzed. Time domain simulation of the CST Studio Suite 2016 is utilized to optimize the cone antenna structure. The top plane is equivalent to the capacitive load, which broadens the low frequency bandwidth and reduces the antenna profile. Besides, the high frequency behavior is produced by the metal cone and the feeding position. In order to display more clearly, the influence of the parameters from 0.5 to 10 GHz is analyzed in Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

Figures 2 and 3 show a detailed description of the top plane in different states. When the top plane is common square shape, the cone antenna mismatches at low frequency band from 2 to 5.08 GHz and from 7.71 to 8.22 GHz. It can be seen that the top-cross structure is designed to improve the impedance

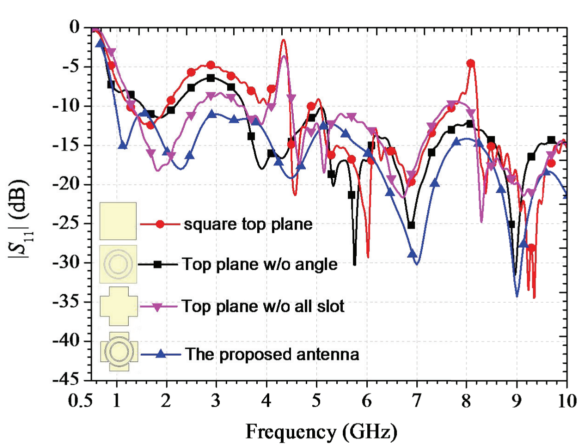


Figure 2. Simulated return loss of the proposed antenna with various situation of the top plane.

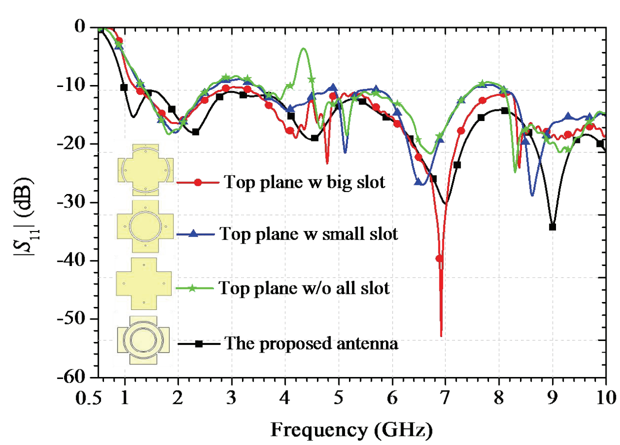


Figure 3. Simulated return loss of the proposed cone antenna with various slot of top plane.

match from 1.2 to 3.55 GHz. The bands from 3.55 to 5.08 GHz and from 7.71 to 8.22 GHz are extended thought cutting two slots on the top plane, which is due to adding the capacitance to balance the reactance of the original cone antenna. The effect of the slots is detailed described in Fig. 3. A small inner slot is cut on the top plane to broaden the operating bandwidth from 4 to 4.6 GHz. The top plane with a big external slot, whose external plane shorted to the ground plane is connected to the internal top plane by slot coupling, can further increase the overall impedance matching.

The crossed structure of the top plane is also critical for cone antenna to broaden the lower frequency band. The simulated results with various $S5$ are plotted in Fig. 4. Results show that the size of top-cross plate mainly produces the low bandwidth from 1.2 to 3.6 GHz. When the size of $S5$ is smaller, the mismatch of impedance bandwidth is more obvious.

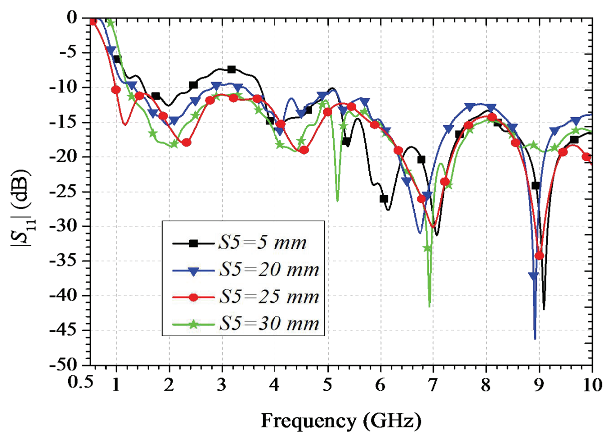


Figure 4. Simulated return loss of various $S5$ of the top-cross plane.

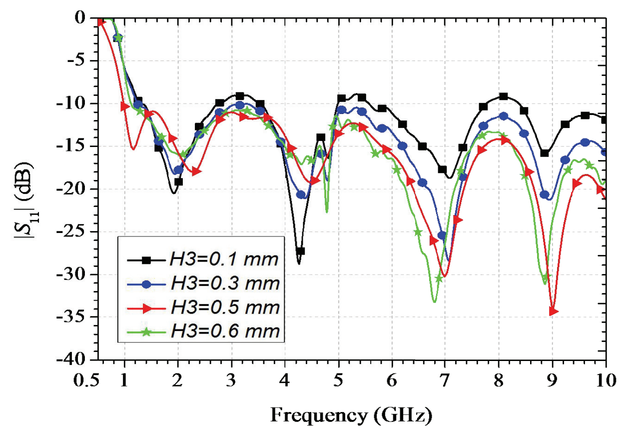


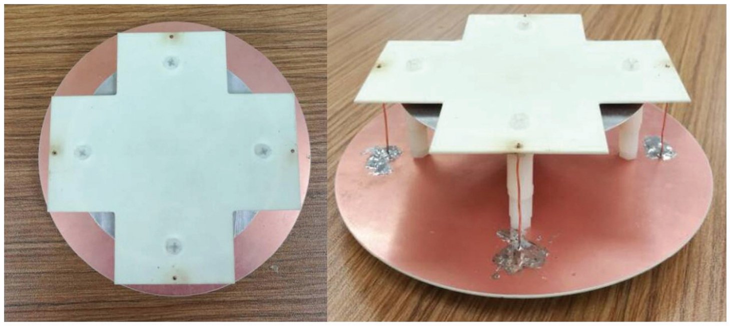
Figure 5. Simulated return loss of the proposed cone antenna with different spacing ($H3$) between cone and ground.

Figure 5 shows the simulated results of S-parameters for the proposed antenna in different spacings between cone and ground plane. The distance $H3$, which is a necessary transition to cone, decides the feed space between SMA connector and ground. It significantly affects impedance matching of the proposed cone antenna, particularly in the high frequency. As we can see, the antenna is closer the ground plane, resulting in S parameters up-shift in -10 dB edge. The value $H3$ is selected to 0.5 mm to optimize the best results.

3. EXPERIMENTAL RESULTS

The structure of the proposed cone antenna is shown in Fig. 6. Utilizing four symmetrical plastic poles to fix the cone, top-cross plate and ground plane, the proposed cone structure is easy to firmly combine, which is beneficial to the practical production. The metal patch structure with slots and chamfer angle is hidden on the bottom of the top substrate to short the ground plane by four poles. Fig. 7 shows the simulated and measured results of $|S_{11}|$ for the proposed cone antenna. As shown, the return loss from 0.98 to 30 GHz (187%) is simulated. The measured bandwidth is from 1.17 to 30 GHz (185%) with $|S_{11}|$ below -10 dB. The measured results agree well with the simulated ones in the range of 30 GHz.

The measured radiation pattern dates are obtained by an anechoic chamber utilizing multi-probe spherical near-field measurement system. Considering the laboratory conditions, the anechoic chamber adopting the frequency domain can only measure up to 6 GHz. Therefore, the radiation patterns of lower frequencies are measured, of which high frequencies characters are exhibited for the simulation results. Fig. 8 illustrates the radiation patterns of the proposed cone antenna in the E plane (yz-plane) and H plane (xy-plane) at 2 GHz, 4 GHz, 6 GHz, 15 GHz and 25 GHz. As illustrated in Fig. 8, the radiation patterns of the proposed antenna are omnidirectional and stable in the H plane. The low cross polarization level is obtained. The maximum measured gain of the antenna is 2.55 dBi, 8.13 dBi



(a) (b)

Figure 6. The photograph of the UWB antenna. (a) Top view. (b) Perspective view.

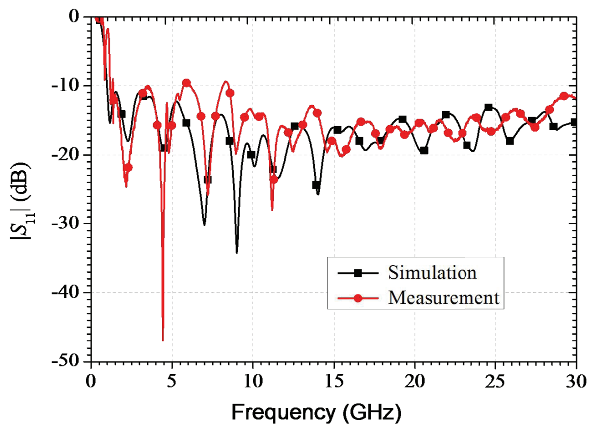


Figure 7. Measured and simulated return loss of the proposed cone antenna.

and 5.96 dBi at 2 GHz, 4 GHz, and 6 GHz. A sharp increase of 60% to 90% for simulated total efficiency is achieved from 1.17 to 1.4 GHz, and the maximum efficiency exceeds 95% from 5.5 to 30 GHz. The deviation between simulation and measurement, such as radiation patterns and S parameters, may be attributed to the connector losses, effect of soldering and installation tolerances of plastic column.

The performances of the proposed antenna and existing various antennas for comparison are listed in Table 2. It is seen that our proposed antenna has the advantages of wide bandwidth and compact size over other cone antennas.

Table 2. Performance comparison of the proposed antenna with others.

Reference	Bandwidth (%)	Profile/λ	Ground plane diameter/λ	Size/λ^3
[2]	121	0.07	0.64	0.0287
[3]	100	0.08	0.67	0.0359
[5]	112	0.15	6.2	5.766
[6]	152	0.23	0.54	0.0526
[7]	148	0.053	0.9	0.4293
This proposed Work	**185**	**0.12**	**0.429**	**0.0173**

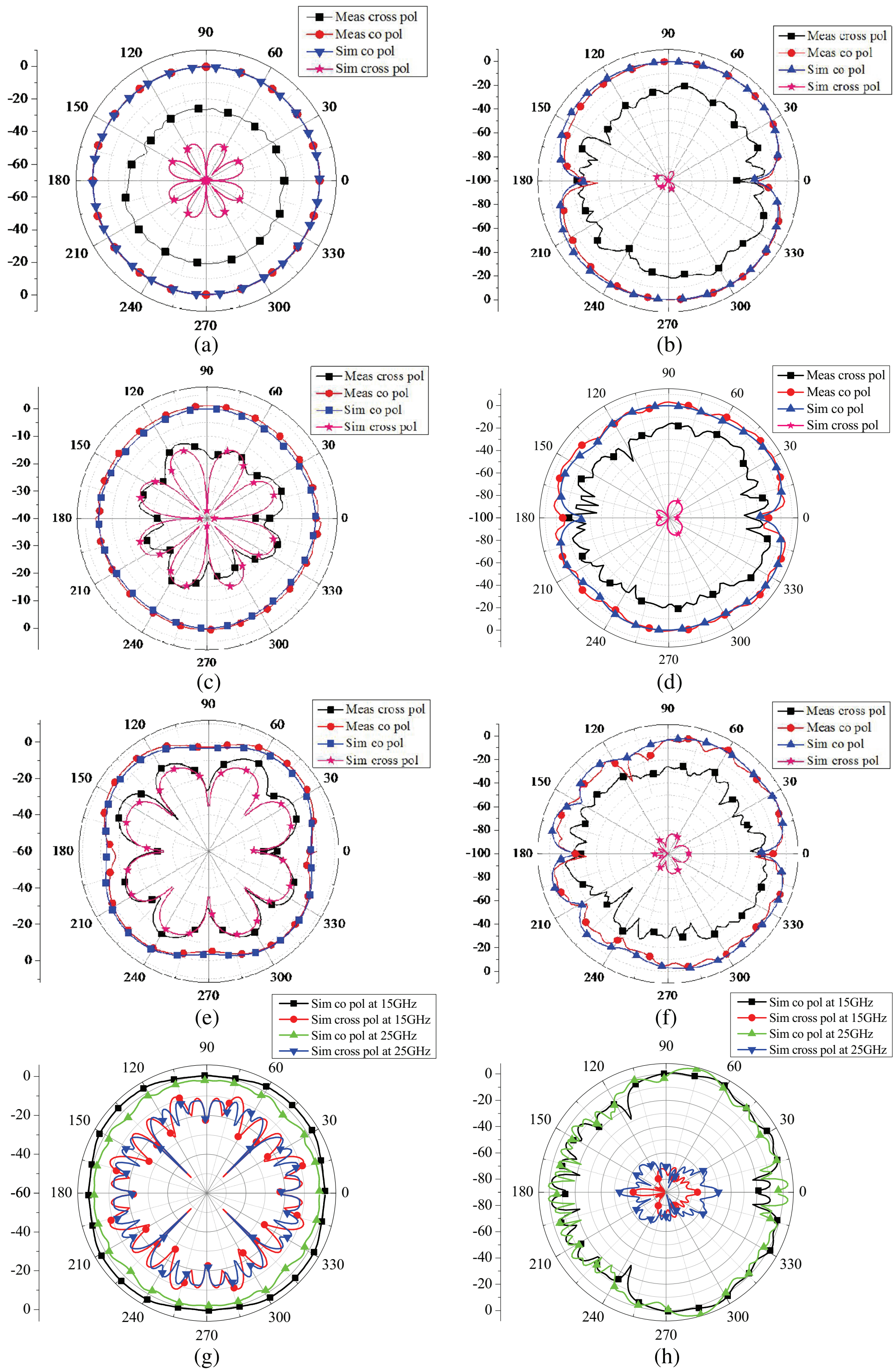


Figure 8. The radiation pattern of the fabricated cone antenna. (a) xy-plane at 2 GHz. (b) yz-plane at 2 GHz. (c) xy-plane at 4 GHz. (d) yz-plane at 4 GHz. (e) xy-plane at 6 GHz. (f) yz-plane at 6 GHz. (g) xy-plane at 15 GHz and 25 GHz. (h) yz-plane at 15 GHz and 25 GHz.

4. CONCLUSIONS

In this letter, a novel ultra-wideband low profile cone antenna with compact structure is presented. The crossed structure and cutting slots of the top plane effectively improve the matching condition of the lower operating frequency. The proposed antenna operates in an ultra-wide frequency band from 1.17 to 30 GHz. The proposed antenna with small size, omnidirectional radiation characteristic and UWB performance, render suitability and usability for Softbank (1427–1500 MHz), DCS1800, PCS1900, UMTS, IMT2000, Wi-Fi (2.4 GHz), WiMAX (2.2–5.5 GHz) and WBAN (3.1–10.6 GHz). In addition, it may also be used for satellite communication in the X band (8–12 GHz), Ku band (12–18 GHz) and Ka band (26.5–30 GHz) applications.

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