Wideband 5G MIMO Antenna With Integrated Orthogonal-Mode Dual-Antenna Pairs for Metal-Rimmed Smartphones

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Abstract—This article presents a wideband orthogonal-mode dual-antenna pair with a shared radiator for fifth-generation (5G) multiple-input multiple-output (MIMO) metal-rimmed smartphones. The wideband decoupling property of the dual-antenna pair is realized by the combination of the orthogonal monopole/dipole modes in the lower band and the orthogonal slot/open-slot modes in the higher band. With the orthogonal-mode design scheme, the dual-antenna pair shows a wide impedance bandwidth of 3.3–5.0 GHz and a high isolation of more than 21.0 dB across the entire band without using any external decoupling structures. By arranging four such dual-antenna pairs at two side edges of the smartphone, an 8 × 8 MIMO system is fulfilled. Both the simulation and measurement results show that the proposed 8 × 8 MIMO system could offer an isolation of better than 12.0 dB and an envelope correlation coefficient of lower than 0.11 between all ports. The measured average antenna efficiencies are 74.7% and 57.8% for the two antenna elements of the dual-antenna pair. We portend that the proposed design scheme, with merits of shared radiator, wide bandwidth, and metal rim compatibility, has the potential for the application of future 5G smartphones.

Index Terms—Antenna diversity, dual-antenna pair, fifth-generation (5G), multiple-input multiple-output (MIMO), orthogonal mode, smartphone antenna.

I. INTRODUCTION

In the past few years, the explosive growth of the communication data volume has exhausted the potentiality of current 4G mobile communication systems. Advanced mobile communication technology is urgently demanded to offer a higher throughput rate, shorter latency, and lower energy consumption for fifth-generation (5G) mobile communication systems [1]. Massive multiple-input and multiple-output (MIMO) technique, with multiple transmit and receive antennas, is one of the key techniques of 5G mobile communication systems. In mobile terminals, about eight 5G MIMO antenna elements together as a building block to effectively reduce the overall occupied footprint of MIMO antennas [31]–[45]. In this scheme, the 8 × 8 MIMO antenna system could be achieved by four such dual-antenna pairs, thus only half of regions are required with an effectively reduced size. However, eliminating the mutual coupling between two closely spaced or shared-radiator antenna elements is a tough work. In [31]–[34], corner-placed orthogonal dual-polarized or tripolarized antennas are proposed to stimulate degenerate modes in a square radiator. Neutralization line method is also utilized to decouple between two closely spaced slot [35] or monopole [36] antennas. In [37] and [38], a novel asymmetrically mirrored coupling-fed scheme is proposed to decouple between two closely spaced loop antennas. Lumped or distributed LC tanks are also investigated in [39]–[41] to reduce the coupling between closely spaced folded monopole elements. Recently, an orthogonal mode decoupling method is proposed by the author to achieve a natural high isolation of more than 20 dB between two closely spaced [42], [43] or shared-radiator [44] antenna elements. The above strategies do make great progress in antenna decoupling and effectively reduce the overall size of 5G MIMO antenna system. However, most of the aforementioned integrated antenna pairs suffer operating at the sub-6 GHz spectrum should be accommodated in a size-limited environment and coexisted with original 2G/3G/4G antennas [2]–[7]. Although MIMO technique has early captured the attention of many researchers [8]–[16], however, designing multiple isolated MIMO antennas in the size-limited environment still remains a tremendous challenge.

The straightforward design scheme for 5G MIMO smartphone antennas is arranging four or eight antenna elements in separated regions of the smartphone [17]–[30]. In this manner, the mutual coupling between antenna elements could be mitigated directly by the spatial distance. In addition, some other decoupling techniques, such as orthogonal polarizations [25], high-order modes [26], defective ground structures [27], decoupling elements [28], and self-isolated elements [29], [30] are investigated to further enhance the isolation. However, the occupied footprints are overmuch in this manner without any spatial reuse, which is not competent for the practical smartphone application.

Another design scheme for 5G MIMO antennas is integrating two closely spaced or shared-radiator antenna elements as one of the key techniques of 5G mobile communication systems. In mobile terminals, about eight 5G MIMO antennas...
a narrow decoupling bandwidth of 3.4–3.6 GHz, which are not competent for the future smartphone antennas with the global 5G bands N77 (3.3–4.2 GHz), N78 (3.3–3.8 GHz), and N79 (4.4–5.0 GHz) [45], [46] covered. As a result, realizing wideband decoupling between integrated dual-antenna pair will become the new challenge and future development trends of 5G smartphone antennas.

In this article, a wideband integrated dual-antenna pair with a shared radiator is proposed for the first time for 5G metal-rimmed smartphone applications. On the one hand, orthogonal T-shaped monopole and coupling-fed dipole antenna elements are merged together as an integrated dual-antenna pair, and metal rim is exploited to effectively widen the bandwidth of the dual-antenna pair. On the other hand, orthogonal slot/open-slot modes are elaborately excited in the higher band to further enhance the bandwidth of the dual-antenna pair. Therefore, with the combination of the orthogonal monopole/dipole modes in the lower band and orthogonal slot/open-slot modes in the higher band, a wide matched and decoupled bandwidth from 3.3 to 5.0 GHz is performed to cover the entire 5G N77/N78/N79 bands. With the orthogonal characteristic modes, the integrated dual-antenna pair could offer a natural high isolation of more than 21.0 dB across 3.3–5.0 GHz without using any external decoupling structures. Then, by arranging four such dual-antenna pair at two side edges of the smartphone, a wideband 8 × 8 MIMO system is fulfilled, which is a good candidate for the future 5G metal-rimmed smartphones.

This article is organized as follows. In Section II, the design process and operating mechanism of the integrated dual-antenna pair is discussed, including the antenna structure, evolution procedure, operating principle, and parameter analysis. In Section III, the antenna fabrication, simulated, and measured results of the 8 × 8 MIMO system are presented. In Section IV, a comparison chart is reported to highlight the merits and novelty of the proposed design scheme. Finally, Section V draws a conclusion of this article.

II. ORTHOGONAL-MODE DUAL-ANTENNA PAIR

A. Antenna Structure

Fig. 1(a) and (b) shows the geometry of the proposed 8 × 8 MIMO system for 5G metal-rimmed smartphones. The whole dimension of the proposed geometry is 150 × 75 × 7.5 mm³, which is applicable to up-to-date smartphones. A 0.8 mm-thick FR-4 substrate (εr = 4.4, tanδ = 0.02) is employed as the main board of the smartphone. A metal ground plane is printed at the back side of the FR-4 substrate. The 0.2 mm-thick metal plates are vertically placed around the ground plane to imitate the metal rim of smartphones. Eight gaps are slit in the metal rim to enable an effective radiation. Four slots are etched at the ground plane to install four sets of antenna pair modules. Every antenna pair module includes two shared radiators yet decoupled antenna elements.

The detailed structure of the integrated dual-antenna pair is shown in Fig. 1(c). The dimension of the etched ground clearance for the dual-antenna pair is 40 × 3 mm².

Ant1 is directly excited by a center strip with a series lumped capacitor (C1 = 0.5 pF) to tune the impedance matching. On the contrary, Ant2 is coupling excited by two differential-fed side strips with out-of-phase signals. Two symmetrical series lumped inductors (L1 = L2 = 2 nH) are used at the differential ports to tune the impedance matching. The dominant radiators for both Ant1 and Ant2 are the metal rim and etched slot, namely, the radiation aperture is shared for these two antennas; however, a high isolation can still be realized between port1 and port2 across a wide bandwidth, which will be analyzed in Section II-C.

B. Evolution of the Dual-Antenna Pair

To clearly exhibit the antenna design process, Fig. 2 illustrates the evolution procedure of the proposed dual-antenna pair. The original motivation is derived from [43] as shown in Fig. 2(a). In [43], a T-shaped monopole and a coupling-fed dipole are closely placed at two sides of the ground plane. Due to the orthogonal current modes in the two antennas, the mutual coupling could be eliminated totally with a high isolation of more than 20 dB across 3.4–3.6 GHz [43]; however, the narrow decoupling bandwidth, dielectric rim, and low integrated level in [43] make it immature to be applied in future 5G smartphones.

First, to reduce the size of the tightly arranged dual-antenna pair in [43], the T-shaped monopole and coupling-fed dipole...
Fig. 2. Evolution procedure of the proposed dual-antenna pair. (a) Case 0: closely spaced monopole and dipole elements proposed in [43]. (b) Case 1: arranging the monopole and dipole elements at the same side to further reduce the size. (c) Case 2: merging the monopole and dipole together as a shared radiator. (d) Case 3: installing the shared radiator in Case 2 into a metal-rimmed circumstance and the horizontal strip is replaced with the metal rim. (e) Case 4 (Proposed): lengthening the etched slot in the ground plane to enable new orthogonal modes. (f)–(h) Comparison of $S_{11}$, $S_{22}$, and $S_{21}$ of the dual-antenna pairs proposed in Case 1–Case 4.

are placed at the same side as shown in Fig. 2(b). This step could realize a significant size reduction for the dual-antenna pair with an extremely closely spaced configuration. However, the antenna bandwidth will be reduced with an increased Q-factor due to the condensed antenna footprint. Second, as shown in Fig. 2(c), by combining the horizontal strips of the T-shaped monopole and coupling-fed dipole, the integrated level of the dual-antenna pair can be further enhanced from the closely spaced configuration to a shared-radiator configuration; however, the resonant frequency of the monopole antenna is sharply reduced due to the increase in the resonant length, while that of the dipole antenna keeps unchanged. Then, for compatibility with the metal-rimmed circumstance in the mainstream smartphones, the horizontal strip of the dual-antenna pair is replaced with the metal rim as shown in Fig. 2(d), which could definitely increase the bandwidth of both antenna elements. Finally, to align the resonant frequency and enhance the bandwidth of Ant1, the etched slot in the ground plane is lengthened to fit the desired 5G spectrums as shown in Fig. 2(e). The mixed-mode S-parameters for the 3-port network with a single-ended port and two differential ports are calculated in the software ADS. The calculated reflection coefficients of Ant1 and Ant2 in cases 1–4 are proposed in Fig. 2(f) and (g), respectively, and the isolations between Ant1 and Ant2 in cases 1–4 are illustrated in Fig. 2(h). Note that the isolations keep in a high level all the time in the evolution process due to the ideal differential excitation and symmetrical center-placed antenna pair configuration in the simulation. However, the amplitude and phase unbalance performance in the practical differential balun and the side-placed antenna pair configuration will slightly deteriorate the antenna isolation, which will be discussed in Section II-D.

C. Operating Principle of the Dual-Antenna Pair

The operating principle of the proposed dual-antenna pair is demonstrated. The simulated vector current distributions in the lower and higher bands are analyzed in Fig. 3. The sketch maps of vector currents and $E$-fields are also illustrated with black and red arrow lines for ease of understand.

At 3.5 GHz, a top-loaded monopole mode is excited when fed through port 1 with $x$-polarized in-phase currents and $y$-polarized out-of-phase currents, whereas a dipole mode is excited when fed through differential port 2 with $x$-polarized out-of-phase currents and $y$-polarized in-phase currents. Mathematically, the in-phase and out-of-phase vector currents are the orthogonal basis of the linear space, thus they will generate two uncorrelated radiation fields without any mutual coupling even though share the same radiator.

At 4.5 GHz, when fed through port 1, the two slot modes are excited with an identical $E$-field distribution at the left and right clearances; interestingly, when fed through differential port 2, the two T-shaped open-slot modes are excited with an identical $E$-field distribution at the left and right clearances. Clearly, the slot mode excites an $x$-polarized radiation field,
Fig. 3. Simulated vector current distributions of the dual-antenna pair. (a) Port 1 is excited at 3.5 GHz. (b) Port 1 is excited at 4.5 GHz. (c) Port 2 is excited at 3.5 GHz. (d) Port 2 is excited at 4.5 GHz.

Fig. 4. Simulated 3-D radiation patterns of the dual-antenna pair. (a) Port 1 is excited at 3.5 GHz. (b) Port 1 is excited at 4.5 GHz. (c) Port 2 is excited at 3.5 GHz. (d) Port 2 is excited at 4.5 GHz.

while the open-slot mode excites a $y$-polarized radiation field. Therefore, the slot and open-slot modes are also orthogonal with each other, enabling a high isolation in the higher band.

To provide a physical insight of the far field radiation performance of the proposed integrated dual-antenna pair, the simulated 3-D radiation patterns are proposed in Fig. 4.

In the lower band of 3.5 GHz, as shown in Fig. 4(a) and (c), the monopole-like and dipole-like radiation patterns are obtained when fed through port 1 and port 2, respectively. The monopole-like pattern has a radiation maximum along $\pm y$ axis and a radiation null along $-x$ axis, whereas the dipole-like pattern has a radiation maximum along $-x$ axis and a radiation null along $\pm y$ axis; therefore, a good radiation pattern diversity performance is achieved in the lower band.

In the higher band of 4.5 GHz, when fed through port 1, a synthetic array pattern of two slot antennas is performed with a radiation null along $-x$ axis as shown in Fig. 4(b), and when fed through port 2, a synthetic array pattern of two open-slot antennas is performed with a radiation maximum along $-x$ axis as shown in Fig. 4(d). As a result, the radiation pattern diversity performance is also obtained in the higher band.

In summary, the proposed dual-antenna pair possesses two sets of orthogonal characteristic modes with a radiation pattern diversity performance in the lower and higher bands, thus contributes to a wideband high isolation response even though the two antennas share the same radiator.

D. Differential-Fed Network and S-Parameters

The proposed integrated dual-antenna pair is simulated and optimized by the full -wave simulation software HFSS. The differential port 2 is driven by a commercial differential balun chip Anaren BD3150N50100AHF [47]. The sketch diagram of the feeding network for the differential port 2 is
shown in Fig. 5(a). The balun chip has a small footprint of $1 \times 1 \text{ mm}^2$ with four pins. Pin 1 is connected to the ground plane. The single-ended signal is input from pin 2, while the differential signal is output from pins 3 and 4. Two 6 mm-length feedlines have to be employed for connecting the differential pins 3 and 4. The detailed performance of this balun chip is shown in Fig. 5(b). The typical operating frequency of this balun chip is 3.1–5.0 GHz with a maximum amplitude unbalance of 0.73 dB at 5.0 GHz and a maximum phase unbalance of $2^\circ$ at 5.0 GHz.

The final simulated S-parameters for the proposed dual-antenna pair with the feeding network considered is shown in Fig. 6. Due to the impact of the feeding network, the reflection coefficients of Ant1 and Ant2 are slightly deteriorated compared to the results (case 4) that are shown in Fig. 2(f) and (g), but they are still better than $-6$ dB across 3.3–5.0 GHz. Also, the isolation between Ant1 and Ant2 is also deteriorated compared with the results (case 4) that are shown in Fig. 2(h) due to the unideal property of the balun chip and side-placed antenna pair configuration. However, a high isolation of better than 21.0 dB is still realized across the entire band of 3.3–5.0 GHz.

E. Parameter Analysis

The width of the metal rim slit $W_0$ is a vital factor to adjust the impedance matching of both Ant1 and Ant2. Fig. 7 shows the simulated $S_{11}$ and $S_{22}$ with the slit width $W_0$ varied from 1 to 3 mm. For Ant1, the resonant frequency shifts downward when decreasing slit width $W_0$ due to the enhancement of the load effect of parasitic shorted rims. For Ant2, the impedance matching in the lower band is significantly improved when increasing $W_0$ from 1 to 3 mm, and because the center metal rim is the dominant radiator in the lower band, the parasitic shorted load will significantly affect the radiation of the dipole mode. Therefore, the optimized value of $W_0$ is 2 mm to realize a good impedance matching for both Ant1 and Ant2.

The feeding position of the differential-driven strips $L_0$ also has a great impact on both Ant1 and Ant2. For Ant1, as shown in Fig. 8(a), the higher frequency is declined with the increase in $L_0$ because the resonant length of the slot mode is lengthened. For Ant2, the impedance matching in the lower band is effectively improved with the increase in $L_0$ as shown in Fig. 8(b), and the resonant frequency in the higher band is declined due to the increase in the resonant length for the open-slot mode.

As discussed before, the feeding network of the differential port2 has an influence on both $S_{11}$ and $S_{22}$, and the impact of the feeding network is proposed in Fig. 9 with the feedline
Fig. 9. (a) Simulated $S_{11}$ with the feedline width $W_f$ varied. (b) Simulated $S_{22}$ with the feedline width $W_f$ varied. (“W/O” represents without the feeding network.)

width $W_f$ [labeled in Fig. 5(a)] varied. As we all know, the width of 50 $\Omega$ microstrip feedline on a 0.8 mm-thick FR-4 substrate is 1.5 mm. However, due to the shared-radiator configuration in our structure, the feedline not only impacts the transmission line (TL) impedance of Ant2 but also has a terminal load effect for Ant1. Therefore, the width of feedline should be optimized for both $S_{11}$ and $S_{22}$ considered. As shown in Fig. 9(a), the higher band of $S_{11}$ is deteriorated with the increase in $W_f$, so a narrow feedline width is satisfactory to obtain a good $S_{11}$. On the contrary, as shown in Fig. 9(b), a good $S_{22}$ is realized when $W_f = 1.5$ mm with a 50 $\Omega$ TL impedance. However, the $S_{11}$ cannot cover the desired band of 3.3–5.0 GHz when $W_f = 1.5$ mm. Therefore, a tradeoff value of $W_f = 0.5$ mm is chosen for both $S_{11}$ and $S_{22}$ bandwidth considered.

III. EIGHT-ANTENNA MIMO SYSTEM

The final 8 $\times$ 8 MIMO system could be easily realized by arranging four such integrated dual-antenna pair along the left and right side edges of the smartphone as shown in Fig. 1(a) and (b).

A. Antenna Fabrication

In order to validate the feasibility of the proposed dual-antenna pair and the final 8 $\times$ 8 MIMO system, a prototype is fabricated as shown in Fig. 10. For a clear view, the dual-antenna pair is enlarged as shown in the inset. The main board is fabricated by printed circuit board process with 0.8 mm-thick FR-4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$). The metal rim is manufactured by 0.2 mm-thick brass plates.

Fig. 10. Photographs of the proposed 8 $\times$ 8 MIMO system.

Fig. 11. Simulated and measured reflection coefficients of the proposed 8 $\times$ 8 MIMO system. ($\sigma = 1.5 \times 10^7$ S/m) with laser cutting process. The metal rim is soldered with the ground plane of the main board. All ports are fed by 50 $\Omega$ semirigid cables. To optimize the cable routing, ports 1, 3, 5, and 7 are fed on the back side of the substrate, while ports 2, 4, 6, and 8 are fed on the front side of the substrate.

B. Reflection Coefficients

Fig. 11 shows the simulated and measured reflection coefficients of the proposed 8 $\times$ 8 MIMO system. Due to the structure symmetry, the reflection coefficients of every dual-antenna pair is the same with each other, thus only $S_{11}$ and $S_{22}$ are shown for brevity. Both of the simulated and measured results are better than $-6$ dB across the desired band from 3.3 to 5.0 GHz. Small frequency deviation of Ant2 occurred due to the fabrication error and the tolerance of lumped components and balun chip.

C. Isolations and ECCs

The simulated and measured isolations and measured envelope correlation coefficients (ECCs) between every dual-antenna pair module are shown in Fig. 12.
Fig. 12. Simulated and measured isolations and ECCs between (a) Module 1 and Module 2, (b) Module 1 and Module 3, and (c) Module 1 and Module 4.

For Module 1 and Module 2, both the simulated and measured isolations are better than 12.0 dB. The worst isolation is between Ant1 and Ant3, which is caused by the traveling-wave current flowing on the ground plane. The measured ECCs are lower than 0.11 across the desired band, indicating a satisfactory diversity performance.

For Module 1 and Module 3, the simulated and measured isolations are better than 17.3 and 20.3 dB due to the separation of the ground plane, respectively. The measured ECCs are lower than 0.01 across the desired band.

For Module 1 and Module 4, the far distance and the separation of the ground plane contribute to a better diversity performance. The simulated and measured isolations are better than 30 and 29.5 dB, respectively. The measured ECCs are lower than 0.012 across the desired band.

Therefore, the isolations are better than 12.0 dB and the ECCs are lower than 0.11 between all ports for the proposed 8 × 8 MIMO system, satisfying the criteria of 5G smartphones.

D. Total Antenna Efficiency

Fig. 13 shows the measured total efficiency of the proposed 8 × 8 MIMO system. The simulated results are not shown due to the impact of the balun chip on the antenna efficiency is hard to assess in the simulation. Due to the structure symmetry, only the measured efficiencies of Ant1 and Ant2 are shown for brevity. For Ant1, the measured antenna efficiency is from 58.9% to 88.6% with an average value of 74.7%. For Ant2, the measured antenna efficiency is from 31.6% to 76.7% with an average value of 57.8%. The efficiency of Ant2 is lower than Ant1 in the lower band, which is caused by the loss of the balun chip.

IV. COMPARISON AND DISCUSSION

To highlight the novelty and advantages of the proposed design scheme, Table I shows the comparison of our design scheme with up-to-date 5G MIMO smartphone antennas. Most of the published work are narrow band and could only cover 3.4–3.6 GHz, which is not competent for the global 5G NR service. Zhao and Ren [45] propose a wideband 8 × 8 MIMO system with 5G N77/N78/N79 bands covered.
However, the eight antenna elements are arranged at eight separated regions without spatial reuse and it is not suitable for the metal-rimmed circumstance. Wong et al. [39] propose a wideband (3.3–6.0 GHz) 4 × 4 MIMO system with closely spaced dual-antenna pair; however, this work is not suitable for the application of metal-rimmed smartphones. Therefore, our design scheme overcomes the bandwidth limitation and possesses both the metal rim compatibility and spatial reuse property, which fills the void of wideband 5G MIMO antennas for metal-rimmed smartphone applications.

V. CONCLUSION

In this article, we propose a wideband 8 × 8 MIMO antenna based on the integrated orthogonal-mode dual-antenna pair for 5G smartphone applications. With the combination of the orthogonal monopole and dipole modes in the lower band and the orthogonal slot and open-slot modes in the higher band, a wideband orthogonal-mode dual-antenna pair with a shared radiator is realized for the first time. Both the simulation and measurement results demonstrate that the dual-antenna pair could offer an isolation of better than 21.0 dB and an ECC of lower than 0.02 across 3.3–5.0 GHz. The final 8 × 8 MIMO system is achieved by arranging four dual-antenna pairs at both side edges of the smartphone. The simulated and measured isolations are better than 12.0 dB and ECCs are lower than 0.1 between all ports for the 8 × 8 MIMO system. The measured average antenna efficiencies are 74.7% and 57.8% for Ant1 and Ant2, respectively. We envision that the proposed design scheme, with merits of shared radiator, wide bandwidth, and metal rim compatibility, has the potential for the application of future 5G smartphones.

REFERENCES


*TABLE I COMPARISONS OF THE 5G MIMO SMARTPHONE ANTENNAS*

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Dual-Antenna Pair</th>
<th>Metal Rim</th>
<th>Bandwidth</th>
<th>Size of Ant. Pair (Length x Ground Clearance x Height)</th>
<th>Isolations</th>
<th>ECCs</th>
<th>Total Efficiency</th>
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<td>[30]</td>
<td>x</td>
<td>x</td>
<td>3.4–3.6 GHz</td>
<td>\</td>
<td>&gt;20 dB</td>
<td>&lt;0.0125</td>
<td>&gt;60%</td>
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<tr>
<td>[45]</td>
<td>x</td>
<td>x</td>
<td>3.3–5.0 GHz</td>
<td>\</td>
<td>&gt;14.5 dB</td>
<td>0.1</td>
<td>&gt;46%</td>
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<td>[35]</td>
<td>√</td>
<td>x</td>
<td>3.4–3.6 GHz</td>
<td>19 x 30 x 8 mm³</td>
<td>&gt;10 dB</td>
<td>0.25</td>
<td>40–60%</td>
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<tr>
<td>[37]</td>
<td>√</td>
<td>x</td>
<td>3.4–3.6 GHz</td>
<td>10 x 17 mm³</td>
<td>&gt;10 dB</td>
<td>0.15</td>
<td>40–52%</td>
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<tr>
<td>[38]</td>
<td>√</td>
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<td>3.4–3.6 GHz</td>
<td>5.725 x 5.875 GHz</td>
<td>&gt;12 dB</td>
<td>0.15</td>
<td>50%</td>
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<td>[39]</td>
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<td>x</td>
<td>3.3–6.0 GHz</td>
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<td>&gt;12 dB</td>
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<td>x</td>
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<td>x</td>
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<td>12 x 18 x 7 mm³</td>
<td>&gt;20 dB</td>
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<td>25 x 15 x 7 mm³</td>
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<td>0.13</td>
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<td>40 x 35 x 7 mm³</td>
<td>&gt;21 dB</td>
<td>0.11</td>
<td>58–88%</td>
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