A Mutual-Coupling-Suppressed Dual-Band Dual-Polarized Base Station Antenna Using Multiple Folded-Dipole Antenna

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Abstract—An interleaved shared-aperture dual-band dual-polarized base station array antenna is proposed in this paper. The lower-band (LB) element is realized by using a multiple folded-dipole antenna (MFDA) and four parasitic loops. To interpret the working principle of the MFDA, a double folded-dipole antenna (DFDA) is firstly analyzed by using the transmission line model. Then, by combining two bended DFDDs and introducing four parasitic loops, a low cross-band scattering LB element with a high out-of-band rejection level of 16 dB is obtained. The higher-band (HB) element with a wide impedance bandwidth of 42.5% (3.0-4.6 GHz), a high roll-off rate (RoR) of 249.2 dB/GHz, and a high out-of-band rejection level of 17 dB is obtained by introducing a meander line loop, a rectangular loop and V-shaped strips near the dipole arms. By combining the proposed low scattering low-pass LB element and the high RoR high-pass HB element, a novel interleaved shared-aperture dual-band dual-polarized array antenna with a small frequency ratio of 1.46 and a high cross-band isolation level of 25 dB is realized. Due to the low-scattering characteristic and filtering response of the LB element, the radiation patterns of the wideband HB sub-arrays are almost unaffected.

Index Terms—Dual-band antenna, base station array antenna, dual-polarized antenna, filtering antenna.

I. INTRODUCTION

SHAREDPERATURE dual/multi-band dual-polarized array antennas have become a trend in the base station application to meet the growing need for fully integrated base stations. Although the shared-aperture design can realize a dual/multi-band antenna array with compact size and low cost, it also brings new design challenges, such as the high mutual-couplings between the closely placed antenna elements, and the cross-band scattering between the lower band (LB) and higher band (HB) elements.

To enhance the port isolations, many new methods are investigated [1]-[17]. By introducing decoupling branches [1],[2] and decouple surface [2], the mutual coupling in [1] and [2] are effectively reduced. In [3]-[5], baffles are used to improve the isolations between the elements. To obtain high isolations and good radiation performance, the structure, position, and height, of the baffle are optimized. Using filtering antennas [6]-[10] is also a popular method to obtain high isolations in the design of dual-multi-band array antenna. By properly designing the structure of the radiator [11] or integrating a filter into the transmission line [12], antenna elements with a high out-of-band rejection level can be obtained. The LB element has nearly no radiation in the operating band of the HB element, and vice versa. Thus, the port isolations in the array antenna maintain a very low level. Although the methods mentioned above can enhance the port isolations in the dual/multi-band array, the cross-band scattering is not fully addressed.

To reduce the cross-band scattering, a novel method is presented in [18]-[22]. By inserting a frequency selective surface (FSS) layer between the LB and HB elements, the cross-band scatterings in [18]-[21] are effectively reduced. In these designs, the HB elements are usually placed above the LB element. For the HB elements, the FSS layer can be equivalent to a ground plane. However, for the LB element, the FSS layer can be seen as EM transparent structure. Thus, not only high port isolation but also low cross-band scattering can be realized by using this method. However, the frequency ratios in these designs are larger than 4.

Apart from inserting the FSS layer, lifting the HB elements [23], using electromagnetic (EM) transparent LB elements [24]-[32], and introducing partially reflecting surfaces [33] can also reduce the cross-band scattering. By lifting the cavity-backed HB elements to the same plane of the LB radiator [23], the blockage effect of the LB element on the...
radiation patterns of HB elements can be eliminated. The limitation of this method is that it is not suitable for the dual-band array antenna design with a small frequency ratio. In [24] and [25], two shared-aperture dual-band array antennas are realized by introducing branches on the radiator of LB element. By changing the length of the branches, the wave-transparent band can be easily adjusted. However, the frequency ratios of these two dual-band array antennas are larger than 2.7. By dividing the dipole arms into short sections and introducing chokes below the gaps between the short sections, a low scattering LB element is presented in [26]. Based on this LB element, a low cross-band scattering dual-band array with a high out-of-band rejection level and low cross-band scattering is realized. The working principle of the MFDA is firstly explained in this paper based on the proposed transmission line model of the double folded-dipole antenna (DFDA). By introducing a meander line loop (MLL), rectangular loop (RL) and V-shaped strips (VSS), a novel filtering antenna with a high Roll-off rate (RoR) is realized to cover the HB. The working principle of the MLL is analyzed in detail in this paper by utilizing an equivalent circuit. To validate the performance of the proposed designs, an interleaved shared-aperture dual-band array antenna including one LB element and four HB elements is designed. The measured and simulated results demonstrate that the proposed designs maintain a good performance in the proposed dual-band array. Besides, to suppress the mutual coupling between the HB sub-arrays, eight shorted strips are introduced next to the HB elements. After introducing the shorted strips, the mutual couplings between the HB arrays can be effectively reduced to below -22 dB. All the simulations in this paper are completed by using the commercial electromagnetic simulation software Ansys HFSS.

II. DESIGN OF ANTENNA ELEMENTS

In this section, LB and HB antenna elements are presented for the design of the dual-band dual-polarized array antenna. The LB MFDA has a wide bandwidth, two upper radiation nulls, and innate EM transparent characteristics in HB. The HB element features wide bandwidth and a high RoR of 242.9 dB/GHz with two radiation nulls in LB.

A. LB Element

The configurations of the proposed MFDA are shown in Fig. 1. The MFDA contains two Rogers RO4003 substrates with a thickness of 0.508 mm ($\varepsilon_r = 3.55$). As can be observed, the MFDA is printed on the upper layer of substrate 1. To
enhance the out-of-band rejection level, four parasitic rectangular loops are placed under the MFDA. The configurations and dimensions of the baluns are given in Fig. 1(d). The radiator and the ground plane are connected by the feeding baluns. By using the above configuration, the proposed MFDA has the advantages of wide bandwidth, two upper radiation nulls, and EM transparent characteristics in HB. To have a deeper insight into the proposed antenna, the working principle of the MFDA is interpreted in the following paragraphs.

For ±45° polarization feeding ports, the proposed MFDA can be assumed as a combination of two bended DFDA as illustrated in Fig. 2. Thus, to have a deeper insight into MFDA, the working principle of DFDA is analyzed first. As shown in Fig. 3, the currents on the DFDA can be decomposed into two distinct modes: a transmission line mode (TL Mode) and a dipole antenna mode (DA Mode).

For the TL Mode, the conductors are driven by two generators with equal magnitude \( V/2 \) and 180° phase difference. The current on the conductors is \( I_{TL} \). By dividing the TL Mode into two identical loaded transmission lines with length \( L_{T1/2} \) at the central plane, the impedance of each part can be derived from:

\[
Z_{TL1} = Z_c + jZ_c \tan (k \frac{L_{T1/2}}{2})
\]

where \( Z_c \) is the characteristic impedance of two-wire transmission lines. \( Z_{FD} \) is the impedance of the folded-dipole antenna. \( k \) is the propagation constant, and \( L_{T1} \) is the length of the transmission line. \( Z_c \) can be calculated by substituting \( W \), and \( g = G_2 \) into (2)-(4) [34]:

\[
Z_c = 120 \pi \frac{K(x)}{K(x')} \quad \quad (2)
\]

\[
x^2 + x'^2 = 1 \quad \quad (3)
\]

\[
x = \frac{g}{g + 2W} \quad \quad (4)
\]

where \( K(x) \) is the complete elliptic function of the first kind. The impedance of the folded-dipole antenna [35] is:

\[
Z_{FD} = \frac{4Z_{DA1}Z_{TL1}}{Z_{DA1} + Z_{TL1}} \quad \quad (5)
\]

where \( Z_{TL1} \) is the impedances of its transmission line mode.

\[
Z_{TL1} = jZ_c \tan (k \frac{L_{T1}}{2}) \quad \quad (6)
\]

By substituting \( l = L_{T1} \) into (7), the impedance of equivalent dipole antenna mode \( Z_{DA1} \) can be obtained [35].

\[
Z_{DA} = \frac{R_{DA} + jX_{DA}}{\sin^2 (kl)} \quad \quad (7)
\]

where \( R_{DA1} \) and \( X_{DA1} \) can be expressed as:

\[
R_{DA} = \frac{\eta}{2\pi} \left\{ \begin{array}{c}
\frac{C + \ln (kl) - C_i (kl)}{2} \\
\frac{\cos (kl)}{2} C + \ln \left( k \frac{l}{2} \right) + C (2kl) \\
-2C_i (kl)
\end{array} \right\} \quad \quad (8)
\]

\[
X_{DA} = \frac{\eta}{4\pi} \left\{ \begin{array}{c}
2S_i (kl) + \\
\cos (kl) \left[ 2S_i (2kl) - S_i (kl) \right] - \\
5 \sin (kl) \left[ 2C_i (kl) - C_i (2kl) - C_i \left( \frac{2k g}{2} \right) \right]
\end{array} \right\} \quad \quad (9)
\]

where \( a_E \) represents the equivalent radius of the dipole and, it can be calculated by substituting \( g = G_1 \) into (9):

\[
a_E = \frac{\sqrt{\frac{W}{4} + \left( \frac{g + W}{2} \right)^2 + \left( \frac{W}{4} \right)^2} - \left( \frac{W}{4} \right)^2}{\sqrt{\frac{W}{4} + \left( \frac{g + W}{2} \right)^2}} \quad \quad (10)
\]

Therefore, the current \( I_{TL} \) can be calculated by using:

\[
I_{TL} = \frac{V/2}{Z_{TL2}} \quad \quad (11)
\]

For the DA Mode, the conductors are driven by two identical generators with equal magnitude \( V/2 \). It can be equivalent to a dipole antenna with equivalent radius \( a_E \) and equivalent length \( L_E \). The equivalent length \( L_E \) can be obtained by using the method in [36]. The impedance of DA Mode \( Z_{DA2} \) can be calculated by substituting \( W, l = L_{T2}, g = G_2 \) into equations (7)-(10). The current for the DA Mode is given by:
Thus, the total current on the DFDA $I_{IN}$ is given by:

$$I_{IN} = I_{TL} + \frac{I_{DA}}{2} = \frac{V(2Z_{DA2} + Z_{TL2})}{4Z_{DA2}Z_{TL2}}$$

(13)

The impedance of DFDA is given by:

$$Z_{IN} = \frac{4Z_{DA2}Z_{TL2}}{2Z_{DA2} + Z_{TL2}}$$

(14)

Based on the analysis above, the input impedance of the DFDA is calculated by using Matlab. As shown in Fig. 4, the calculated results agree well with the simulated results. Thus, the proposed TL and DA model can be used to accurately analyze impedance characteristic of DFDA.

As shown in Fig. 5, a radiative resonant mode and radiation null appears at 3.2 GHz and 4.1 GHz, respectively. To understand the working principles of them, the simulated current distributions are given in Fig. 6. It can be seen from Fig. 6(a) that the DA mode plays a dominate role at 3.2 GHz in effective radiation. Owing to the currents flowing in the same direction on both sides, the symmetrical plane (A-B) can be equivalent to an open circuit, and the currents flow in the same direction on both sides. The current distribution of the DFDA in Fig. 6(b) demonstrates that the TL mode is the dominant mode at 4.1 GHz. At this frequency, the currents on the central part of the DFDA flow in opposite directions. It can be seen as a section of transmission line. The current distribution on the two folded dipoles show that they work under their 1st-order mode [37]. As mentioned in [37], the input resistance of the 1st-order mode of linear folded dipole is very large and close to infinite. So, they can be equivalent to open circuits. Therefore, no power will be radiated into the free space at this frequency. This can also be verified by the current distribution in Fig. 6(b). It can be seen that there are four current nulls at the inputs of the folded dipoles. All the power will be reflected back to the source at this frequency. Thus, a radiation null appears at this frequency. Then, by combining two bended DFDA, a MFDA is obtained. It can be seen in Fig. 5 that the resonant frequencies of the radiative mode and radiation null of the MFDA are almost same as the DFDA.

It is worth noting that the influences of the substrate on the DFDA and MFDA are not included in the calculation and
simulation presented above. To facilitate fabrication, a Rogers 4003 substrate with a thickness of 0.508mm is introduced to support the MFDA. As given in Fig. 7, the resonant mode and radiation null shift towards a lower frequency band after introducing the substrate.

In the presented antenna, four parasitic rectangular loops are placed under the MFDA to further enhance the out-of-band rejection level of the higher frequency band. As shown in Fig. 8, the 1st radiation null shifts towards lower frequency after introducing the parasitic loops, and the input impedance of the radiative resonant mode is reduced. Furthermore, a new radiation null (2nd radiation null) is introduced at 4.5 GHz. To interpret the working principle of the 2nd radiation null, the simulated current distribution of the antenna at 4.5 GHz is given in Fig. 9. It can be observed that the current distributions on the parasitic rectangular loops are opposite to the current distributions on the MFDA. Thus, the radiation power in the far-field zone is cancelled by each other. Due to all the power being reflected back to the source, a new radiation null is obtained at this frequency.

Then, by feeding the antenna using two orthogonal printed baluns, a ± 45° dual-polarization antenna with a compact size and upper out-of-band rejection is achieved. The simulated peak realized gain and reflection coefficient are shown in Fig. 10. The proposed antenna can cover the frequency range of 2.3 GHz -2.7 GHz. Besides, the out-of-band rejection level is higher than 16 dB.

Apart from the advantages mentioned above, the proposed antenna also has an electromagnetic transparent characteristic at higher frequency band. The simulated transmission coefficient of the proposed radiator is shown in Fig. 11. It can be observed that the simulated transmission coefficient of the proposed radiator is higher than -0.5 dB from 3.0 GHz to 4.3 GHz. Due to the high transmission coefficient level, the proposed LB antenna has little influence on the radiation patterns of the HB antennas.

As shown in Fig. 12(a), the LB radiator has four open loop resonators (OLRs). Each OLR can be equivalent to a LC parallel resonance circuit, working as a bandpass surface, which is transparent to the wave radiated from the HB antenna. As shown in Fig. 12(b), when -45° polarized incident electromagnetic wave irradiates the LB radiator, the OLR 2 and 4 are excited and play an important role in transmitting the wave through them. Due to the symmetry of the radiator, it will be the same phenomenon that the OLR 1 and 3 will be
excited when +45° polarized incident electromagnetic wave irradiates on the LB radiator. As a result, HB electromagnetic wave can be transmitted through the LB radiator without being affected. Therefore, the LB antenna can be seen as an electromagnetic transparent antenna for the HB antennas. The resonant frequency of the OLRs (central frequency of the EM transparent band) can be calculated by using:

$$f_{OLR} \approx \frac{c}{2L_{OLR}}$$

(15)

where $c$ is the speed of the light in free space, $L_{OLR}$ is the length of the OLR.

In this sub-section, the DFDA is firstly analyzed by using TL and DA modes. The calculated input impedance of the DFDA agrees well with the simulated one. Based on the analysis, the working mode of the DFDA can be divided into DA mode and TL mode. Under the TL mode, the DFDA will transmit the electromagnetic wave into free space. Under the TL mode, all the power will be reflected back to the source. Therefore, by combining two bended DFDA and introducing four parasitic loops, a LB antenna with compact size and good performance can be obtained. Moreover, the proposed antenna has little influence on the radiation patterns of the HB array owing to the EM transparent characteristic. These are very important advantages in the design of dual-band dual-polarized base station array antenna.

### B. HB Element

Having a HB element with a good out-of-band suppression level in lower frequency band is critical in the design of a dual-band base station array antenna with low couplings. In this section, a HB element with a high suppression level and sharp cut-off in the lower frequency band is achieved by using meander line loop (MLL), rectangular loop (RL) and V-shaped strips (VSS).

The configurations and dimensions of the proposed HB antenna are given in Fig. 13. It can be seen that all conductors of the proposed HB element are printed on three Rogers RO4003 substrates with a thickness of 0.508 mm, 0.305 mm, and 0.508 mm, respectively. The VSS and MLL are printed on the upper and lower layer of substrate 1. The RL is printed on the lower layer of Substrate 2. The dipole arms of this antenna are vertically printed and connected to the baluns.

The simulated peak realized gain and reflection coefficient are shown in Fig. 14. It can be seen that the proposed HB element has a wide impedance bandwidth of 42.5% (3.0-4.62 GHz).
GHz), a stable peak realized gain of 8.9 dBi and a good out-of-band rejection level of 17 dB. Besides, the proposed antenna obtains a high Roll-off rate ($RoR$) of 242.9 dB/GHz ($f_{20\,\text{dB}}$ is 2.87 GHz, $f_{3\,\text{dB}}$ is 2.94 GHz), which is crucial in the design of multi-band array antenna with low frequency ratio. The $RoR$ is calculated by using [38]:

$$RoR = \frac{20 - 3}{|f_{20\,\text{dB}} - f_{3\,\text{dB}}|} \quad (16)$$

where the frequency $f_{3\,\text{dB}}$ and $f_{20\,\text{dB}}$ are the frequencies where the average peak realized gain drops by 3 dB and 20 dB, respectively.

To better demonstrate the working principle of the proposed HB element, three reference antennas are given in Fig. 15. The Ant.1 is a vertically printed crossed dipole antenna. By introducing a RL under the arms of the Ant.1, 1$^{st}$ radiation null and a new resonant mode can be obtained to suppress the out-of-band radiation and expand the impedance bandwidth [39]. To further enhance the roll-off rate, a MLL is placed above the arms of the crossed dipoles in Ant.2. After introducing the MLL, a new radiation null appears at the in-band of the antenna. Finally, four VSS are introduced above the MLL to shift the 2$^{nd}$ radiation null towards lower frequency band.

Fig. 16 shows the simulated results of the reference antennas and proposed HB element. It can be observed that the out-of-band rejection of the Ant.1 can be effectively developed by introducing the RL. Besides, the bandwidth is increased due to the new resonant mode. Then, by introducing a MLL above the dipole arms, the 2$^{nd}$ radiation null is realized at 3.5 GHz.

To interpret the working principle of the 2$^{nd}$ radiation null, the equivalent circuit of MLL is given in Fig. 17. For the -45$^\circ$ polarization, the MLL can be divided into two identical parts (Part 1 and Part 2). Each part has two meander line (ML) elements. One is horizontally printed; another is vertically printed. For horizontal electric field ($E_h$), ML$_1$ can be equivalent to a shunt inductance over an equivalent transmission line and ML$_2$ can be equivalent to a shunt capacitance. For vertical electric field ($E_v$), ML$_1$ will acts like a shunt capacitance and ML$_2$ will acts like a shunt inductance [40]. Therefore, for the horizontal and vertical electric field, Part 1 can be equivalent to a series $L$-$C$ resonator. The MLL acts like a band-stop filter. The resonant frequency of the MLL can be calculated by employing:

$$f_{\text{null}} = \frac{1}{2\pi\sqrt{L_1C_1}} \quad (17)$$

To shift the 2$^{nd}$ radiation null out of the operating band of the HB element, four parasitic VSSs are introduced above the MLL. It can be observed from Fig. 16 that the 2$^{nd}$ radiation null is moved from 3.5 GHz to 2.9 GHz without increasing the aperture of the antenna after introducing the VSSs. Besides, the $RoR$ increases from 45.9 dB/GHz to 242.9 dB/GHz.

Fig. 16. Simulated normalized peak realized gain and reflection coefficients of the proposed HB element and reference antennas.

Fig. 17. Equivalent circuits of the MLL.
Overall, in this sub-section, a novel HB element with high RoR is proposed by combining the RL, MLL, and VSS. Firstly, a RL is placed under the arms of the crossed dipoles to obtain the 1st radiation null and excite a new resonant mode. Then, to enhance the RoR and out-of-band rejection level, a MLL is printed above the dipole arms. The working principle of the MLL is then analyzed. By introducing four VSSs, the 2nd radiation null can be shifted towards the lower frequency band. As a result, a HB element with wide impedance bandwidth and a high roll-off rate is achieved in this work.

III. DUAL-BAND DUAL-POLARIZED ARRAY

Based on the LB and HB elements designed above, a dual-band dual-polarized array antenna is realized in this section. As shown in Fig. 18, the size of the ground plane is 164 mm × 142 mm. The LB element is placed in the center of the ground plane and above the HB elements. The four HB elements are divided into two columns. Elements in each column are fed by two Wilkinson power dividers. The distances between the elements along the x-axis and y-axis are 46 mm and 62 mm, respectively.

It should be noted that eight shorted strips are introduced to reduce the coupling between the input ports of the HB elements. Fig. 19 shows the simulated reflection coefficients of the proposed HB array with and without shorted strips. As can be seen, the isolation between port H1 and port H2 increase from 15 dB to 19 dB after introducing the shorted strips. It demonstrates that the shorted strips play an important role in reducing the mutual couplings between the HB sub-arrays.

To verify the performance of the proposed antenna, a reference dual-band array antenna is designed by using the most common crossed dipole elements. The configurations of these two dual-band array antennas are the same except for the LB elements. The configuration and simulated results of the reference LB element are shown in Fig. 20. The E-field distributions of the HB sub-array are given in Fig. 21. It can be observed that the HB sub-array is severely blocked by the reference LB antenna when using the ordinary dual-polarized crossed dipole antenna. The E-field of the HB sub-array is disturbed and reflected. As a result, the radiation performance of the HB sub-array will be seriously distorted. The simulated peak realized gains of the HB sub-array under different configurations.
configurations are shown in Fig. 22. It can be seen the peak realized gain of the HB sub-array drops 3.6 dB at 3 GHz after introducing the reference LB element, which is unacceptable in dual-band base station application. However, by comparing the E-field distributions in Fig. 21 (a) and (c), it is not difficult to find that the proposed LB element has little influence on the radiation performance of the HB sub-array and it can be seen as an EM transparent antenna at this frequency. Besides, as depicted in Fig. 22, the peak realized gain of the HB sub-array keeps almost unchanged after introducing the proposed LB element. The max gain difference is only 0.2 dB.

The comparison between the radiation patterns of the higher band sub-array (without LB element, with reference LB element, and with proposed LB element) is given in Fig. 23. As depicted, the reference LB element has a great influence on the radiation patterns of the HB sub-array. When using the ordinary LB element, both co-polarized and cross-polarized radiation patterns of the HB sub-array are deteriorated. However, by replacing it with the proposed LB element, the radiation patterns of the HB sub-array remain almost unchanged. This is highly desirable for nowadays base station applications.

Besides, due to the good filtering performance of the proposed LB element, the cross-band coupling of the proposed dual-band array antenna is much lower than the reference one, as depicted in Fig. 24. The simulated isolations between the HB sub-array and the reference LB element are higher than 10 dB from 3 GHz to 4.3 GHz. However, in the proposed dual-band array antenna, the isolations between the HB sub-array and the proposed LB element are higher than 24 dB within the same frequency band, which shows a significant improvement in the array design.

In this section, based on the proposed LB element and HB element, a novel dual-band dual-polarized base station array antenna is achieved. To validate the advantages of the proposed antenna, a reference dual-band array antenna is designed. It is worth noting that the only difference between these two dual-band array antennas is the structure of the LB element. Simulated results demonstrate the proposed LB element has little influence on the radiation performance of the HB array. Furthermore, the proposed dual-band array antenna shows a significant improvement in cross-band isolation.
IV. RESULTS AND DISCUSSION

For verification, a prototype of the proposed dual-band dual-polarized array antenna is fabricated as shown in Fig.25. The measured S-parameters are obtained by using the R&S®ZVL vector network analyzer. The far-field results are obtained in the anechoic chamber at University of Kent. Fig. 26 shows the measured and simulated reflection coefficients of the LB element and HB array in the dual-band array. According to the measured results, the proposed LB element has an impedance bandwidth of 18.8% (2.26 GHz-2.73 GHz) with a reflection coefficient < -14 dB. For the HB sub-array, the measured and simulated results are in reasonable agreement with each other. The measured results indicate that the proposed HB sub-array realize a wide bandwidth of 36% (2.98 GHz- 4.3 GHz) for reflection coefficients lower than -14 dB.

Fig. 27 exhibits the measured and simulated in-band and cross-band mutual couplings of the proposed dual-band array antenna. It can be observed from the measured results that the in-band isolations between the port H1 and port H2 are higher than 22 dB. The isolations between other ports of the HB sub-arrays are higher than 25 dB. Due to the good filtering performance of the proposed LB and HB element, the cross-band mutual couplings between the input ports of the LB element and HB sub-arrays are all higher than 25 dB.

The measured and simulated broadside realized gains of the proposed dual-band array antenna are shown in Fig. 28. For the LB element, an average measured realized gain of 8.9 dBi is achieved within the operating band. It is slightly lower than the simulated value of 9.2 dBi because of the loss of the cables and test environment. For the HB sub-array, the measured realized gains distribute between 9.4 dBi and 10.5 dBi while the simulated one is all within the range of 10 dBi -10.7 dBi. The ripples in the operating band, as well as the slight gain variation between the measured and simulated curves, can be attributed to the loss of the test equipment and fabrication error.

The measured and simulated normalized radiation patterns of the LB element in the horizontal plane at (a) 2.3 GHz, and (b) 2.7 GHz.

The measured and simulated normalized radiation patterns of the HB sub-array in the horizontal plane at (a) 3.0 GHz, (b) 3.6 GHz, (c) 4.0 GHz, and (d) 4.3 GHz.
different frequencies are shown in Fig. 29 and Fig. 30, respectively. As can be observed, the measured results are in good agreement with the simulated results. The measured cross-polarization levels of the LB element and HB array are 20 dB and 21 dB lower than their co-polarization levels in broadside.

The comparisons between the proposed antenna and recently published dual-band dual-polarized array antennas are shown in Table I. By introducing FSS structure [20],[21] and etching the HB elements in the dipole arms of the LB element [23], three dual-band arrays with high cross-band isolations are developed. However, the frequency ratios of these antennas are larger than 4.3. In [24] and [25], two interleaved shared-aperture dual-band array antennas are realized by introducing branches on the radiator of LB element. However, the frequency ratios of these two dual-band array antennas are near twice of the proposed antenna. Four dual-band array antennas with frequency ratios smaller than 2 are developed in [27], [29]-[31]. Although the LB element in [27], [29], and [30] obtain a wider impedance bandwidth than the proposed one, the wave-transparent band of them are much narrower than our work. Besides, the proposed dual-band array antenna realizes a smaller frequency ratio, a higher gain, and a higher isolation than the designs in [27] and [30]. LB element in [31] achieves a high realized gain of 9.1 dBi, however, the impedance bandwidths of both LB and HB in this design are narrower than our work.

V. CONCLUSION

Two new methods are proposed in this paper to design the LB and HB elements in the dual-band dual-polarized array antenna. Based on the proposed method, a novel low scattering low-pass LB element and a novel high RoR high-pass HB element are able to realize. By combining these two high-performance elements and introducing eight shorted strips, a novel shared-aperture dual-band dual-polarized array antenna with wide impedance bandwiths, high in-band and cross-band isolation, and low cross-band scattering can be realized. The measured results show that the proposed array antenna works at 2.26- 2.73 GHz and 2.98- 4.3 GHz with reflection coefficients lower than -14 dB. The in-band and cross-band isolations of the proposed array antenna are higher than 22dB and 25 dB, respectively. Such a high-performance dual-band dual-polarized array antenna is a good candidate for nowadays base station applications.

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