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# STUDY ON A MINIATURE UWB WAFER-DIPOLE PRINTED ANTENNA FED BY BALANCED MICROSTRIP LINE

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**Abstract**—A novel wafer-dipole printed antenna fed by balanced microstrip line is proposed, and the adoption of the balanced microstrip line can effectively solve the feeding problem of the UWB dipole antenna. The wafer-dipole and a branch of the balanced microstrip line are printed on one side of FR-4 substrate (1 mm thickness), and the later is connected to a wafer directly, while the other branch is printed on the back side and connected to the other wafer with a via-hole. The measured results show that the antenna impedance bandwidth is from 3.0 GHz to 15.0 GHz with VSWR $< 2$, and the ratio bandwidth is about 5 : 1. Moreover, the antenna size is just 40 mm $\times$ 20 mm with simple structure, which is well suited for short-distance UWB communications.

## 1. INTRODUCTION

With the development of the frequency hopping technique and the spread spectrum technique in communication areas, ultra wideband (UWB) technology has been widely applied to various communication systems, and UWB antennas with excellent performance are in

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urgent demand. According to the sanction of civil UWB in 3.1–10.6 GHz formulated by U.S. federal communications commission (FCC), researchers have proposed a lot of UWB antenna designs, which mainly focus on various flat heterotype monopole antennas, including circular disc monopole antenna [1], elliptical monopole antenna [2], and different polygonal monopole antennas [3–5]. In addition, these monopole antennas are fed by coplanar waveguide (CPW) [6] and microstrip line [7, 8]. However, studies on UWB dipole antenna attract less attention than the monopole. But compared with the monopole antenna, the impedance of dipole antenna is much higher, which is better for impedance matching. What's more, dipole antenna can achieve well omnidirectional characteristic.

A novel wafer-dipole printed antenna fed by balanced microstrip line is proposed in this letter. The introduction of this feeding structure applied as antenna feeder can effectively solve the feeding problem of dipole antenna. One branch of the microstrip line is directly connected with a pole of the dipole, while the other branch is connected the other pole with via-hole. In this case, the design may cause unbalancing in antenna performance. However, the electrical dimension of the via-hole is too small so that the unbalancing problem can be omitted. Design of the proposed antenna, as well as the simulated and experimental results would be presented in the following sections.

## 2. ANTENNA STRUCTURE

Structure of the proposed antenna is presented in Fig. 1 as following. The antenna is fed by balanced microstrip line [9], which is printed on both sides of a FR-4 substrate. The feeding structure is unique because it is designed to utilize a via-hole with diameter of 0.5 mm to make the right wafer connect with the metal feed line on the back. This design can cause constant-amplitude and reverse-phase of currents, which flow along the left and right wafers in the proposed antenna, to achieve balanced feeding.

## 3. ANALYSIS OF ANTENNA RADIATION MECHANISM

The antenna model is simulated by CST MICROWAVE STUDIO®, a 3-dimensional full wave electromagnetic simulation software. The relative permittivity of the substrate is denoted by $\varepsilon_r$ and the thickness of which is denoted by $t$. The two parameters are set values as $\varepsilon_r = 4.4$, $t = 1$ mm during the simulation. Terminal current of the feeding line has been simulated and the result is shown in Fig. 2. During a broad band from 1.2 GHz to 15 GHz, magnitude of the

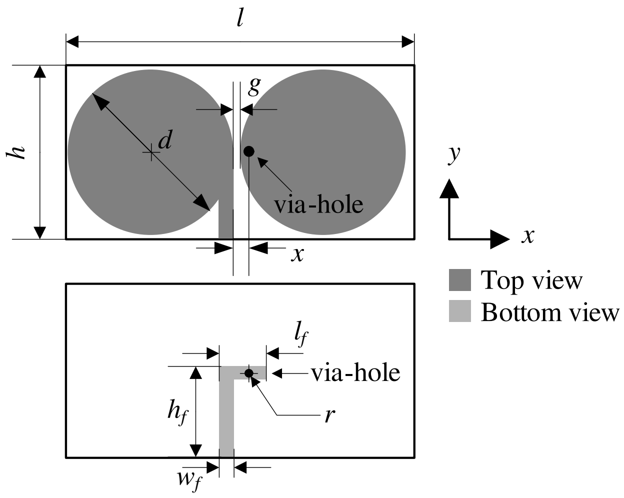



**Figure 1.** Sketch of the proposed antenna with associated geometrical parameters ($d = 19\,\text{mm}$, $w_f = 1.5\,\text{mm}$, $h_f = 10.75\,\text{mm}$, $l_f = 3.75\,\text{mm}$, $r = 2.5\,\text{mm}$, $h = 20\,\text{mm}$, $l = 40\,\text{mm}$, $x = 0.7\,\text{mm}$, $g = 0.5\,\text{mm}$).

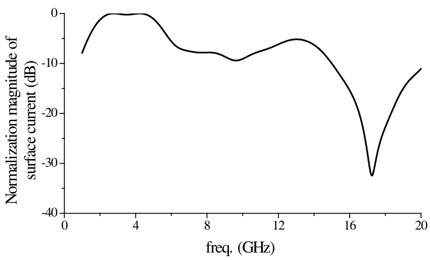



**Figure 2.** The simulated result of current at the end of feeding line.

terminal current maintains a large value, which demonstrates all the currents in this range have been fed in the terminal load — wafer, and electromagnetic waves radiate from the wafers. Fig. 3 shows the simulated results of surface current at three typical frequencies on the wafers. It can be seen that the antenna current distribution presents a form of standing wave resonance, and the number of wave node grows when frequency increases, distributing on the edge of the wafers. What's more, this distribution is symmetric versus the connecting line between two wafers' centres, which would produce the radiated field with horizontal polarization. When observing from the end of feeding line, antenna structure looks like an arc gradually opening, so that the

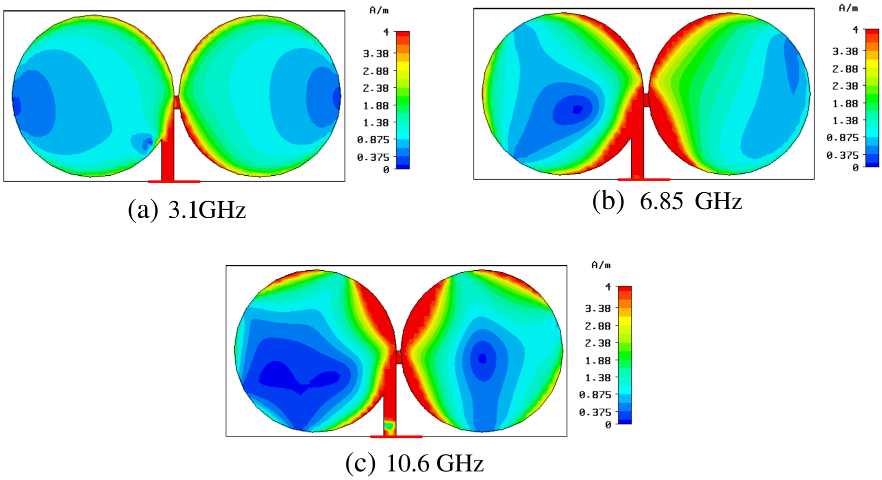



**Figure 3.** The simulated results of surface current on wafers.

total antenna can be treated as an integrated system composing with multi-resonant elements, which can realize broadband characteristic. Further simulation indicates the dimensions of radiated element and feeding element would influence antenna impedance characteristic. Parameters including the wafer's diameter ($d$), spacing between wafers ($g$) and width of feeding line ($w_f$) can decide antenna performance. Due to the current distribution on wafers presents a form of standing wave resonance so that the size of antenna, namely, $d$, can decide the lowest operating frequency, and their relation can be obtained from simulation, shown in formula (1). Fig. 4 presents it can use formula (1) to figure out $d$'s value, where $\lambda$ is the corresponding free-space wavelength of the lowest operating frequency.

$$d/\lambda = 0.17 \sim 0.20 \tag{1}$$

The spacing between wafers ($g$) can influence impedance characteristic so that control antenna bandwidth. Fig. 5 shows the simulated results of reflection coefficient when $g$ takes 0.5 mm, 0.7 mm and 1.5 mm respectively. As $g$ reduces, the reflection coefficient in high-frequency band also decreases and higher the frequency is, more obvious the decrease trend is. It can be explained that the increase of feeding distance can poor the effect of gradual-opening structure in the feeding terminal, and what's more, with frequency increasing, namely, operation wavelength reducing, the value of $g$'s electric size would increase, which renders the poor effect more significantly. Moreover, from Fig. 5, when $g = 1.5$ mm, antenna has lost its broadband

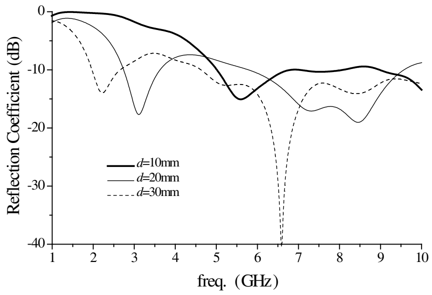



**Figure 4.** The simulated results of reflection coefficient with varying $d$.

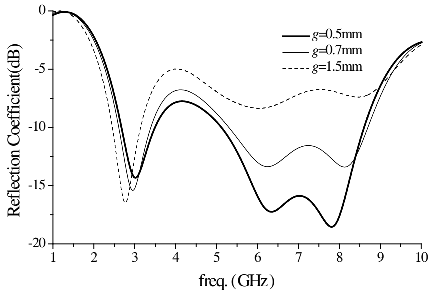



**Figure 5.** The simulated results of reflection coefficient with varying $g$.

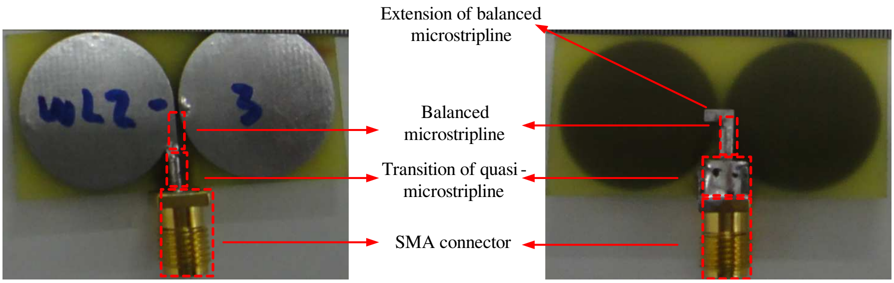
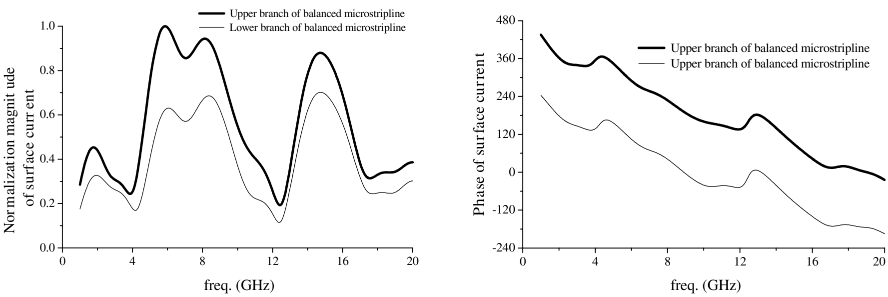



**Figure 6.** The feeding structure of coaxial-line-to-quasi-microstrip-line-to-balanced-microstrip-line.

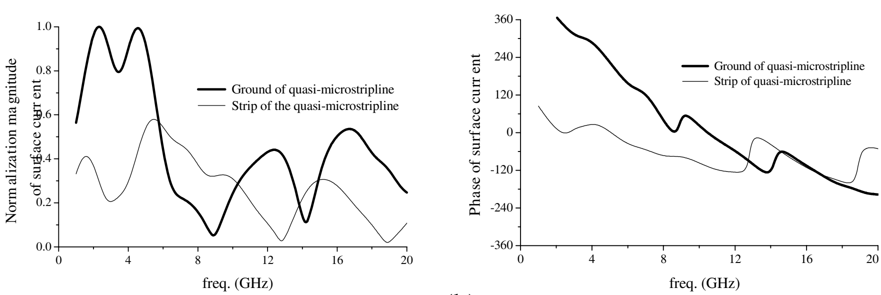
characteristic. Therefore, $g$ should be controlled within a range less than 1.5 mm. The width of feeding line, $w_f$, also controls the antenna input impedance. To achieve satisfactory matching, it is required to adjust $w_f$ to make characteristic impedance equal to the input impedance of wafer-dipole antenna. After the values of $\varepsilon_r$ and $h$ are fixed, with the increase of $w_f$, the characteristic impedance of feeding line would decrease.

## 4. ANTENNA FEEDING STRUCTURE

Commonly, the SMA connector adopted for feeding is a form of coaxial line, which is an unbalanced feeding structure possessing wideband for TEM wave transmission. However, the dipole antenna requires balanced feeding and balanced microstrip line is a transmission line possessing balanced structure and ultra-broadband characteristic for TEM wave transmission. The balanced microstrip line has been widely applied in the feeding part of printed dipole antenna. For instance, all the feeding structures in Reference [10, 11] are division balancers, but this method would narrow antenna bandwidth and is inappropriate for the feeding of UWB antenna. A method of coaxial-line-to-quasi-microstrip line-to-balanced-microstrip line is proposed in this paper to solve the problem, as shown in Fig. 6. The width of quasi-microstrip line has little error with its ground, but the balanced microstrip line consists of two equip-width metal-strips, printing on both sides of substrate. Fig. 7 indicates that, during the ultra band set in the simulation, there is little error between the terminal current of two balanced microstrip line branches on both sides of substrate, the phase error of which is about 180°. Overall, the equip-amplitude and reverse-phase in UWB can be achieved. However, at the end of the quasi-microstrip line, currents differ a lot and the phase error is not




(a)




(b)

**Figure 7.** The simulated results of surface currents' magnitude and phase for quasi-microstrip-line-to-balanced-microstrip-line. (a) The simulated results of surface currents' magnitude and phase at the end of balanced microstrip-line. (b) The simulated results of surface currents' magnitude and phase at the end of quasi-microstrip-line.

stable. Using the quasi-microstrip line for transition, the transmission line connecting the dipole wafers is a balanced microstripline so that antenna can achieve feeding balance. And mostly, printed dipole antenna is printed on both sides of substrate, which would cause the two poles not sharing the same axis and the radiation patterns would be impaired. To prevent this phenomenon, the two poles of dipole are printed on the same side of substrate and one pole is directly connected with one branch of balanced microstrip line, the other is connected with other side's balanced microstrip line through a metal-via-hole on the extended strip. Due to feeding vertexes of the dipole are too close and substrate is too thin so that the extended strip and metal-via-hole would not bring much additional phase-shift and impedance changing. But in this case, electric potentials of the two poles still retain equip-amplitude and reverse-phase.

## 5. MEASURED RESULTS AND ANALYSIS

After adjusting the structural parameters according to the regularities above, the final optimum antenna model has been obtained. Prototype of this proposed antenna, shown in Fig. 8, is manufactured according to the optimal parameters and measured in anechoic chamber. The impedance bandwidth is measured by Agilent E8363B vector network analyzer. Fig. 9 presents the measured values of antenna voltage standing wave ratio (VSWR) and the comparison between simulated and measured results. From Fig. 9, the measured impedance bandwidth is from 3.0 GHz to 15.0 GHz with VSWR $<$ 2.0, which well match the simulated, and the ratio bandwidth is about 5 : 1. The proposed antenna can realize the UWB characteristic. Moreover, both the measured and simulated results on antenna radiation pattern are presented in Fig. 10. The results indicate that the proposed wafer-

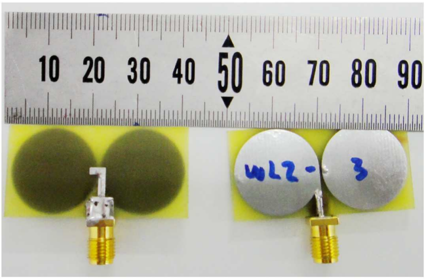



**Figure 8.** The prototype of the proposed antenna.

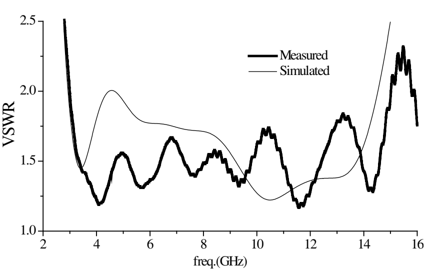



**Figure 9.** The prototype of the proposed antenna.

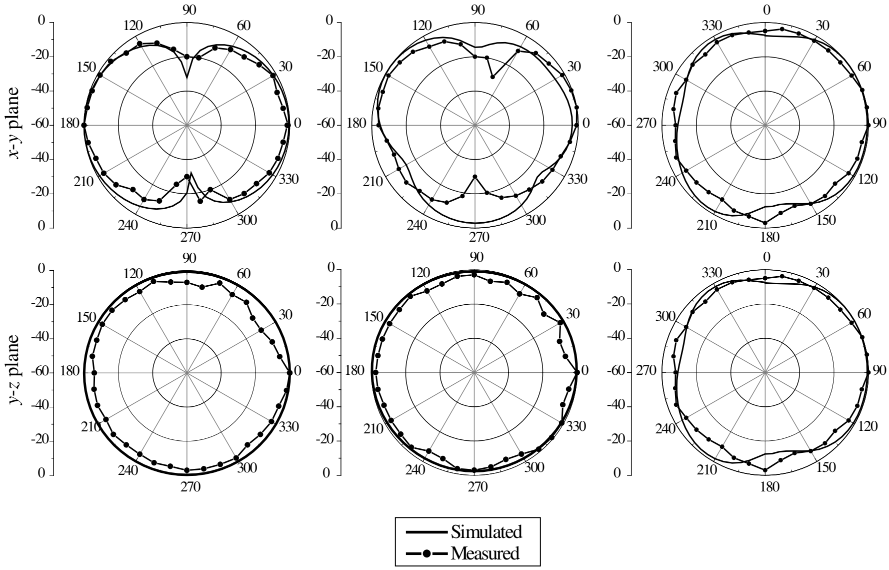



**Figure 10.** The measured and simulated results of antenna radiation pattern.

dipole antenna can achieve satisfied omni-directional radiation in $H$ plane.

However, there exists certain error, as following, between the experimental results and the simulated. (1) Although in the range of testing frequency ($2 \sim 16\,\text{GHz}$), the measured results well match the simulated at the starting frequency, the measured values are some lower than the simulated in two ranges $3.5 \sim 9.6\,\text{GHz}$ and $14.0 \sim 16.0\,\text{GHz}$, the difference of which renders the measured impedance-bandwidth ($3 \sim 15\,\text{GHz}$, absolute bandwidth 12 GHz) is a little broader than the simulated ($3 \sim 14.5\,\text{GHz}$, absolute bandwidth 11.5 GHz). (2) The measured radiation pattern is close to the simulated in the maximum radiation direction other than other directions. The differences above can be explained by the following reasons. (a) The substrate is FR-4 board, consisting of lossy materials with $10^{-2}$ order of dielectric loss tangent and the large loss would reduce reflection power in the port of feeding line, as well as VSWR. (b) During the prototype manufacture, the uncertainty of SMA solder joint would poor the impedance matching characteristic in $10 \sim 14\,\text{GHz}$ but reflection power grows up, which could produce a higher VSWR under the condition of large loss. (c) The in-homogeneity and dispersion characteristic of FR-4 substrate would cause difference in radiation pattern versus the simulated results, which is in homogeneous material. (d) In the experiment, the clamp using to fix up antenna, which locates in the feeding part, and the shelter of feeding-line are the two main reasons causing differences between experimental results of radiation pattern and the simulated.

Moreover, the proposed antenna obtains the maximum radiation in the direction perpendicular with polarization, which is different from the monopole wideband antennas in Reference [12–14]. In their designs, owning to the effect of finite ground, the maximum radiation-direction of monopole antenna is not easy to control and usually is not in the direction orthogonal with polarization. Whereas in this paper, the symmetric dipole and quasi-microstrip line-to-balanced-microstrip line feeding structure are adopted in design of the proposed antenna and the balanced feeding problem in UWB has been successfully solved. In the direction orthogonal with polarization, the electrical level is $5 \sim 10\,\mathrm{dB}$ higher than traditional monopole UWB antennas [12–14]. In addition, the antenna size is miniature and the length in polarization direction is just 40% of operating wavelength of the lowest frequency, which is also smaller than that of traditional dipole antenna.

## 6. CONCLUSION

A UWB wafer-dipole printed antenna is proposed, and its performance influenced by different parameters has been discussed and analyzed in detail. Introducing the quasi-microstrip line-to-balanced-microstrip line as feeding method can effectively solve the balanced feeding problem of the UWB dipole antenna. The proposed antenna can achieve impedance bandwidth from 3.0 GHz to 15.0 GHz with VSWR $< 2.0$ and the radiation in $H$ plane has omni-directional characteristic. This antenna is printed on FR-4 substrate, and the total size is just $40 \times 20 \times 1.0\,\mathrm{mm}^3$. The compact antenna can easily integrate into communication systems. Finally, the main performance characteristics of the proposed antenna can meet the requirements of UWB application, which can be used in UWB short-range communications and can cover a broad military communication band.

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