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# MICROSTRIP ARRAY DOUBLE-ANTENNA (MADA) TECHNOLOGY APPLIED IN MILLIMETER WAVE COMPACT RADAR FRONT-END

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**Abstract**—A kind of microstrip array double-antenna (MADA) and its corresponding radar front-end are presented in this paper. The double-antenna comprises two individual 4-patch arrays which are coplanar in a round substrate with 25 mm diameter and are used as receiver antenna and transmitter antenna respectively in 36 GHz radar front-end. Both simulation and test results of the antenna are exhibited, which shows better isolation between two arrays below −42 dB in a wide band. Test results of radar front-end with MADA are also presented, from which we can see perfect performance the system has. With improvement of radar system, a more compact MADA with 18.6mm diameter is designed, fabricated and measured, which shows a good response.

## 1. INTRODUCTION

Recently, short-range linear frequency modulated continuous wave (FMCW) radar plays more and more roles in reconnaissance, velocity estimation and collision warning, due to the ability of almost all-weather employment and short range high resolution rate detection and imaging [1]. However the conventional radar is composed of waveguide structure whose size and weight are irreducible. With the development of monolithic microwave integrated circuit (MMIC), low cost and minimized size are realized [2], sequentially, compact antenna is required accordingly. Microstrip antennas have reached a widespread usage, due to a plethora of reasons, such as lightweight,

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low profile, relatively low manufacturing cost, easily fabricated [3], especially in restricted space of compact radar transceiver. Some popular FMCW radars employ single antenna system, in which receiver and transmitter use a common antenna, and circulator is applied to isolate two paths [4]. There are some disadvantages of this system. First is the bad isolation of circulator. 20 dB's isolation is the common value of circulator and it hardly meets high criterion of radar front-end. Secondly, high price also limits its application in low cost system. In this paper, a microstrip arrays double-antenna (MADA) with high isolation and compact architecture which is composed of two 4-patch parallel linear arrays on same plane is proposed. The MADA is fabricated in a round substrate with 25 mm diameter, and acts as transmitter and receiver antennas respectively in a compact radar front-end operated in Ka band frequency. By designing matching network and adjusting distance of two arrays appropriately, isolation −42 dB between receiver and transmitter antennas and gain 12 dB each can be achieved. At the end of paper, a more compact MADA topology is presented. Two 4-patch arrays are designed abreast and reversely on the substrate with 18.6 mm diameter. The test results show isolation −39 dB and gain 10.5 dB respectively.

## 2. MADA DESIGN

To obtain good performance, there are many feeding methods, such as CPW in the ground feeding microstrip antenna [5], and CPW with stub patch feeding slot antenna [6]. However, considering the connection with radar front-end circuit, microstrip antenna without any figure in the ground is necessary and coaxial probe feeding is best for the simple structure. A MADA designed for 36 GHz radar front-end is described, which adopts parallel linear array and quarter wavelength transformers to realize impedance matching. Rogers material ($\varepsilon_r = 2.2,\ \tan\delta = 0.0009$ at 10 GHz) is used as the antenna's substrate due to its superior characteristics such as a high gain and wider bandwidth. Layout of the MADA is shown in Fig. 1(a). The two antenna arrays have the same architectures so both of them can be the receiver antenna or transmitter antenna. They are fed by coaxial probes and feed points are symmetrical to the center of substrate. Geometry of the 4-patch array antenna is shown in Fig. 1(b). The values of the antenna patches are evaluated by the classical equations as follow [1], and adjusted with software simulation.

$$a = \frac{c}{2f\sqrt{\dfrac{\varepsilon_r + 1}{2}}}, \qquad b = \frac{c}{2f\sqrt{\varepsilon_e}} - 2\Delta l$$

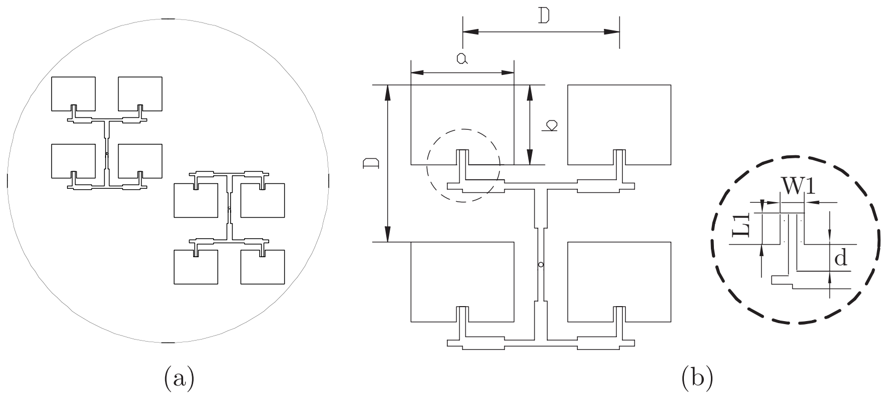



**Figure 1.** Layout of the antenna (a) Simulation module (b) Geometry of the 4-patch array antenna.

$$\Delta l = 0.412h\frac{(\varepsilon_e+0.3)\left(\dfrac{w}{h}+0.264\right)}{(\varepsilon_e-0.258)\left(\dfrac{w}{h}+0.8\right)},\quad \varepsilon_e = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{10h}{w}\right)^{-\frac{1}{2}} \tag{1}$$

These equations base on transmission line model and $w$ is width of microstrip line. Here $w$ is equal to width of antenna patch $a$. Length of the patch is $b$, and thickness and relative permittivity are $h$ and $\varepsilon_r$. $D$ is distance of two patches on both directions, which can control mutual coupling between patches.

Considering impedance matching of patches and microstrip lines, inset feeding structure is used. The inset width is $w1$, and depth is $L1$. Distance of the patches away from the transverse feeding line is $d$. All parameters have been optimized and their values are list in Table 1.

**Table 1.** Design parameters of MADA (unit: mm).

| $\varepsilon_r$ =2.2, h=0 .254 mm, $\tan\delta$ =0.0009 | | | | |
|---|---|---|---|---|
| a=3.4 | b=2.63 | D=5.17 | W1=0.4 | L1=0.5 |
| d=0.49 | W2=0.2 | L2=1.39 | W3=0.42 | L3=0.5 |

Feeding network is designed to realize impedance matching by using quarter wavelength impedance transformers. Dimensions of the network are shown in detail in Fig. 2. Network begins with a center

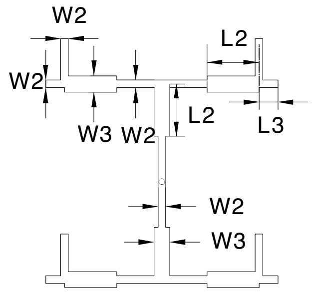



**Figure 2.** Feeding network.

line of 100 Ω which is fed at its center by a 50 Ω coaxial probe. Then impedance is transformed to 50 Ω through a 70.7 quarter wavelength line. At the end of the transformer, network splits into two 100 Ω lines, which is transformed to 50 Ω again by following 70.7 Ω quarter wavelength lines. Impedance fed into patches finally is 100 Ω after split again, and the other stub acts as impedance adjustment. The feeding network ensures each patch has the same feed excitation. By adjusting with software, final values are list in Table 1.

The MADA is fabricated by photolithographic techniques on a round substrate which has 25 mm diameter, 0.254 mm thickness and 17.5 um copper layers on top and bottom. Design of feeding network is also based on reliability of narrow line width that is possible in photolithography. Because the minimum line width of 0.15 mm is realizable in foundry, we choose material with $\varepsilon_r = 2.2$, on which 100 Ω line is 0.2 mm width. One antenna can be obtained from the other one by rotating 180 degree about $z$ axis, and this architecture is the best way of increasing isolation between two antennas in limit space.

## 3. MADA SIMULATION AND TEST RESULTS

Parameters listed above are optimized with Ansoft HFSS 9.0, and antenna is fabricated by technologies such as photolithography, etching, electroplate etc. A photograph of MADA is shown in Fig. 3. Test results of return losses are compared with simulation ones in Fig. 4. $S_{11}$ and $S_{22}$ are return losses of two arrays respectively, and they should be the same because of the same structures. However they are different slightly, for the existence of errors of SMA and fabrication. From the figures we can see that center frequencies of test results agree well with simulation results both in $S_{11}$ and $S_{22}$ curves, while test values are larger than the simulation values, which also result

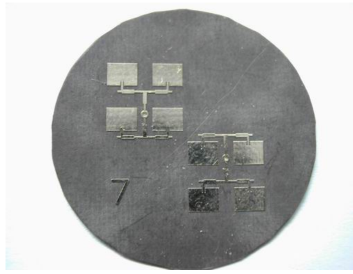



**Figure 3.** Photograph of 36 GHz MADA.

from losses of SMA and errors existed in fabrication. Bandwidths of two antennas are 1.34 GHz when $S_{11}$ ($S_{22}$) $< -10$ dB. $S_{21}$ is isolation between two antenna arrays. It is below $-42$ dB in a wide width which ensures the least interfere between two antennas. Fig. 4(d) and (e) are the gain curves of $H$-plane and E-plane, respectively. Maximum point of gain is 13 dB at 36 GHz, and 3 dB beamwidth of $E$ plane and $H$ plane are 46° and 38° in simulation results, and 28° and 16° in test results. The reason that test results of 3 dB beamwidth are much smaller than simulation ones is the error existed in our test. Test of antenna in our anechoic chamber is totally manual and the two turntables are difficult to adjust in one plane. Because the dimension of the antenna is small, measurement error increases drastically against the angle deflection from the center. However, the trends of the measured curves agree with the simulated ones well. Fig. 4(f) is 3D picture of antenna gain at 36 GHz.

S parameters are measured with hp8722D vector network analyzer and radiation pattern is measured in anechoic chamber with Agilent E8247C signal generator and Anritsu MS2668C spectrum analyzer.

## 4. MADA APPLIED IN RADAR FRONT-END SYSTEM

Radar front-end we mentioned in this paper is designed based on homodyne FMCW radar system [7]. The circuit employs hybrid integration. The multi-Chip module (MCM) technology is applied to combine MMIC chips into a single module which contains all interconnects, DC bias and other passive components. MMIC chips are fabricated using 0.25 um GaAs pHEMT technology. The circuit done on substrate whose permittivity is 10.2 and thickness is 0.254mm locates in a cylindrical box, and antenna is connected to circuit by coaxial probes from the back of it. Schematic diagram is shown in Fig. 5.

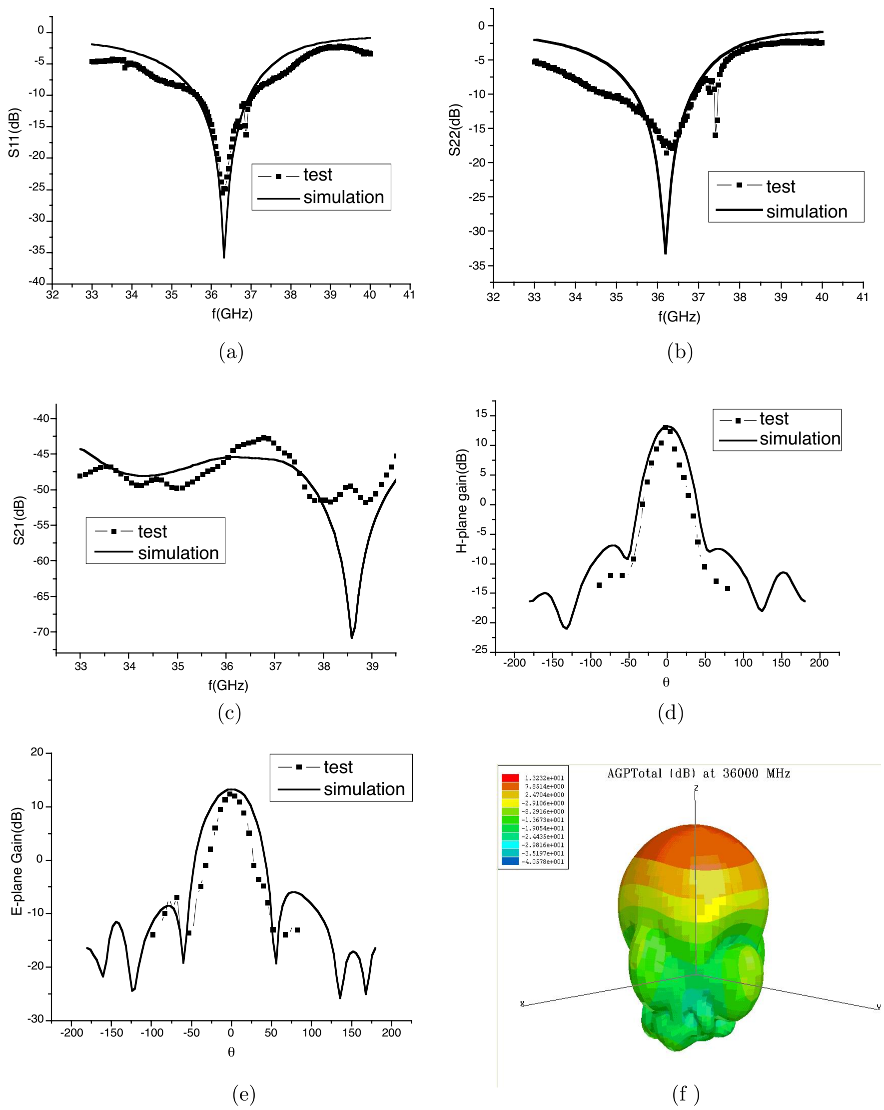



**Figure 4.** Comparison of test and simulation results (a), (b) Return losses of two antenna arrays, (c) Isolation between two antennas (d) Gain curves of $H$-plane (e) Gain curves of $E$-plane (f) 3D picture of gain.

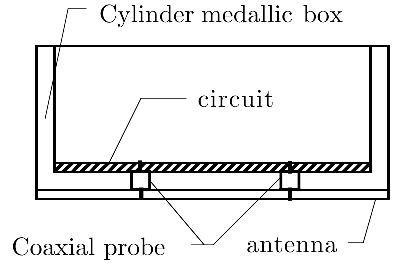



**Figure 5.** Schematic of radar front-end.

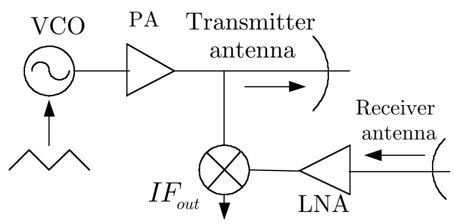



**Figure 6.** Block diagram of radar front-end.

Block diagram of FMCW radar module is shown in Fig. 6. Transmitter and receiver channels have their own antennas independently. Key components integrated by MCM technology include three MMIC chips: VCO, PA, LNA, and a flip diode single balance mixer. Emission signal whose frequency modulated by CW is generated from VCO and amplified by PA. A portion of transmit power is coupled to receiving channel and used as LO source for mixer, the remainder is fed to transmitter antenna. Receiver path, a single balanced rat-race mixer is utilized to generate IF from LO signal and received signal which is gathered in from receiver antenna and amplified by LNA. The whole radar front-end is integrated on a round substrate with 25mm diameter. Photograph of millimeter radar integration front-end is shown in Fig. 7. Antenna is glued with silver epoxy onto the bottom of copper box, and connected to circuit inside the box bottom by two coaxial probes.

Test results of system are shown in Fig. 8. Distance of radar detection is ten meter, and IF output signal is processed by a HF and amplified by AGC circuit. Fig. 8(a) is comparison of IF signal processed by HF and AGC and unprocessed signal with triangular wave leakage. In Fig. 8(b), a test evaluation of the radar data is performed via an interface card and a personal computer. IF signal

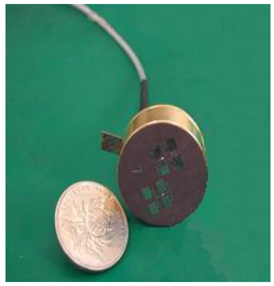
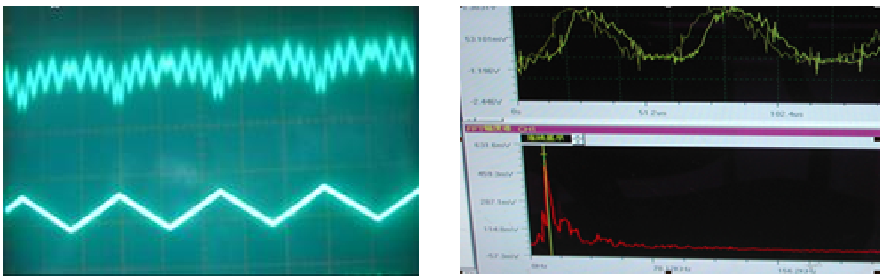


**Figure 7.** Photograph of the radar front-end.



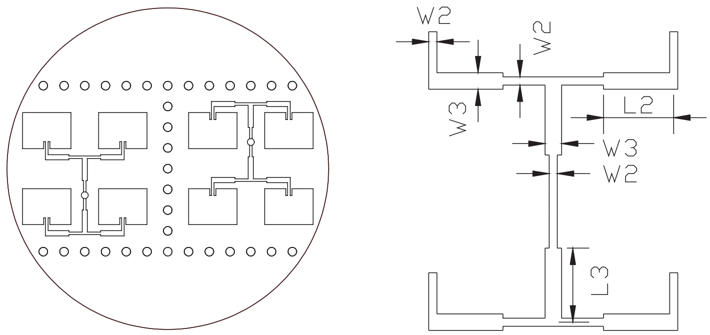
(a) (b)

**Figure 8.** Return wave received by radar (a) Comparison of IF signal processed by HF and AGC and unprocessed with triangular wave leakage (b) IF signal with triangular wave leakage and spectrum after HF and AGC.

is AD converted, stored, and then transferred to the PC, where a fast Fourier transform is done. The curve upside is IF signal with triangular leakage and the downside is its spectrum. From the curves we can see that the radar system works well.

## 5. IMPROVED MADA WITH MORE COMPACT STRUCTURE

With increasing demand of small size radar, another MADA is designed with 18.6 mm diameter. This antenna adopt material with $\varepsilon_r = 3.48$, which agree with substrate of new circuit used, for the sake of same stress. The two substrates will glue together directly without copper box between them. To get better isolation between two antenna arrays, we make several regular grounded via holes. It proved that they played a role to improve the isolation. Impedance matching network




(a) (b)

**Figure 9.** Layout of the improved MADA (a) Simulation model (b) Feeding network.

**Figure 10.** Photograph of the improved MADA.

is adjusted for limited space. Layout of this smaller MADA and its matching network are shown in Fig. 9. Parameters of patches shown in Fig. 1(b) and dimensions of network shown in Fig. 9(b) are list in Table 2. Network is also designed with quarter wavelength impedance transformers and structure is still symmetrical. Two antenna arrays are located abreast and reversely which can make full use of space and ensure isolation. Feed points are symmetrical to the center of substrate. Photograph of the improved MADA is shown in Fig. 10.

Considering of the new contact method that circuit glues with antenna directly and feeds antenna by metallic poles rather than coaxial probes, simulation model of the antenna is changed a little. As the real situation, two layers are built and the antenna at the top layer is fed by a section of microstrip line at the back of the second layer, and metallic poles are added to connect them. For the convenience of test with SMA, model fed by coaxial probes are also simulated with

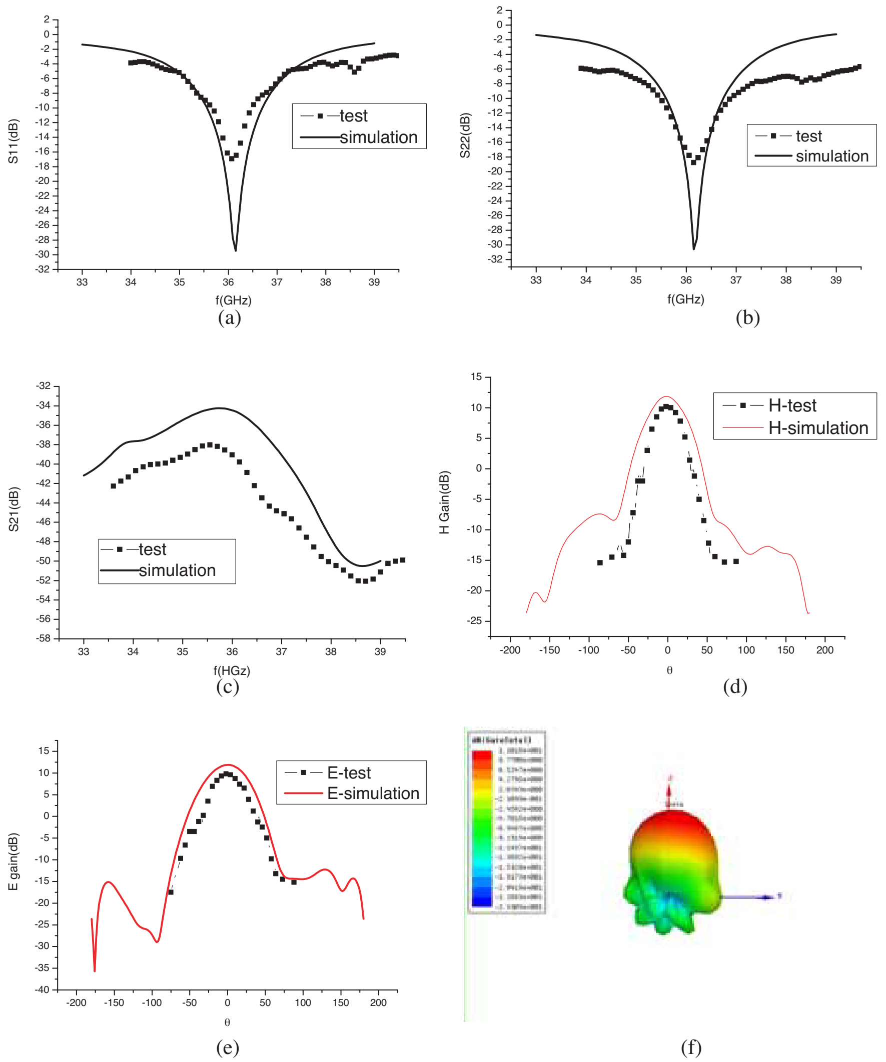



**Figure 11.** Comparison of test and simulation results of the improved MADA (a), (b) Return losses of two antenna arrays, (c) Isolation between two antennas (d) Gain curves of $H$-plane (e) Gain curves of $E$-plane (f) 3D picture of gain.

**Table 2.** Design parameters of improved MADA (unit: mm).

| $\varepsilon_r$ =3.48, h=0.254mm, $\tan\delta$ =0.0037 | | | | |
|---|---|---|---|---|
| a=2.8 | b=2.06 | D=4.4 | W1=0.36 | L1=0.4 |
| d=0.35 | W2=0.15 | L2=1.28 | W3=0.3 | L3=1.35 |

no change of antenna structure. Its results are used to compare with the test ones. Comparison of test and simulation are shown in Fig. 11.

From test curves we can see that resonance frequency is about 36.2 GHz, bandwidth of $E$-plane is 1.38 GHz, $H$-plane is 0.78 GHz when $S_{11} < -10$ dB, $S_{21}$ is $-39$ dB at 36 GHz, 3 dB beamwidth of $E$-plane is 36° and $H$-plane is 34°, gain is 10.5 dB at 36 GHz. From the figures, we can see that the trends of test curves agree well with the simulation ones. Errors still exist mentioned before, in addition, Rogers material with $\varepsilon_r = 3.48$ has greater dielectric loss than $\varepsilon_r = 2.2$. The improved MADA has wider 3 dB beamwidth in both $E$-plane and $H$-plane, which is better for radar detecting aims.

## 6. CONCLUSIONS

Two compact microstrip arrays double-antenna (MADA) with high isolation are presented in the paper. The geometry dimensions with 25 mm and 18.6 mm diameters respectively meet the requirement of compact radar front-end. The test results demonstrate the good performance of MADA, which shows the application potentiality in munitions and civil industry in the future.

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