DESIGN OF A BROADBAND STACKED MICROSTRIP PATCH ANTENNA ARRAY

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Abstract: The linear antenna array composed of four stacked microstrip dual-patch elements with the capacitance compensation probe feeds is designed. NH-1 aramid paper honeycomb is used as the substrate to reduce the weight of the antenna and to extend its frequency bandwidth. In the range of frequency from 950 to 1275 *MHz*, the bandwidth of the antenna exceeds 15.7% for SWR<1.5. The mutual coupling of the array between two adjacent radiating elements also satisfies the engineering design requirement.

DESIGN OF THE MICROSTRIP PATCH ELEMENT

Structure of the Microstrip Patch Element. The sandwich structure of the stacked microstrip dual-patch antenna element is shown in Fig.1, where $\varepsilon_{r1}=\varepsilon_{r3}=2.65$, and $\varepsilon_{r2}=\varepsilon_{r4}=1.05$. In order to compensate for the probe-feed inductance and extend the frequency bandwidth, a small metal disk is introduced and mounted on top of the probe. Furthermore, NH-1 aramid paper honeycomb having low dielectric constant is used as the substrate to reduce the weight of the antenna and to extend further its frequency bandwidth.

Preliminary Determination of the Parameters. The working frequency of the patch element and the size of the array (including its length, width and height) are determined in advance according to the requirement of the engineering. Then, according to these preconditions, we can roughly determine the patch sizes by the following approximate design formulas, i.e.,

$$F_1 = \frac{C_0}{2L_1\sqrt{\varepsilon_{e1}}} \cdot \frac{1-\zeta_1}{1+\zeta_1 \ln\left(1.123 L_1 \sqrt{\varepsilon_{e1}} \Big/ \sum_{i=1}^{4} d_i\right)}, \tag{1}$$

$$F_3 = \frac{C_0}{2\left(L_3 + 2\Delta L_3\right)\sqrt{\varepsilon_{e3}}}, \tag{2}$$

where F_1, F_3 refer to the lower and upper bound of the working frequency, respectively. C_0 is the velocity of light in the free space, and

$$\varepsilon_{ej} = \frac{\sum_{i=1}^{4} d_i}{2\sum_{i=1}^{4} \frac{d_i}{\varepsilon_{ri}}} + \frac{1}{2} + \left(\frac{\sum_{i=1}^{4} d_i}{2\sum_{i=1}^{4} \frac{d_i}{\varepsilon_{ri}}} - \frac{1}{2}\right) \cdot \left[1+\left(10.0\sum_{i=j}^{4} d_i\right)\Big/ L_j\right]^{-1/2}, (j=1,3) \tag{3}$$

$$\zeta_1 = \frac{2}{\pi\varepsilon_{e1}\left[L_1\Big/\sum_{i=1}^{4} d_i + 1.393 + 0.667\ln\left(L_1\Big/\sum_{i=1}^{4} d_i + 1.444\right)\right]}, \tag{4}$$

$$\Delta L_3 = 0.412\sum_{i=3}^{4} d_i \left[\frac{\varepsilon_{e3}+0.3}{\varepsilon_{e3}-0.258}\right]\left[\left(\frac{L_3}{\sum_{i=3}^{4} d_i}+0.264\right)\Bigg/\left(\frac{L_3}{\sum_{i=3}^{4} d_i}+0.8\right)\right]. \tag{5}$$

Final Determination of the Microstrip Patch Element. The Mixed-Potential Integral Equation (MPIE) is applied on the surfaces of the two stacked patches and the capacitance disk and solved by using the method of moments (MoM), that is,

$$\hat{z}\times\vec{E}^{e}(r)=\hat{z}\times\left[Z_S\vec{J}_S(r)+j\omega\int_S dS'\overline{\overline{G}}_A(r\,|\,r').\vec{J}_S(r')+\nabla\int_S dS'G_V(r\,|\,r').q_S(r')\right], \qquad (6)$$

where the Green's functions $\overline{\overline{G}}_A$ and G_V for such four-layer structure can be obtained easily according to the general form shown in ref.[2].

Through those well-known steps of MoM, the integral equation for the unknown surface currents, eq.(6), finally reduces to a matrix equation, that is,

$$Z\vec{I}=\vec{V}\ , \qquad (7)$$

which can be used to solve for the unknown I_{1n}, I_{2n} and I_{3n}. The vector *V* can be derived by using the reciprocity principle, and therefore,

$$V_{im}=\left\langle\hat{z}\times\vec{E}_i^{e},\vec{J}_{im}\right\rangle=\int_V\vec{E}_{i(t)}^{e}\cdot\vec{J}_{im}d\tau=\int_V\vec{E}_{im}\cdot\vec{J}_{\rho}d\tau\ , \qquad (8)$$

where $\vec{J}_{\rho}$ represents the current of the probe feed.

Once the matrix equation is solved and all of the amplitude coefficients I_{1n}, I_{2n} and I_{3n} are obtained, the input impedance of the coaxial-fed stacked antenna element can be found according to the voltage and current at the feeding point, i.e.,

$$Z_{in}=\frac{-\int_V\vec{E}_{total}\cdot\vec{J}_{\rho}d\tau}{\left(I_{\rho}\right)^2}\ . \qquad (9)$$

By following the aforementioned basic steps, the input impedance of the stacked dual-patch antenna element with the capacitance compensation probe feed is calculated numerically. We have noticed through the analysis that to a certain extent the SWR of the dual-patch element for lower frequencies decreases with the increase of the size of the upper patch, while that for higher frequencies reduces if the size of the lower patch is diminished. In addition, the capacitance disk will only affect the imaginary part of the antenna element input impedance, so that the diameter of it can be determined by searching the best matching point for the patch element.

Based upon the above-mentioned analysis, the original design parameters are then adjusted and improved through experiment. The final design results for a single element are obtained as follows. The length and width of the two patches are $L_1=W_1=96mm$ and $L_3=W_3=90mm$. The diameter of the capacitance disk is $D=11mm$. The thickness parameters of all of the dielectric substrates are $d_1=d_3=0.8mm$ and $d_2=d_4=15mm$. In the frequency range of 950~1275*MHz*, the measured bandwidth of this antenna element exceeds 15.7% for SWR<1.5 (see Fig.3).

DESIGN OF THE MICROSTRIP PATCH ARRAY

The structure of a four-element linear antenna array is shown in Fig.2, wherein the above-mentioned stacked microstrip dual-patch element is adopted. The mutual couplings between different elements are then presented in Fig.4. It can be seen that the mutual coupling decreases with the increasing distance between any two elements, and the maximum value of the mutual coupling between two adjacent elements is no more than -15dB, which well satisfies the engineering requirement.

From Fig.4 we can also see that the mutual coupling between element 1 and element 2 is a little different from that between element 2 and element 3 because of the fringe effects produced by limited size of this antenna array. The spacing interval between these elements is fixed as 50mm so as to achieve the better radiation pattern characteristics.

CONCLUSION

The linear antenna array composed of four stacked microstrip dual-patch elements with the capacitance compensation probe feeds is designed. NH-1 aramid paper honeycomb is used as the substrate to reduce the weight of the antenna and to extend further its frequency bandwidth. In the range of frequency 950~1275*MHz*， the bandwidth of the element exceeds 15.7% for SWR<1.5. The mutual coupling of the array between two adjacent radiating elements satisfies the engineering requirement. The design time consumption for this microstrip patch antenna array is deduced drastically through the combination of the approximate analytical formulas, the numerical analysis and the experiments.

REFERENCES

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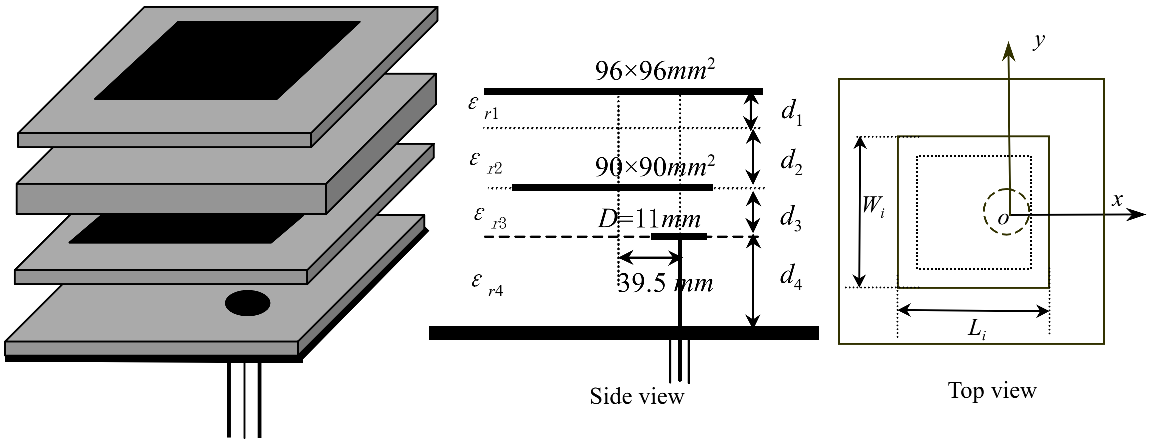

Fig.1 Geometry of the stacked microstrip dual-patch element with a capacitance compensation probe feed

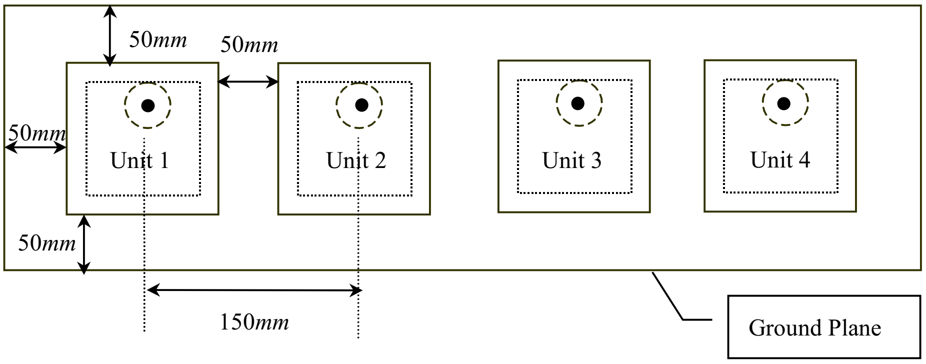

Fig.2 The antenna array composed of four elements shown in Fig.1

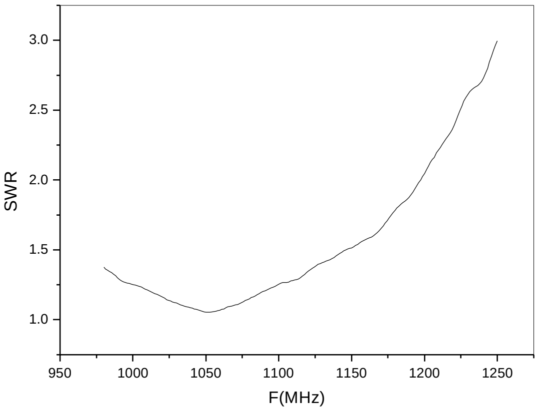

Fig. 3 Measured SWR of the patch element

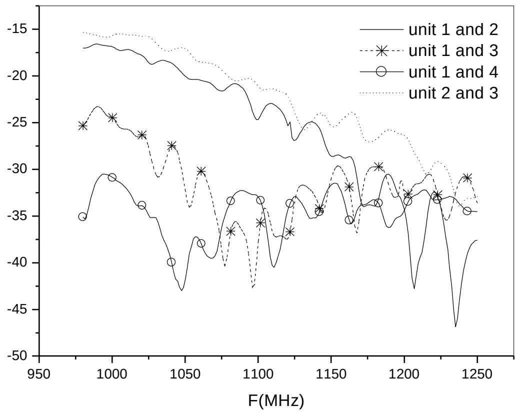

Fig.4 Mutual coupling of different elements of the array in the H-plane