Dual-Polarization Star Microstrip Antennas

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Abstract – **This paper briefly presents a new approach to understanding arbitrarily-shaped microstrip antennas as supergain arrays of the main antenna and its images. Experimental validation is presented on several multi-layer antennas that have non-conventional shapes, such as diamonds and stars. In particular, we present the design and frequency scaling of a dual-polarized two-layer star antenna for use in polarization-diversity wireless links, in which the different shape of the patch allowed us to obtain better polarization properties than with a standard square design. Measured simulation and experimental results at 1.7GHz and a scaled version at 10GHz are shown.**

I. INTRODUCTION

Dual-polarized microstrip antennas have been demonstrated by a number of authors, e.g. [1]. A number of commercial MoM full-wave solvers are capable of accurate design of arbitrarily-shaped microstrip patches. In this paper, we present a simple theory that gives insight into how such antennas operate, allowing for guidelines in choosing the antenna geometrical properties prior to simulations. There are several definitions of supergain antennas, but it seems that all, implicitely or explicitely, include the following properties [2,3]: the total current in all the elements of the antenna is much smaller than currents in individual elements; and the distances between the elements along any direction of large radiation are electrically small. This means that supergain antennas are structures operating at or near resonance. Microstrip antennas are precisely of this type: the currents in antenna patches (including the ground plane) are much larger than the total current in all the elements; the height of the antenna (this is most often the direction of maximal radiation) is electrically small; and microstrip antennas are always excited at or near resonance. In this paper, a microstrip antenna is treated as a superdirective array, consisting of the patch, possible parasitic superstrate patch and the corresponding images due to the presence of the ground plane. As a specific example, the design, implementation and characterization of a star-shaped microstrip antenna with dual feeds is presented. A 1.7-GHz coaxially-fed star, a single-polarized truncated star (diamond), and a scaled 10-GHz dual-polarized star are designed and characterized.

II. SUPERGAIN BEHAVIOR OF MICROSTRIP ANTENNAS

Assume that a flat multilayered plate has such currents in the layers that on one side of the plate near its surface the Poynting vector is directed away from the plate at all instants, and that at its other side it is directed towards the plate at all instants. If its area is not electrically small, the plate in this case radiates in the direction of the Poynting vector. Although at first glance such a structure might not seem realizable, we show below that it can be approximately implemented. Such a plate, as well as any structure similar to it, is here referred to as a *Poynting-vector antenna*. First the simplest form of the Poynting-vector antenna is described, than it is shown that such an antenna is a surpergain antenna, and finally that microstrip antennas are also Poynting-vector antennas.

Consider an open-circuited strip line of width w and distance between the strips d, driven by a generator of angular frequency w at one end. The currents on such a line are opposite, distributed uniformly over the strip-line cross-section, and go to zero at the open circuit. Let the surface current density over the strips be $J_{sx}(x)$ and $-J_{sx}(x)$, where x is the distance along the line, measured from the generator. Between the strips, the magnetic field is y-oriented with intensity

$$B_y(x)=\mu_0\, J_{sx}(x) \tag{1}$$

and the magnetic field outside the strips is very small. According to Faraday's law, outside the strips and close to their surface, there is an electric field, with approximate magnitude equal to

$$E_x(x)= -j\omega\, \mu_0\, J_{sx}(x)\, \delta\,/2, \tag{2}$$

on one side of the line, and an electric field with the same magnitude, but of opposite direction on the other side. Since the two strips are not overlapping, there is a small phase difference of the fields due to the currents in the two strips, and the structure radiates as a supergain antenna equally in the directions of the two sides of the strip-line. Assume now that we add another strip between the two strips. Further, assume that a surface current $J'_{sx}(x)=CJ_{sx}(x)$, where C is a constant, is generated over this third strip, and that this current does not considerably affect the current distribution on the strip-line. The result is a magnetic field $H_y(x)=CJ_{sx}(x)/2$ in addition to the electric field in eq.(2) on one side of the line, and the same magnetic field in the opposite direction on the other side. Note that the Poynting vector on the two strip-line sides is oriented in the same direction, so that such a structure behaves as a Huygens source (which in fact it is). Finally, if the constant C is adjusted to be

$$C=-j\omega\, \delta\, \sqrt{\varepsilon_0\, \mu_0} \tag{3}$$

the ratio of the electric and magnetic fields becomes

$$E_x(x)\, /\, H_y(x) = \sqrt{\mu_0\, /\varepsilon_0}\ \ . \tag{4}$$

In this case, the structure is approximately "matched" to free space and should radiate as a plane wave patch. A strip-line with slightly unbalanced currents can also produce a similar effect. Let the surface current density on one strip be as earlier $J_{sx}(x)$, but on the other, due to an appropriate delay device, the surface current at all points be slightly delayed, and equal to $[-J_{sx}(x)\exp(-j\beta\delta)]$. Such a delay is produced, e.g., by a short wire segment between the generator and the other strip, as in microstrip antennas excited by a coaxial line. The radiation in the direction from the first strip towards the second strip is then zero. Radiation in the opposite direction is not zero, and corresponds to a total surface current density over the strips equal to

$$J_{sx,\,total}\,(x)= J_{sx}\,(x)\,[1- \exp(-2j\beta\, \delta)]\ . \tag{5}$$

Note that this is similar to the case of the third (middle) plate in the above example having a surface current density of

$$J'_{sx}\,(x) = J_{sx}\,(x)\, \exp[(j\beta\, \delta/2)]. \tag{6}$$

Thus, for sufficiently large surface currents, as in the case of the system in or close to resonance, the strip-line radiation can be significant. Physically, this is the operating mode of all single-patch microstrip antennas, although the current distribution over the antenna patch and the ground plane is more complex than in this example.

Two interesting conclusions follow from the simple reasoning above. First, the ground plane and the dielectric of a microstrip antenna can be cut to follow the patch shape, and the antenna would still radiate predominantly in one direction. Second, microstrip antennas can be made to have any patch shape which enables large resonant currents, e.g., the shape of a straight [4] or bent strip, deltoid, n-legged star, etc. In specific, this paper is devoted to the analysis of four-legged star patch antennas with one and two feeds. Physical intuition tells us that such a patch antenna with relatively narrow star legs should have reduced coupling between the two ports and therefore a better isolation between two orthogonal linear polarizations when compared with a rectangular or circular patch antenna.

III. RESULTS – SIMULATIONS AND EXPERIMENT

The geometry of the antennas used for this study is shown in Fig.1. The two dielectric layers are characterized by their thicknesses, h_1 and h_2, and their relative permittivities, e_1 and e_2. Both patch layers have the shape of a symmetrical four-legged star, described by an outer circle radius (R_{1o}, R_{2o}) and inner circle radius (r_{1i}, r_{2i}). The feed shown in Fig.1 is coaxial, of inner radius a, and the distance from the center of the antenna is labeled as F. The star antenna has two feeds corresponding to two orthogonal linear polarizations. When one of the star branches is removed, a linearly-polarized diamond antenna results, as shown in Fig.1 on the right.

The simulations of the 1.7 GHz star were performed using a fast MoM integral-equation solver with large-domain basis functions, which is capable of simulating finite ground planes and dielectric layers on a modest personal computer [5]. The simulated reflection coefficient and comparison with measurements is shown in Fig.2. This antenna was then approximately scaled to 10 GHz, using available substrates. The relevant dimensions are shown in Table 1. It was found in simulations that a thin inner conductor wire (radius 0.1mm) is needed for a 50-Ω match in this case.

The measured radiation patterns of both antennas are shown in Fig.3 and Fig.4. For the 1.7-GHz antenna, patterns at both feeds are shown to illustrate the dual-polarization properties of the antenna. Fig.4 contains the measured cross-polarized patterns at 10 GHz, showing that the polarization of the star antenna is better than that of a standard patch antenna, while taking up less area.

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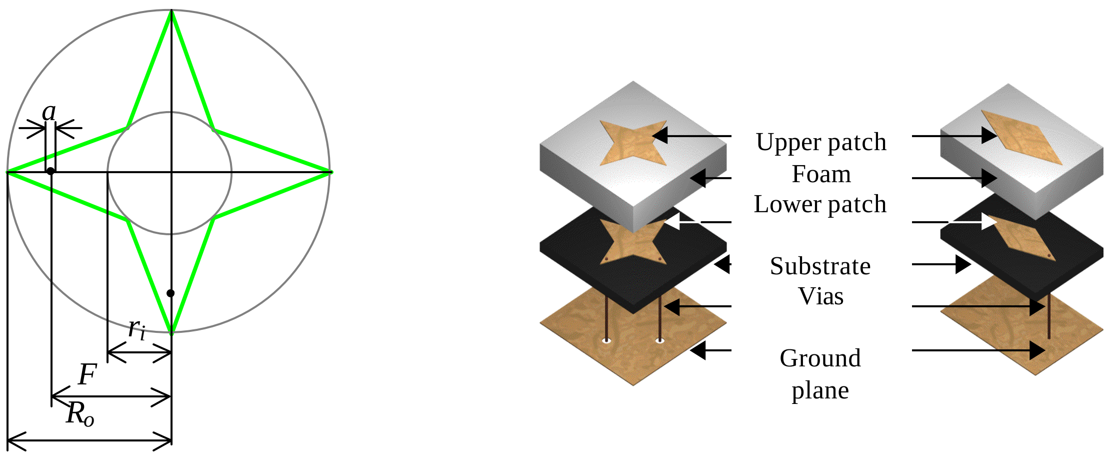

Fig. 1. Sketch of star antenna, top view (left). *R* is the outer radius of the star branches, *r* is the inner radius, *F* is the distance of the feed from the center, and *2a* is the diameter of the coaxial feed. The stacking of the substrates for both the star and diamond antenna are shown on the right side of the figure.

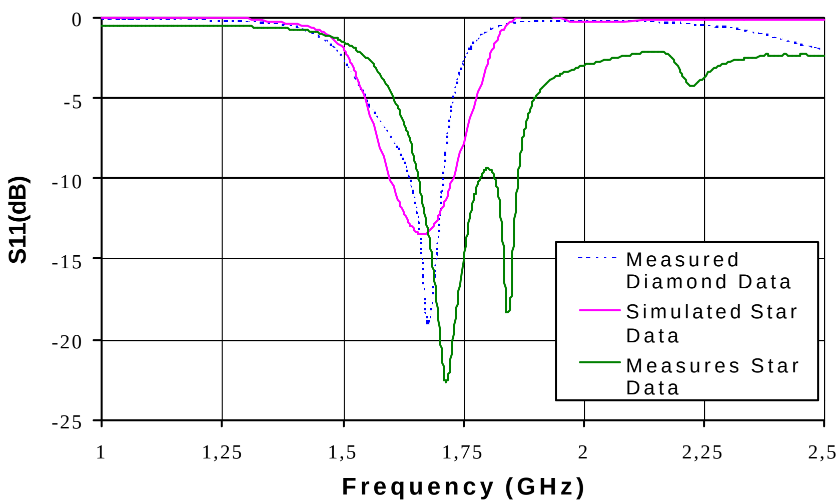

Fig.2. Simulation and measurements of the input match w.r.t. 50 ohms for the star and diamond antennas with geometric parameters shown in Table 1. The second higher measured resonance of the star antenna is believed not to be due to radiation.

Table 1. Dimensions of two star antennas

f(GHz)	1.7	10
h_1(mm)	1.16	0.254
h_2(mm)	9	1.3
R (mm)	50	8.3
r (mm)	20	3.3
F (mm)	41	6
a (mm)	0.25	0.1

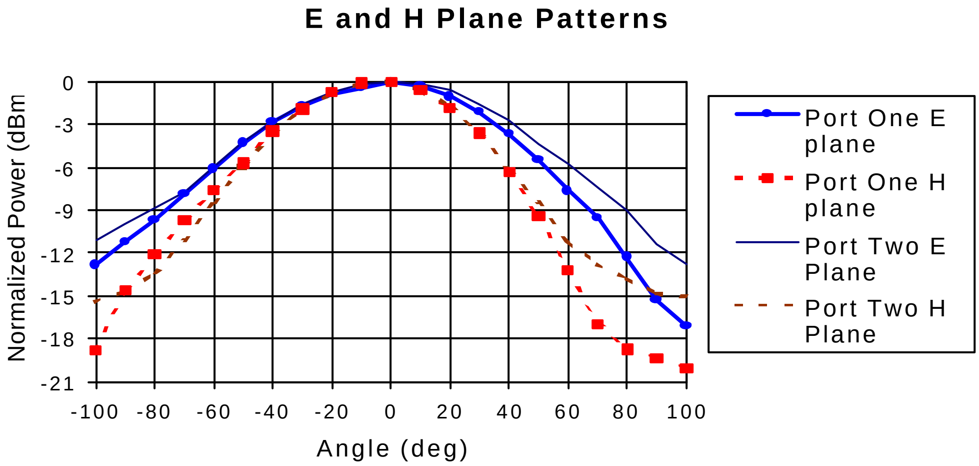

Fig.3. Measured E and H-plane patterns at 1.7GHz for the two ports of the cross-polarized star antenna.

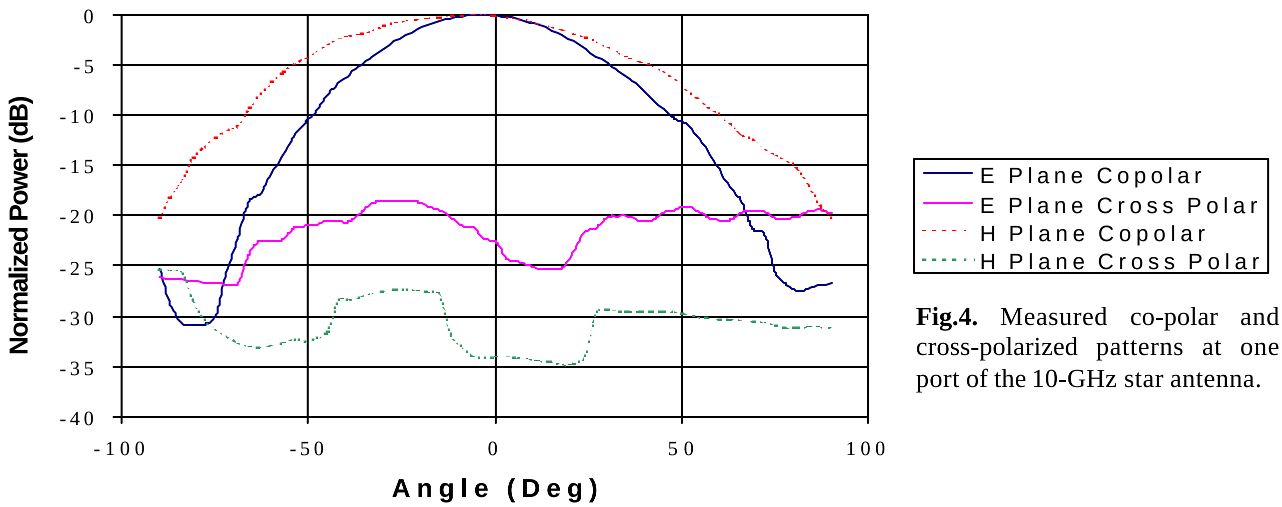

Fig.4. Measured co-polar and cross-polarized patterns at one port of the 10-GHz star antenna.