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Mechanically Reconfigurable Radiation Pattern Slot Antenna Array Feeded by Bended Sectoral Horn and Metalized Wood Splitter

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Abstract—In this paper, an antenna with reconfigurable radiation pattern in H-plane at 2.45 GHz for high power applications is presented. It is based on a 3-slot array in E-plane covered partially with two mobile metallic flaps in order to reduce their length, and in consequence, they ensure the mechanical reconfiguration pattern in H-plane. The power distribution of the array is ensured with a power splitter in E-plane, and the uniform and in phase field distribution on the slots is ensured with a sectorial horn placed before the splitter. To reduce cost and weight, the power splitter is realized with metalized wood.

1. INTRODUCTION

High Power Microwave (HPM) antennas are well suited for high pulsed power application [1] such as non-lethal weapon and drones interception. In this field of applications, antennas must provide good efficiency, low losses and low back-side radiation. Radiation pattern control, especially Half Power Beamwidth (HPBW) reconfiguration, is important to focus only on the target. However, there is a challenge to maintain a suitable power handling with high reconfiguration pattern.

Two particular ways were proposed to design reconfigurable radiation pattern with variable HPBM. The first one is based on a high power electronic device to electronically control the radiation pattern [2]. The other is to use a mechanical system as in [3] with a defocusing system on a parabolic antenna. Recently in [4], the authors propose a solution based on coupled three slots array. This solution is limited in term of choosing inter-element distance (typically $0.75\lambda_0$). The proposed solution allows to choose any distance and is achieved by using a three-way waveguide splitter. Also the phase and magnitude can be easily fixed.

In this paper, an H-plane mechanically actuated radiation pattern antenna is presented. The HPBW reconfiguration between 20° and 45° is provided by physically moving two parasitic flaps as described in [4]. The E-plane pattern is fixed by a 3-slot array distributed by an E-plane power splitter [5] after a sectorial horn. In this paper, the splitter consist of one dissymmetric splitter (1/3 and 2/3), and the powered one is divided using another symmetric splitter (1/2, 1/2). Finally, the global splitter divides by 1/3, 1/3, 1/3.

The antenna design concerns the radiation but also a good matching in all reconfiguration cases. A set of measurements including reflection coefficient and radiation patterns is presented and compared to the simulation. The power splitter is realized with metalized wood to reduce cost and weight.

2. ANTENNA DESIGN AND FABRICATION

The proposed antenna is based on a sectorial horn antenna radiating aperture with the illustrated uniform E-field amplitude and phase distribution (Fig. 1). The objective of the design is to mechanically

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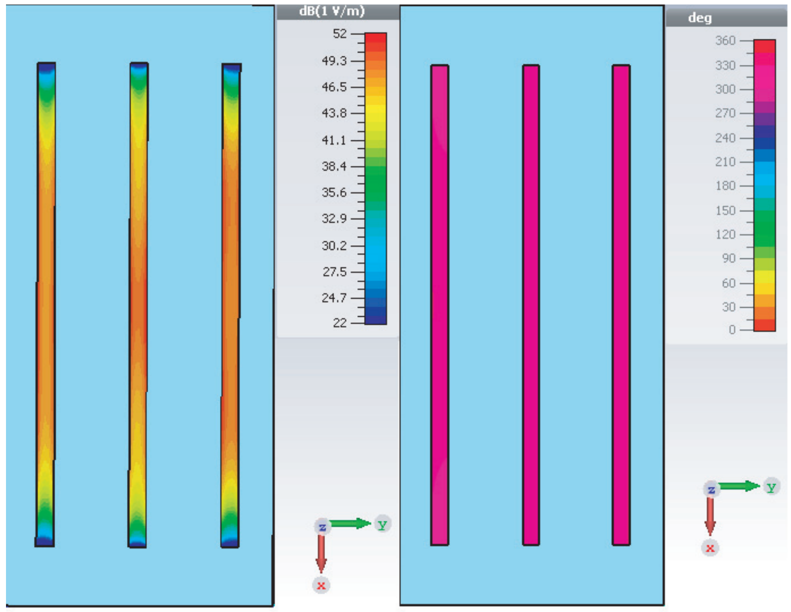

Figure 1. Electrical Field distribution into the apertures.

change the physical aperture length in order to obtain the reconfigurable radiation pattern in the H-plane. According to [6], the mathematical relation between the physical aperture length a and the corresponding HPBW ($\theta_{H(-3\,\mathrm{dB})}$ in degrees) can be expressed approximately as follows (for uniform electric field distribution along the aperture):

$$\theta_{H(-3\,\mathrm{dB})} = \lambda_0 \times \frac{180}{a \times \pi} \tag{1}$$

where λ_0 is the wavelength in the free space and a the length of the aperture. In order to be compliant with a HPBW variation in the H-plane from 20° to 60°, it is deduced that the antenna's aperture length a should evolve from 351 mm to 117 mm (at 2.45 GHz). In this design, the length is fixed to 400 mm. This length is mechanically changed hiding a part of the radiating slots with two metallic flaps.

To provide the constant amplitude and phase distribution along an aperture, an H-plane sectorial horn is used as a feeder. The length of the horn is fixed to 390 mm to guarantee the phase constant. In order to keep the E-plane beamwidth to 30°, a three-slot array with inter-element distance equal to $0.6\lambda_0$ at 2.45 GHz is used.

To provide the amplitude and phase distribution to each aperture (E-plane), a power splitter in the E-plane is used after the horn. The global design is presented in Fig. 2. The detail of the power splitter is presented in Fig. 3. To design it, an optical approach is first used to theoretically determine the dimensions. To provide the same phase in all apertures, we must have:

$$\frac{v_1.\pi}{2} + \lambda_g = v_4.\pi + l_1 + \frac{v_2.\pi}{2} + l_3 \tag{2}$$

$$\frac{v_1.\pi}{2} + 2\lambda_g = 2v_4.\pi + l_1 + \frac{v_3.\pi}{2} + l_4. \tag{3}$$

Then, with the physical constraints (space between apertures d and level of apertures) we obtain:

$$v_1 + d = v_2 + l_1 + 2v_4 \tag{4}$$

$$v_1 + b + 2v_4 - \frac{b_1}{2} = l_3 + v_2 + b_3 + \frac{b_2}{2} \tag{5}$$

$$v_1 + 2d = v_3 + l_2 + l_1 + 4v_4 \tag{6}$$

$$v_1 + b + 4v_4 - \frac{b_1}{2} = l_4 + v_3 + \frac{b_3}{2} \tag{7}$$

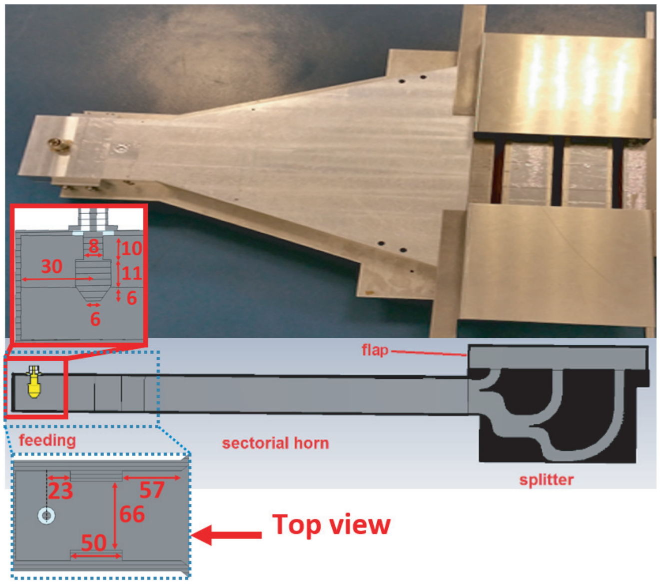

Figure 2. Global design of the antenna.

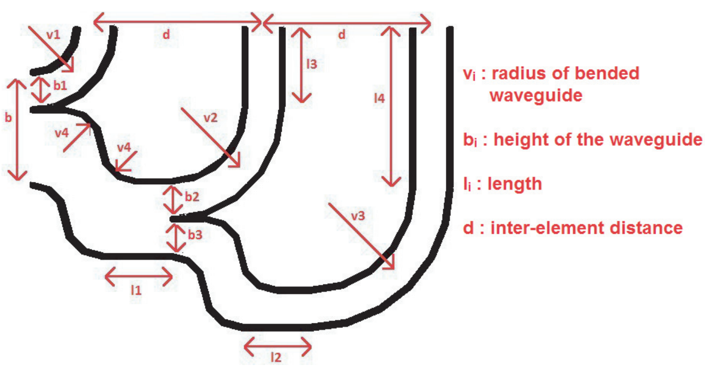

Figure 3. Global design of the power splitter.

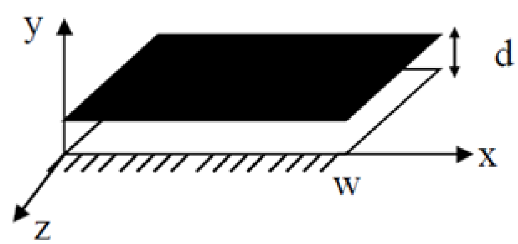

Figure 4. Model of the input of the splitter.

with $\lambda_g = \frac{\lambda_0}{\sqrt{1-(\frac{\lambda_0}{2a})^2}}$ [7] and b the width of the waveguide at the input of the horn ($b = 43.18\,\text{mm}$). Resolution of this system gives:

$$l_1 = \frac{b + d(\pi - 2) - b_3 - 2(\lambda_g - 4v_4)}{\pi - 4} = 28\,\text{mm} \tag{8}$$

$$l_2 = \frac{b + d(\pi - 2) - b_1 - 2(\lambda_g - 4v_4)}{\pi - 4} = 28\,\text{mm} \tag{9}$$

$$l_3 = \frac{b(\pi - 2) + 4d - b_3(\pi - 2) - 4\lambda_g + 8v_4(\pi - 2)}{2(\pi - 4)} = 33\,\text{mm} \tag{10}$$

$$l_4 = \frac{b(\pi - 2) + 8d - b_3(\pi - 2) - 8\lambda_g + 16v_4(\pi - 2)}{2(\pi - 4)} = 65\,\text{mm} \tag{11}$$

$$v_2 = \frac{-b - 2d + b_3 + 2\lambda_g + v_1(\pi - 4) - 2\pi v_4(\pi - 2)}{\pi - 4} = 30\,\text{mm} \tag{12}$$

$$v_3 = \frac{-b - 4d - b_2 + 4\lambda_g + v_1(\pi - 4) - 4\pi v_4}{\pi - 4} = 41\,\text{mm} \tag{13}$$

The mobile metallic flaps are placed above the radiating apertures at a distance $h = \lambda_0/4$ to minimize their influence on matching. Finally, we fix $v_1 = \lambda_0/(2\pi) = 19\,\text{mm}$ to have the wave from the first aperture reflected toward the flap that comes back on the splitter to radiate in phase.

We fix arbitrarily $v_4 = b/3 = 14\,\text{mm}$ which is one solution to have a positive solution for each parameters.

About the amplitude, we want the same on each aperture. The global splitter is composed of two different splitters. The first one at the input is an asymmetrical division (1 to 1/3 and 2/3) and the second symmetrical (1 to 1/2 and 1/2). At the input of the power divider, we have a TEM mode thanks to the horn feeder. So the electric field is as the one between two metallic plates (Fig. 4) with:

$$\vec{E} = \frac{V}{d} e^{jkz} \vec{y} \tag{14}$$

$$\vec{H} = \frac{V}{\eta d} e^{jkz} \vec{x}. \tag{15}$$

So the power is:

$$P = \iint \frac{1}{2} (\vec{E} \wedge \vec{H}^*) \cdot \overrightarrow{dS} = \frac{V^2 a}{2\eta d} \tag{16}$$

Thus, with the same length a (E-plane power splitter), the power is inversely proportional to d, the height of the waveguide. Hence, with a height b of the waveguide at the input of the splitter, the heights of the two waveguides at the output of the first division are $b_1 = b/3$ and $2b/3$ and at the output of the second division $b_2 = b/3$ and $b_3 = b/3$ to have the desired power. It is worth noting that this principle can be used to design a splitter to feed a slot array with different amplitudes and phases to have a specific radiation pattern, which is not the case in [4].

To reduce both cost and weight, the splitter is realized with metalized wood. 4 pieces are fabricated, and each has 23 slices of 17 mm thickness realized with a water jet cutting process and then fixed together (Fig. 5). It is metalized with a silver filled spray with a sheet resistance between 0.3 and 0.77 Ω/sq. Three coatings are used to decrease the sheet resistance of the layer. All other parts (flats, horn and feeding part) are machined aluminum to consider having metal loss only in the splitter. Finally, the sectoral horn part is fed by the monopole probe described in [4]. The matching part (top view of Fig. 3) is optimized to have a higher agility at 2.45 GHz.

Figure 5. Pictures of splitter before and after assembling.

3. SIMULATION AND MEASUREMENTS

The simulation is performed on CST Microwave Studio [8] with all parts in aluminum. Fig. 6 presents the return loss of the antenna for different values of the distance between the two flaps l_f. The flaps are manually moved to change this distance for measurements; however, it can be easily motorized in a final version of the antenna. There is a small frequency shift between simulation and measurement (10 MHz). The antenna is adapted ($|S_{11}| < -10$ dB) for l_f between 400 mm (no flaps over the apertures) and 150 mm.

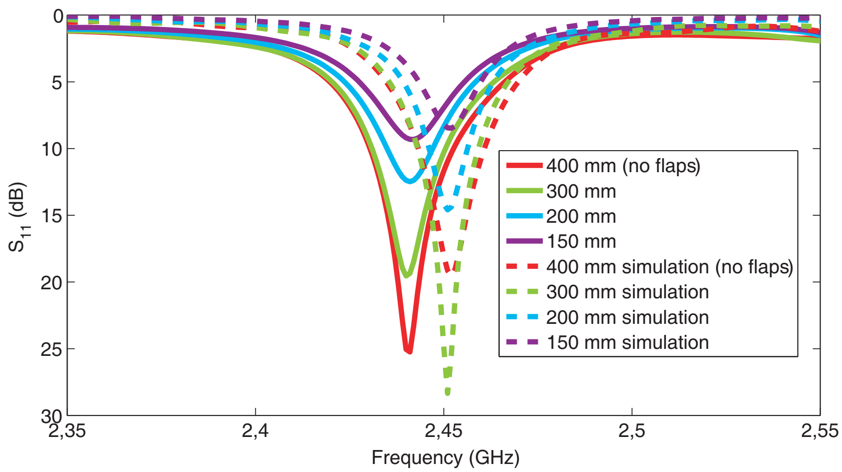

Figure 6. Simulation and measurement of the return loss.

Measurement of the radiation pattern is performed on a SATIMO anechoic chamber at 2.44 GHz on both E-plane (Fig. 7) and H-plane (Fig. 8). At this frequency, the antenna presents a better matching than 2.45 GHz in simulation. A good agreement can be observed between simulation and measurement, with only a small shift on frequency (0.5%).

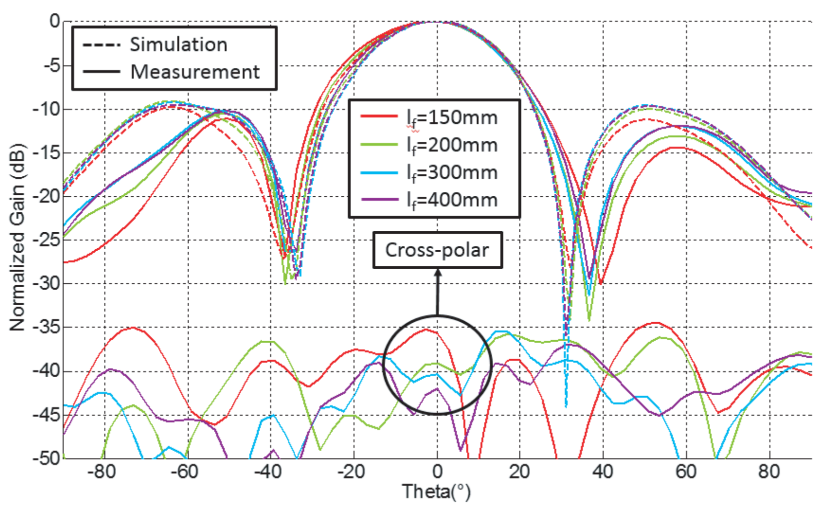

Figure 7. E-plane radiation pattern.

The radiation pattern in the E-plane does not change when the flaps move with a HPBW of 30° and side lobe level below −10 dB. On the H-plane, the HPBW changes from 18° (flaps opened $l_f = 400$ mm) to 44° (flaps closed $l_f = 150$ mm) with side-lobe levels below −15 dB. The gain varies between 12 dBi and 18 dBi (because of the changing HPBW). Fig. 9 summarizes these results, showing the gain and the

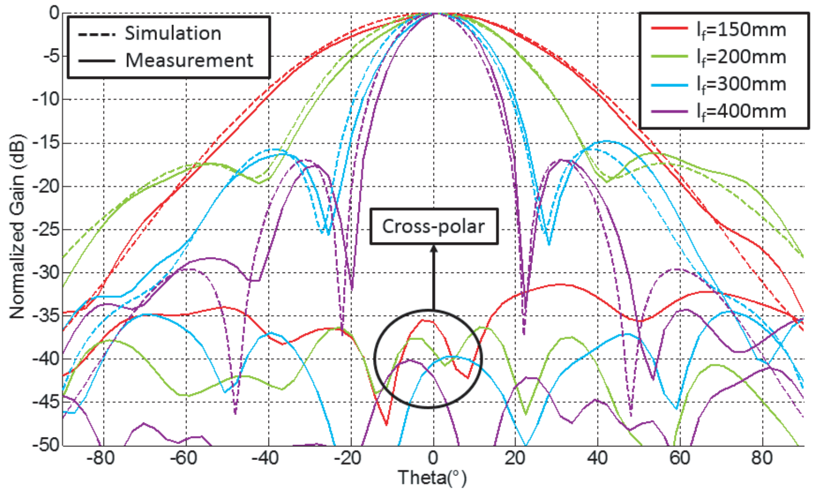

Figure 8. H-plane radiation pattern.

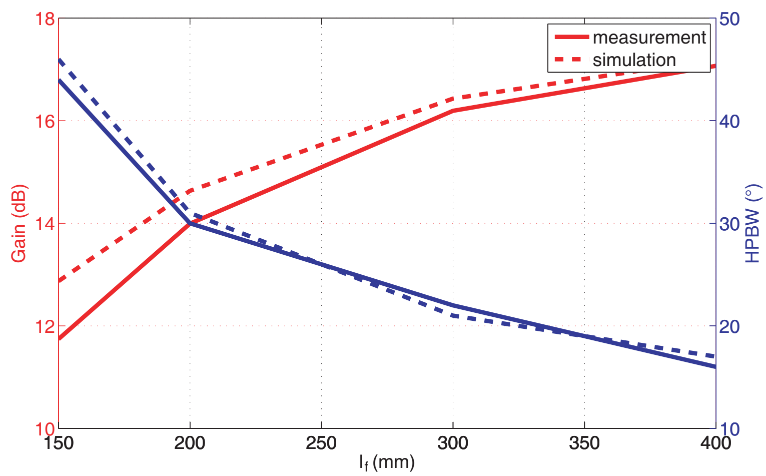

Figure 9. Gain and HPBW in H-plane versus distance between flats (l_f).

HPBW versus l_f. The gain difference between simulation and measurement can be due to losses inside the splitter for high HPBW. These results are close to those with coupled slots in [4]: same side-lobe level, but the HPBW agility is a bit lower because of the matching (17° to 59° in coupled slots and 18° to 44° here).

4. CONCLUSION

A high power pattern mechanically reconfigurable antenna has been designed with a sectorial horn feeder and a power splitter coupled with a mechanical metallic flaps. The radiation pattern is constant in the E-plane (HPBW of 30°) with the splitter and changes in the H-plane (HPBW from 18° to 44°) with the flats movement. A weight and cost reduction has been done replacing aluminum by metalized wood for the splitter. To go further, the matching part and the feeder could be improved to enlarge the bandwidth and the HPBW agility. Moreover, it could be interesting to replace the metallic flaps by an electronic system to increase the speed of the configuration change, but this system has to accept hight power. Some work using GaN technology is in progress. To finish, high power measurements have to be done to verify the high power handling of the antenna (specifically for the matching part and the metalized wood splitter).

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