

MICROSTRIP REFLECTARRAYS AS VERSATILE SOLUTION FOR BEAM-SCANNING AND MULTI-BEAM APPLICATIONS

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Abstract

Passive and active microstrip reflectarrays are investigated as versatile solution for beam-scanning and multi-beam applications. A new approach based on a varactor loaded patch is proposed for dynamic reflectarray beam steering. A phase only synthesis algorithm is adopted to synthesize multi-beam reflectarray radiation patterns. Both experimental and simulated results are presented.

1 Introduction

Reflectarray antennas are planar arrays of microstrip patches illuminated by a feed. The phase of the field scattered from each element is controlled in order to steer the main beam along a specified direction. The required phase contributions can be obtained by varying the patch resonant size, or using other methods such as patches of the same size loaded by passive delay lines with different lengths. Furthermore the main reflectarray beam can be electronically scanned by implanting low-bit and low-loss phase shifters into the printed elements or mechanically scanned by placing miniatures motors under the patches when circular polarisation is needed [1]. All these techniques introduce a small shift in the resonant frequency of the elements, so changing the phase of the reflected fields. Reflectarray scattering properties can be controlled by a proper design of the single printed element. This feature makes reflectarrays much more versatile with respect to conventional reflectors. The use of microstrip technology gives itself significant improvements such as low-cost, less-weight and easy installation.

In this work, microstrip reflectarrays are proposed as versatile solution for beam-scanning and multi-beam applications. Both passive and active reflectarray antennas are extensively analysed. A new approach to dynamically steer the main reflectarray beam is tested by loading each microstrip element with a reverse biased varactor.

An iterative projection method [2] is applied for synthesising the reflecting surface to scatter most of the incident radiation along one or more prescribed directions simultaneously .

2 Analysis of passive and active reflectarrays

The design of microstrip reflectarrays entails the use of a phase design curve. Unfortunately, the problem of retrieving the reflection phase of a patch surrounded by different elements becomes computationally impractical for arrays with thousands of elements.

A simplified approach based on a commercial simulation tool has been used for designing both active and passive reflectarrays. The overall procedure relies on the possibility to estimate the scattering properties of each patch by analysing the phase of the field reflected by an isolated reflectarray unit cell without considering the effects of the surrounding elements (Fig. 1). This approach is based on the consideration that mutual coupling in reflectarrays can be ignored provided

that a thin substrate is used and that the spacing between adjacent patches is at least a quarter wavelength in the dielectric. Under these conditions, the Method of Moments is used to produce data for the amplitude and phase of the field reflected from a reflectarray isolated element. As it is well known, conventional MoM simulators substitute the patch with an equivalent sheet of electric current radiating in presence of the infinite ground plane. This configuration does not take into account the reflections from the ground plane which are essential for the reflectarray antennas design. In order to include the finite ground plane effects, an efficient method has been adopted, which uses standard MoM to compute the re-radiation from the patch only and Physical Optics theory to evaluate the contribution of the finite ground plane [3, 4].

The proposed analysis method has been tested by considering both active and passive reflectarrays. Firstly, a set of microstrip passive patches of different sizes printed on a 18×18 mm grounded dielectric slab 0.762mm height and with $\epsilon_r = 2.33$ has been realized.

The phase of the field scattered by the isolated patch is reported under Fig. 2 versus the patch resonant size. An overall variation of 360 degrees is obtained with element dimension spanning from 5.55 mm up to 12.96 mm. Measurements are also compared in Fig. 2 with simulation results.

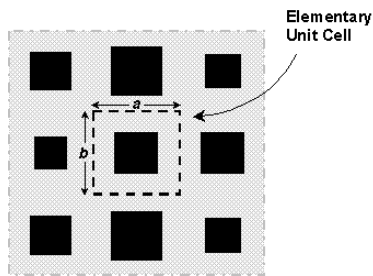


Figure 1 - Elementary Unit Cell

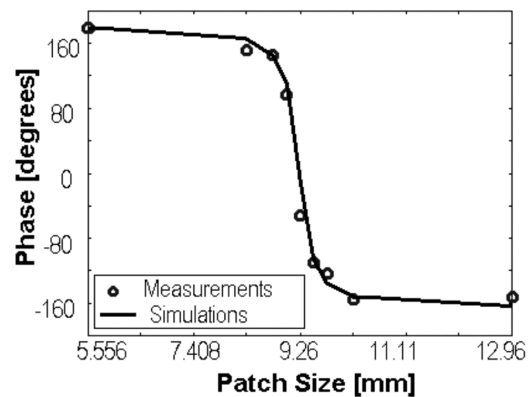


Figure 2 - Reflection phase vs patch size: measurements and simulations.

In a second assessment, the reflection phase of a simple active reflectarray cell consisting of a varactor loaded microstrip element has been examined (Fig. 3). The voltage controlled varactor introduces a variable capacitive reactance at the open end of the antenna which modifies the electrical length of the patch. By electrically adjusting the capacitance of the diode, the resonant frequency of the antenna can be varied within a specified range. The small shift in the resonant frequency introduced by the tuning diodes changes the reflection phase of the single element, so allowing a dynamic phase control.

As in the passive case, the reflection phase of the reflectarray element has been experimentally verified [5]. A rectangular microstrip patch with $W=13\text{mm}$ and $L=9.2\text{mm}$, printed on a $13.2\times 15\text{mm}$ grounded dielectric slab with $h=0.762\text{mm}$ and $\epsilon_r=2.33$ has been considered. A Microsemi GC15006 diode, with a tuning range of 1.8-0.3pF when reversed biased between 0 and 22V, has been used to load one of the patch radiating edges. In order to reduce the varactor perturbation on the antenna radiation pattern, the diode has been positioned at $d=0.5\text{mm}$. The active device has been biased by means of a thin wire connected at the middle of a non radiating edge of the patch and derived through the antenna ground plane. In Fig. 4 is shown the normalized phase variation versus diode capacitance at 10.8GHz which is the resonant frequency of the patch when the varactor presents a capacitance of 1pF. As it can be seen, the phase varies within a range of 180 degrees, which is the maximum expected value in the case of a purely capacitive load.

Measured data are presented together with the simulated ones in Fig. 4 confirming the reliability of the proposed analysis approach also for the active case.

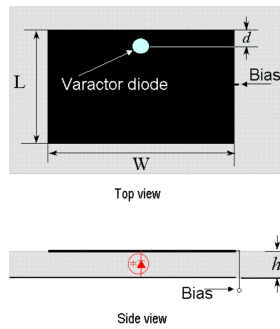


Figure 3 - Varactor loaded microstrip patch.

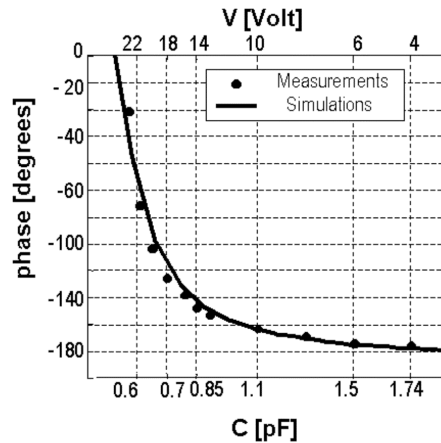


Figure 4 - Reflection phase of the varactor loaded patch: simulations and measurements.

3 Beam scanning capabilities of varactor loaded reflectarrays

A linear reflectarray of varactor loaded microstrip antennas has been developed as a proof of principle of the proposed beam steering technique. The array is made of five patches spaced 0.54λ at 10.8GHz and printed on a 13.2×75 mm grounded dielectric slab. In this configuration, the available reflection phase range permits at most to continuously scan the array main beam within a range of ± 15 degrees from broadside direction.

The reflectarray is fed using a horn placed in the far field of the array. The horn is located in a way that it does not interfere with the array pattern in the broadside direction. Each varactor has been biased by connecting the bias line to a dedicated power supply. Two different measurements have been carried out to verify the beam scanning capability of the reflectarray. Firstly the radiation pattern of the reflectarray has been measured with the bias voltages fixed to an identical value thus the main beam is located in the broadside direction. A second configuration has been chosen to scan the main reflectarray beam 15 degrees off broadside. According to Fig. 4 and Fig. 5, the required progressive phase shift can be achieved by tuning the diode reverse bias voltages to the following listed values: $V_1=2V$, $V_2=14.2V$, $V_3=19V$, $V_4=21V$, $V_5=22V$.

The measured radiation patterns in the two cases are presented in Fig. 6, showing that the reflectarray main beam scans, as expected, from 0 to 15 degrees off when the diodes are reconfigured.

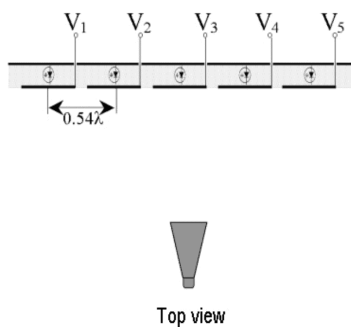


Figure 5 - Linear varactor loaded reflectarray.

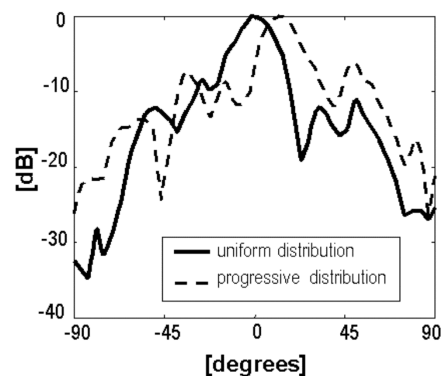


Figure 6 - Measured radiation patterns of the active reflectarray antennas.

4 Multi-beam reflectarrays synthesis

Reflectarray multi-beam capabilities have been investigated by applying a phase only synthesis algorithm. The phase tuning technique based on patches of different size is adopted. As shown in Fig. 2, little changes in the elements size are required to obtain the overall 2π phase variation, so the fields scattered by the elements can be considered substantially identical in shape and an array factor notation can be used for the reflectarray total field.

As consequence of this, the synthesis problem can be simply formulated as the finding of an array factor satisfying the prescribed requirements. The iterative projection method presented in [2] is adopted which finds the synthesis solution as the intersection $M \cap B$, where M is the set of the array factors which fulfil the pattern requirements, while the set B depends on the excitation constraints obtained from the analysis procedure. The approximate solution x is achieved by an iterative process of the kind:

$$x_{n+1} = P_B P_M x_n$$

where P_B and P_M denote the projection operators on the sets B and M , respectively.

The method is adopted in [6] to design reflectarrays as stable target points in SAR Interferometry applications. A maximum backscattering in the direction $\theta = 23$ degrees at $f = 5.3$ GHz (typical ERS1/2 SAR incidence angle and frequency) is imposed. The simulated radiation pattern (elevation cut), fitting a suitable amplitude mask, is reported under Fig. 7.

As proof of multi-beam reflectarray capabilities, a 10GHz reflectarray is synthesized with 25x25 variable size elements chosen from the curve in Fig. 2. The solution given by the synthesis algorithm is reported under Fig. 8, showing three main lobes along 10, 30 and 45 degrees.

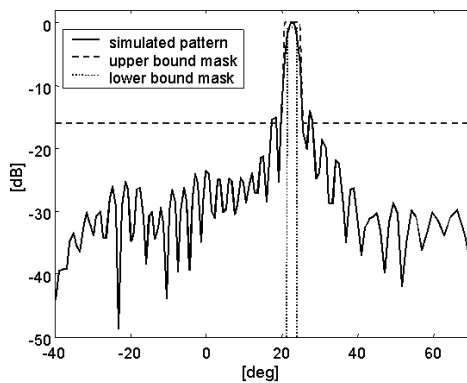


Figure 7 - Simulated radiation pattern at 5.3 GHz. (Elevation plane)

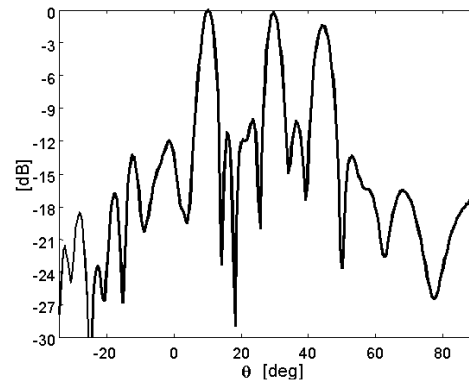


Figure 8 - Synthesized multi beam reflectarray radiation pattern

Conclusions

The research activity on microstrip reflectarrays is described. The reflectarray concept is proposed as alternative solution for beam scanning and multi-beam applications.

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