ACTIVE SCAN-BEAM REFLECTARRAY ANTENNA LOADED WITH TUNABLE CAPACITOR

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ABSTRACT

In this paper, the design concept of an active reconfigurable reflectarray antenna has been proposed and tested. The elementary radiators are hollow patch antennas loaded with varactor-diode device which its reflected phase can be varied. This phase alteration is based on the variation of the diode capacitance which can be achieved by varying the biasing voltage of the active varactor device. By activating these varactor devices, the phase of each antenna element in the array configuration can be adopted dynamically and consequently its radiation beam can be reconfigured. The advantage above the MEMS switches is complexity of the integration and continues beam scanning capability. The reflectarray incorporating active elements has been built and tested at 6.0GHz. The performance of the proposed active antenna is excellent which pioneers design of arbitrarily reconfigurable antennas.

1. INTRODUCTION

In the past decade the research and development on analytical and experimental techniques for Microstrip ReflectArray (MRA) antennas has received considerable attention for replacement of reflector antennas. This is due to the their compactness, light weight and low cost production [1, 5]. In this paper the relevant aspects related to the design of a reconfigurable active MRA using capacitive loading hollow patches are presented. In [6], the authors suggest a technology using patch aperture-coupled to a transmission line and loaded with two diodes. The suggested technology in that paper is different and more complex than the concept introduced here. The phasing technique proposed in this paper make use of hollow patch elements. The phasing is achieved by varying the capacitance of the varactor diode through different biasing. The varactor chips have been designed and developed at DIMES (Delft Institute for Micro-Electronics and Submicrontechnology) and act as tunable capacitive devices[7, 8]. A prototype active reflectarray has been designed to demonstrate the suggested concept. The antenna is build and measurements are performed to validate the simulated results.

2. GEOMETRY OF A VARACTOR LOADED HOLLOW PATCH

The hollow patch loaded with the varactor is depicted in Figure 1. The central part of the patch consists of the varactor chip with an additional metalized plate, which two vias are used to transfer the Bias and GND control signals between the two sides of the PCB. The connection between points A and B through the chip represents the RF path. The chip has five connection points on top which are wired to the patch laminate using bondwires. The capacitance value of the varactor is varied using a bias voltage between -12 and 0 Volts. On the bottom, the patch consists of a groundplane with islands directly under the center of the chip. To ensure decoupling of the control signal from the RF signal, a Surface Mounted Device (SMD) capacitor is integrated on the bottom of the patch.

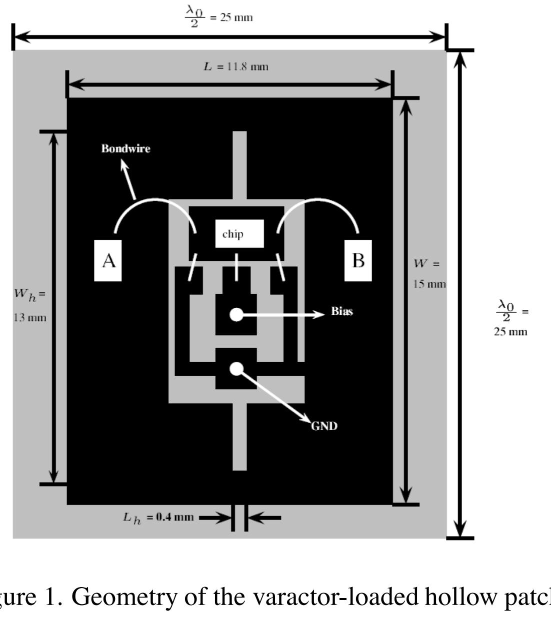
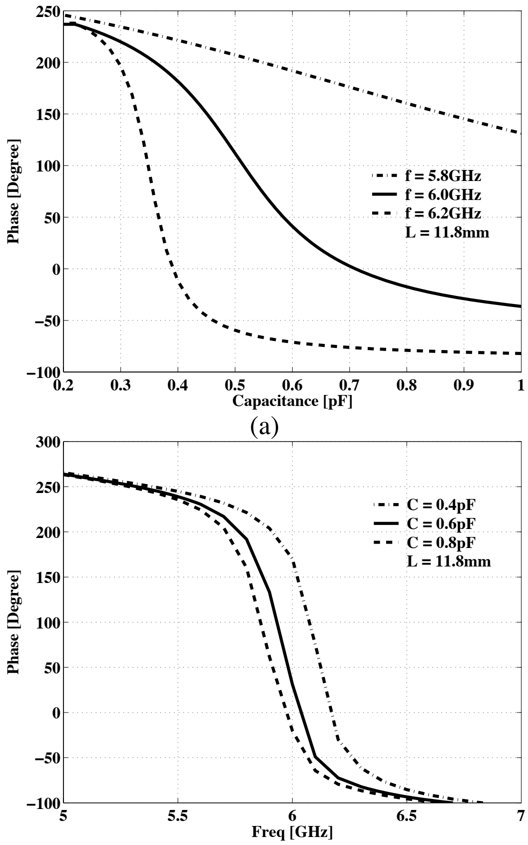


Figure 1. Geometry of the varactor-loaded hollow patch.

3. PHASE DIAGRAM

The design procedure is very similar to that of the SMD MRA [9]. The capacitance is directly proportional to the corresponding bias voltage which subsequently control the reflected phase of each elementary cell in the array architecture.



(a)

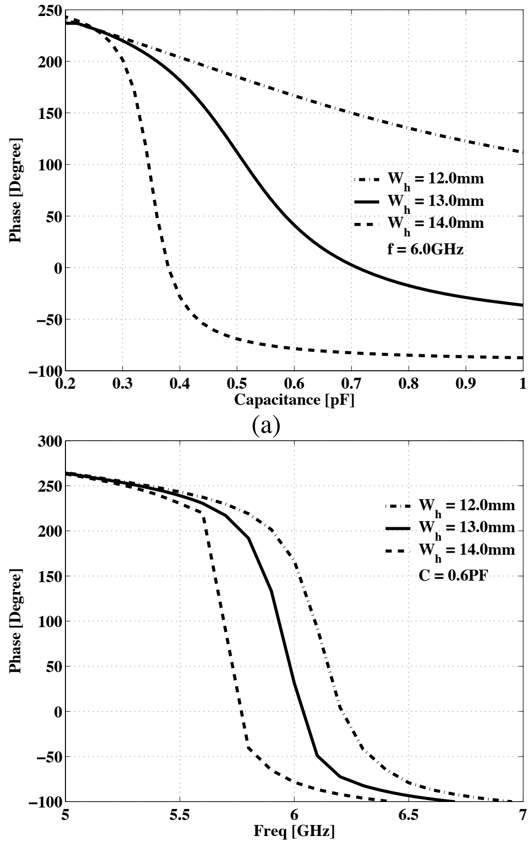
(b)

Figure 2. Phase diagram of a hollow patch loaded with tunable varactor as function of (a) capacitance, (b) frequency.

Figure 2(a) illustrates the reflected phase as function of the capacitance across the hollow patch for different frequencies. The phase range for a varying capacitance 0.3pF$\leq C \leq$0.8pF is about 250° with a maximum sensitivity of 40°/0.05pF. The performance at frequencies f=5.8GHz and f=6.2GHz is deteriorated which demonstrate a narrow band behaviour of the antenna. Figure 2(b) presents the frequency response of the phase diagram for different values of the capacitance across the slot. The resonance frequency is shifted to higher frequencies as C decreases.

3.1. Slot Width

The varactor hollow patch is sensitive to parameters such as slot width. Figure 3(a) presents the reflected phase as function of the capacitance for different values of the slot width at f = 6.0GHz. A dominating effect of the slot width on the phase diagram is visible. Figure 3(b) depicts the frequency response of the reflected phase for different values of the slot width and a fixed capacitance of 0.6pF. A decrease in slot width leads to an increase in the resonance frequency due to the smaller path length currents need to travel.



(a)

(b)

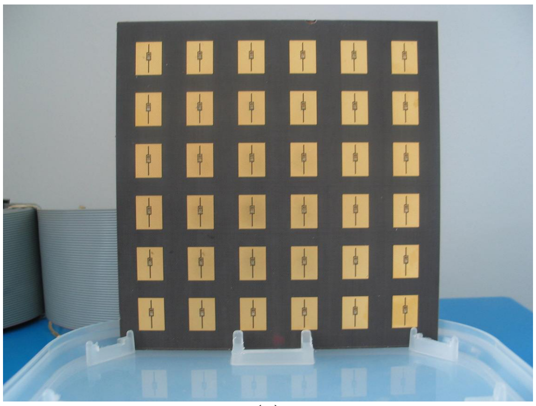
Figure 3. Effect of the slot width on the phase diagram for a varactor-loaded patch as function of (a) capacitance at f = 6.0GHz, (b) frequency with C_0 = 0.6pF.

4. TECHNOLOGICAL ASPECTS AND EXPERIMENTAL RESULTS

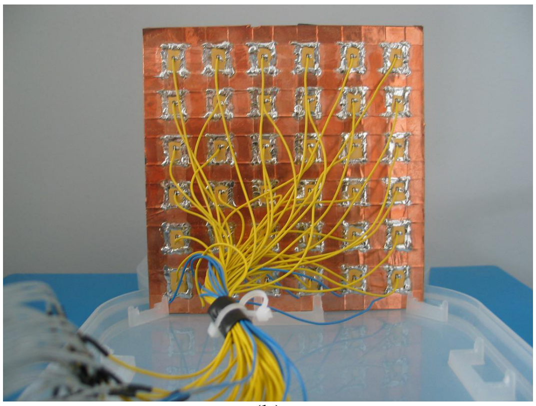
For bond wiring, vias with a diameter of 0.3mm have been drilled in the PCB laminate and were made of golden material using bondable gold. The bond wires with diameter of 17μm are integrated using the "Wedge Wedge" process technique [10]. It has a Gaussian bell form with a height of 300μm. The varactor chip with the thickness of 500μm is assembled on the top of the metalized island, glued having a thickness of 60 μm. The glue is not a conductive material and it is carefully injected and spread manually over the metallic island. The chip is subsequently mounted on the glue. The complete antenna is then kept in the oven for over two hours with a maximum temperature of 100° C.

The 6$\times$6 planar integrated active hollowed MRA antenna is depicted in Figure 4 was built in printed technology using high frequency laminated material TLX-0-0620-

C1/C1 from Taconic with a thickness of 1.57mm and dielectric permittivity of ϵ_r= 2.45.



(a)



(b)

Figure 4. Manufactured active antennas: (a) front view; (b) rear view.

As depicted in Figure 4(b), the control signals include 36 wires for the biasing (yellow wires)- and 6 lines for the grounding (blue wires) which have been soldered on the bottom side of each radiator in the array. Each column of the array requires one line for grounding.

Experimental results

The experimental results presented in this paragraph were performed in DUCAT (Delft University Chamber for Antenna Test). PCI-766 DAC (Digital-to-Analog converter) with an advanced multi-channel analogue output board with optimised 16 channels each with full 16-bit resolution is used to control the bias. The DAC was already available in the laboratory and in order to keep the costs low it was decided to use this one and not purchasing an extra DAC. The drawback is that in this case, a DAC channel is used to provide the information on the number of antenna element simultaneously. The feed antenna was WR159 operational in 4.9GHz$\leq$f$\leq$7.05GHz frequency-band. A PC has been used to control and execute automatically the DAC output during the pattern measurements. The output of the DAC is via a ScSi and a 50 input-50 output universal adapter connected with 50 lines flat cable (length of 4 m) to the array antenna inside the DUCAT. From the 50 lines of the flat cable, only 42 lines were used, 36 for the biasing and 6 for the ground signals. The radiation pattern of the manufactured antenna have been investigated in the E-plane at f = 6.15GHz and is depicted in Figure 5 scanning from -15° $\leq \theta_{\rm scan} \leq$ 15° demonstrate the concept. The sidelobe levels are

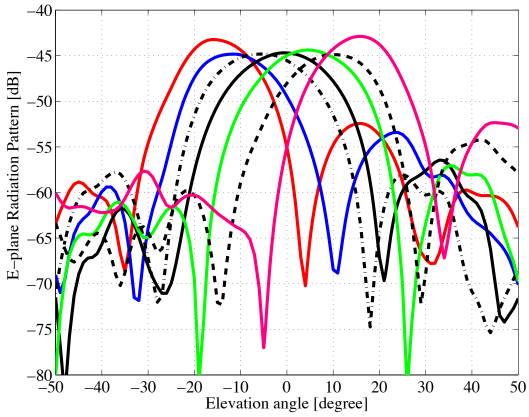


Figure 5. Measured radiation pattern of the active hollow MRA at 6.15GHz.

more sensitive to the tuning of each element than the main lobe. However at the same time, it can be observed that the side-lobe remains around and below -10dB. Since it was not possible to tune each individual varactor chip on the array, it is not fully correct to compare the measured radiation patterns to the optimised numerical results. However, the measured and simulated radiation patterns for different scanning angles are depicted in Figure 6. The field patterns are shown in the E-plane only. The measurements are in good agreement with the simulations. The differences are more visible at the larger scan angles. A final set of measurements, refers to the frequency response of the array which gives insight into the operational bandwidth of the antenna. In Figure 7 the measured patterns of the active array for $\theta_{\rm scan}$ = ± 15° and $\theta_{\rm scan}$ = ± 10° are shown for different frequencies. Based on this definition, we conclude from the patterns that the antenna exhibits a moderate 70MHz bandwidth. The frequency response of the measured patterns at $\theta_{\rm scan}$ = ± 5° and $\theta_{\rm scan}$ = 0° are not presented here, but they reveal the same bandwidth range.

5. CONCLUSIONS

A general design approach has been presented for active MRA's. The proposed active MRA consists of integrating hollow patches with tunable capacitors in the form of varactor diodes. An effective computational solution incorporating a full-wave analysis of the active array has been presented. A complex measurement setup has been realized in DUCAT for performing radiation pattern measurements and steering each individual varactor chip. Considering the drawback of the DAC employed in the measurement setup, the experimental results and our nu-

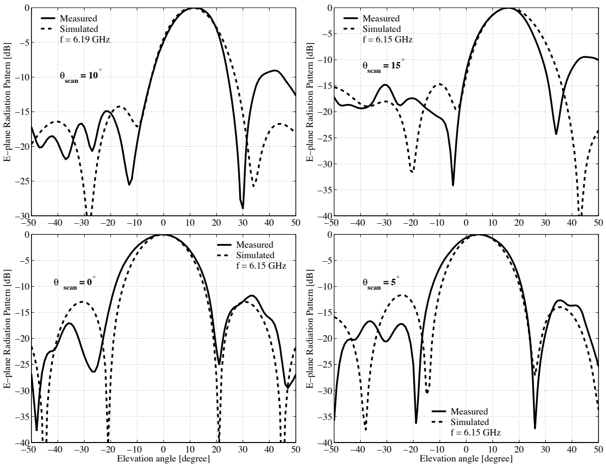


Figure 6. Measured and simulated radiation patterns at f = 6.15GHz for $\theta_{\text{scan}} = 0°, 5°, 15°$ and at f = 6.19GHz for $\theta_{\text{scan}} = 10°$.

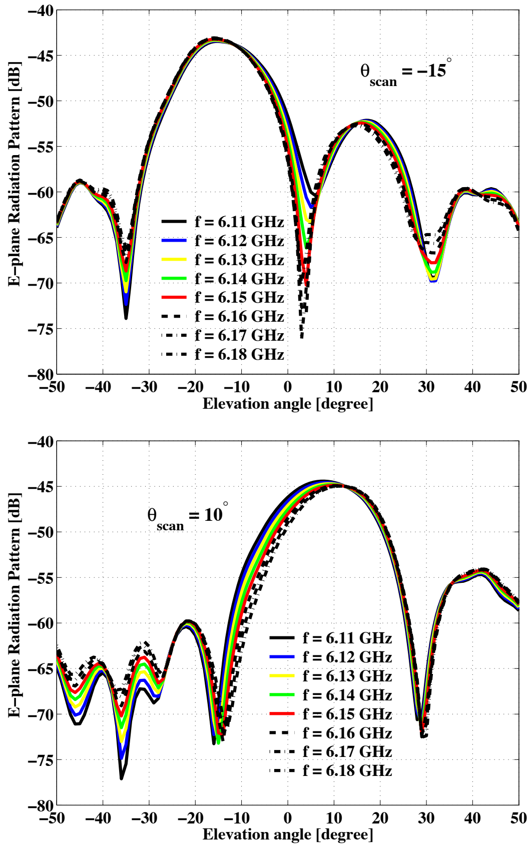


Figure 7. Measured radiation pattern for different scan angle at different frequencies: (a) $\theta_{\text{scan}} = -15°$, (b) $\theta_{\text{scan}} = 10°$.

merical solution obtained by the full wave analysis are in good agreement. It is observed that due to the realized capacitance versus voltage characteristics of the varactor, the scanning capability of the array is limited to elevation scan angles up to $\pm 18°$. A new design methodology is in progress for extending the performance of varactors at DIMES. The operational frequency of the varactor opens the possibilities to examine array antennas at higher frequencies.

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