Triple-slot phase-shifting cell loaded with one variable capacitance for reflectarray applications

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Triple-Slot Phase-Shifting Cell Loaded with One Variable Capacitance for Reflectarray Applications

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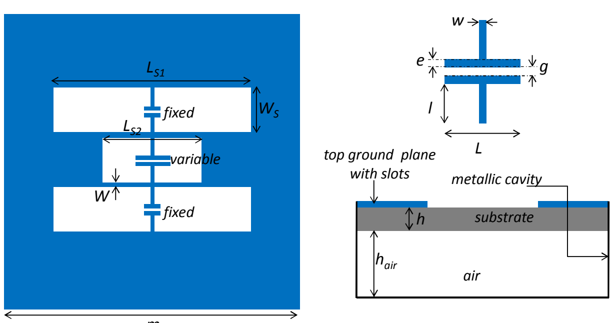
This letter presents a new linearly polarized phase-shifting cell for reflectarray applications. It consists of three parallel rectangular slots etched in a ground plane and loaded with a combination of variable and fixed capacitances to provide a 2-bit phase-shifter. The proposed cell is fabricated and characterized in C-band using the waveguide simulation approach with four fixed states.

Introduction: Active reflectarrays are promising solutions for reconfigurable radiating apertures at reasonable cost [1]. One of the main challenges is to design phase-shifting cells whose phase can be controlled dynamically over a 360° phase range with smooth frequency variations, low losses and reduced number of active elements. MEMS [2] or diodes [3] are usually used to dynamically control the electric length of a single resonator. On the other hand, multiple resonators have been advantageously used to increase the overall phase range of passive cells up to twice or three times the required 360° value [4, 5]. Single-layer structures are preferable as they result in a simpler technological process. In [6] and [7], simulations showed the capabilities of reconfigurable single-layer structures, using either 2- or 3-slot resonators controlled by a convenient capacitive loading. This tuning mechanism is appropriate to modulate the slot's length without fundamentally changing its resonant mode (as may be observed for switched multiple-resonators [8]). In this letter, experimental validation for the new triple-slot phase-shifting cell is presented; we demonstrate that very satisfying performances can be achieved with just one variable capacitance loading the central slot while benefiting from the bandwidth enlargement brought by both external slots.

Proposed phase-shifting cell: The proposed cell is illustrated in Fig. 1. It consists of a set of three parallel rectangular slots etched in a square ground plane. Two different slot lengths (L_{S1} for external slots and L_{S2} for central slot) are combined to improve the bandwidth. The ground plane is printed on a 1.6 mm substrate with 2.17 dielectric constant, suspended 15.7mm above a square metallic cavity (m^2=35*35mm^2). The principle of this structure is to control the reflected phase by a single capacitance loading the central slot. The value of the capacitance can be tuned by choosing the electrode's length (*L*). In a future active version, the gap capacitance could be replaced either by capacitive MEMS or by varicap diode. The external slots are used to achieve a smooth phase evolution (and consequently a large bandwidth). To do so, the resonant frequency of these external slots has to be optimized. Here, this is done by loading the external slots with a fixed capacitance (*L*=1mm). Indeed, this capacitance increases the electrical length of the slots with no need to bend them or to raise cell size, which improves the compactness.



f_0=5.35GHz, h_{air}=15.7mm, h=1.6mm, L_{S1}=21mm, L_{S2}=10mm, W_S=5mm, W=0.2mm, m=35mm, w=0.5mm, l=2.2mm, e=0.2mm, g=0.2mm, L=1mm for external capacitances, L variable for central capacitance

Fig. 1 *Proposed phase-shifting cell.*

Simulation and experimental results: The performances of the proposed topology have been assessed at 5.35GHz. Numerical characterizations with HFSS® have been carried out using the waveguide simulator approach by placing the cell at the end of a 35*35mm^2 square metallic waveguide. The cell is excited with the TE_{10} mode with electric field perpendicular to the slots. In order to validate the simulations and to assess the potential of the cell to achieve the desired behaviour, four different layouts, each of which corresponds to a different value of the central slot capacitance length (*L*), were fabricated and measured in a C-band metallic waveguide. The simulated and measured reflected phases are given in Fig. 2. The agreement between both is quite good; the deviation is less than 45°. Fig. 3 shows the stability of the phase standard deviation which reflects the parallelism between the curves. The ideal value is 26° for a 2-bit phase-shifter. Here, a 31° value is measured, in the useful band from 5.2GHz to 5.6GHz (7.4% bandwidth), corresponding to a 1.74-bit phase-shifter. The maximum measured losses are less than 0.8 dB in the useful band as it is illustrated in Fig. 4.

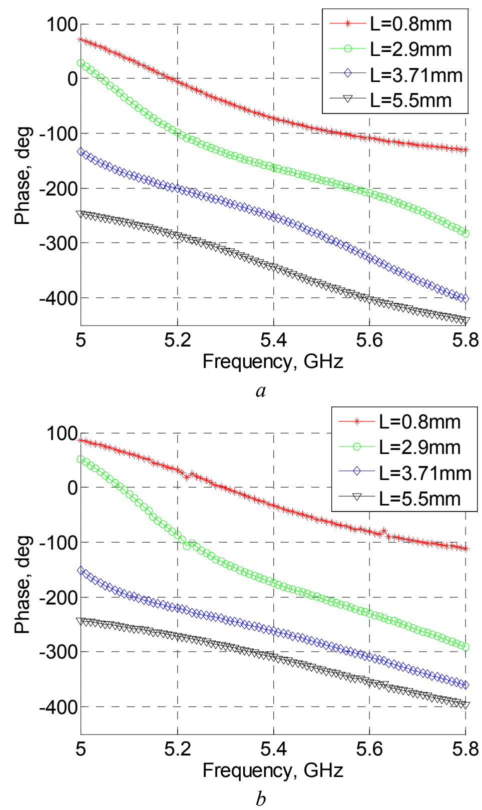


Fig. 2 *Phase versus frequency for different values of the loading capacitance.*
a Simulated reflected phase
b Measured reflected phase

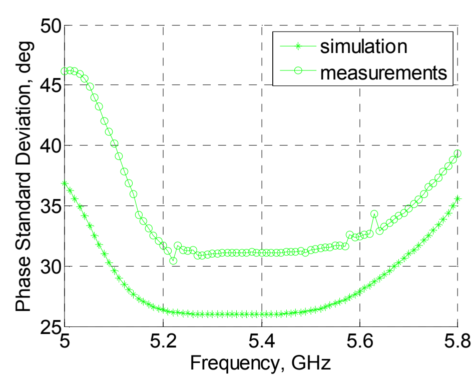


Fig. 3 *Simulated and measured phase standard deviation versus frequency.*

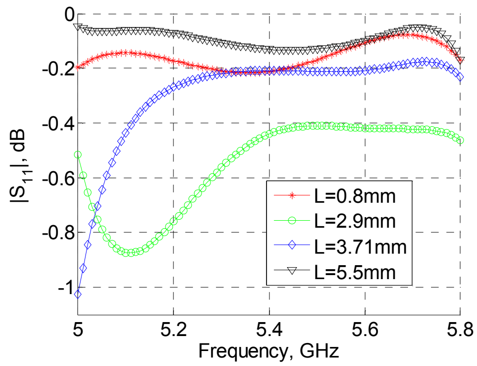


Fig. 4 *Measured losses versus frequency for different values of the loading capacitance*

Conclusion: In this letter, a new phase-shifting cell for reflectarrays has been proposed. It uses two external slots loaded with the same fixed capacitance, and a central slot whose loading capacitance is varied. Measurements, in good agreement with simulations, have demonstrated that the phase varies quite linearly with frequency and that the modification of the central capacitance's value is sufficient to provide 4 uniformly distributed phase states with low losses and low dispersion.

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