

An optically reconfigurable unit-cell for Ka-Band reflectarray antennas

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A new method for achieving amplitude reconfiguration in a reflectarray antenna is presented in this letter. The individual unit-cell is a compact multilayer structure, including a silver inkjet printed layer for rapid prototyping of the reflectarray. A small infrared light emitting diode (IR-LED) illuminating a silicon wafer provides the reconfiguration in the system. Various illumination intensities of the IR-LED allow for differing magnitudes of reflection from the unit-cell. This provides the potential for radiation pattern tapering or amplitude modifications of the gain of the reflectarray. Simulation and measurement results for a single unit-cell are presented here, with the matching between measurement and simulation also allowing for the change in the values of conductivity of the silicon to be extracted.

Introduction: The incorporation of reconfigurability in such an antenna typically focusses on the use of active elements to adjust the reflection phase [1]. PIN diodes, microelectromechanical (MEMS) switches and liquid crystals have been demonstrated in reflectarray antennas to provide variation in the reflection phase of the unit-cells [2, 3]. Similarly, adjustment of the reflection amplitude of each unit-cell is another area in which reconfiguration can be incorporated. This has potential advantages in a full reflectarray configuration, in which the sidelobe levels of the radiation pattern can be adjusted using an amplitude-only reconfiguration mechanism for each cell. Traditional methods of reconfiguration as mentioned above, will not continuously adjust the reflection magnitude, and as a result of this, a novel unit-cell is designed here, making use of silicon as an optically reconfigurable substrate.

The use of optically activated semiconductors such as silicon to provide reconfigurability has been implemented previously. In [4], a silicon switch is used for a beam and frequency reconfigurable antenna. When illuminated with sufficient optical power (above the bandgap energy of the material), electron-hole pairs are generated through photon absorption. This creates a plasma in the material, the conductivity of which is dependent on the optical power used [5]. Despite the potential advantage of continuous reconfiguration without the need for unpredictable bias lines, optical reconfiguration has an inherent disadvantage in that it requires high power illumination sources [6]. Nevertheless, it has been shown that a high power IR-LED, as opposed to a bulky laser source can provide sufficient optical illumination power [7, 8]. The use of an IR-LED light source removes the need for a large and expensive optical source, giving this method of reconfiguration the potential for large-scale applications, as developed in this letter.

Description of the unit cell: The proposed unit-cell for reflection amplitude variation makes use of a high power surface mount IR-LED in close proximity to the silicon surface to act as the reconfiguration mechanism. A plasma layer is generated in the silicon, thus controlling the reflectivity of the unit-cell. A multilayer structure, shown in Fig. 1 is used for the biasing and control lines of the LED, ensuring that these have minimal impact on the performance of the structure. A thin layer of Rogers RT Duroid 5880 with no metallisation is placed above the silicon, to act as a protective layer. In this case, medium resistivity silicon is used. An inkjet-printed metallic grating is placed above the layer of silicon, providing both a reflective surface, whilst allowing the incident radiation of the feed horn to reach the silicon layer. To satisfy the requirement of phase distribution across the reflectarray surface, the size of the slots and the overall area of each grating element can be varied. This grating is printed by a Diamatix Materials Printer (DMP-2831) on a polyethylene terephthalate (PET) substrate using silver ink, as shown in Fig. 2. This allows for rapid prototyping of the grating.

Waveguide characterisation procedure: Waveguide characterisation of unit-cells for reflectarrays is a common technique, both in simulation and in measurement scenarios [9]. The use of the waveguide characterisation setup allows for rapid prototyping of the array, without

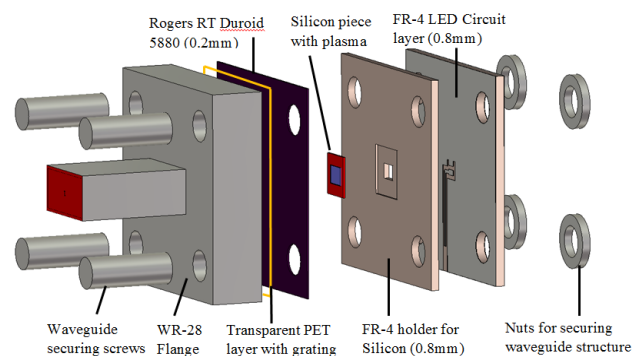


Fig. 1: The simulated multilayer structure of the unit-cell under test, used for both silicon characterisation and unit-cell characterisation.

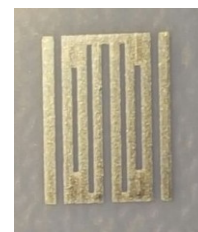


Fig. 2 The top metallic grating layer, printed using silver ink on PET.

the need for costly fabrication of the full structure of the reflectarray. The experimental waveguide setup used in this work is shown in Fig. 3. The characterisation process used here has a two-fold purpose: first, to characterise the response of the silicon substrate under illumination, and secondly to ascertain the reflection properties of the reflectarray unit-cell itself.

When characterising the response of the silicon, the property of interest is that of the conductivity of the plasma layer. For this, the top PET grating layer is not used, removing any potential uncertainty from this layer in terms of its material properties. All other layers of the unit-cell are used, and the reflection response of the structure under different IR-LED illumination powers is measured and recorded. Variation of the illumination power is realised by changing the DC bias voltage and current. To ascertain the conductivity levels, the measured results are compared and matched to an accurate simulation model generated in CST Microwave Studio, with the only variable parameter being the conductivity level of the silicon. The conductivity level that can be achieved is important for the continuing design of the full reflectarray antenna.

For the characterisation of the reflectarray unit-cell itself, the grating is put in place and the illumination power of the IR-LED is varied, in a similar fashion to that used in the silicon characterisation. It is important in this case that the reflection phase remains predictable throughout the variation of illumination power.

Experimental results: The first results presented show the measured and simulated results for the characterisation of the silicon substrate. The results presented in Fig. 4 show the differences between the active and the off-state of the silicon. By fixing all other parameters of the CST simulation model, it is possible to match the simulation and



Fig. 3 Experimental setup for the unit-cell characterisation

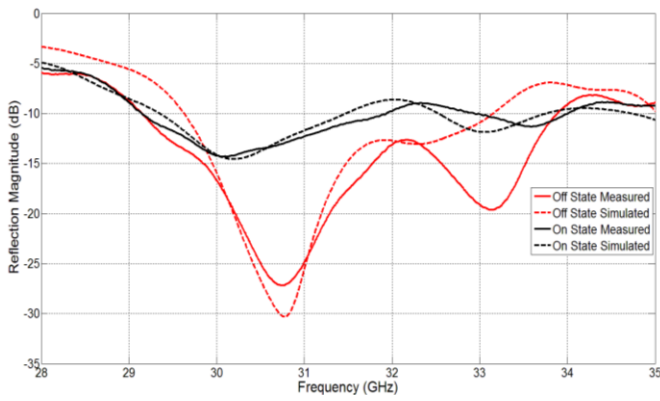


Fig. 4: Simulated and measured results for the silicon in its on and off states, using parametric sweeps to match the conductivity values.

measurement results, using only the conductivity values. The conductivity value extracted for the off-state was 5 S/m, while for the active state it was 80 S/m.

These values are the first reported Ka-band conductivity levels achieved using LED illumination rather than laser sources. The profile of the results presented in Fig. 4 shows that there are a number of resonances in the structure, the causes of which can be determined through parametric analysis of the structure, which is done once the conductivity level is ascertained. The depth of the first resonance at 30.7 GHz is predominately controlled by the size of any air gaps between the FR-4 LED circuit layer and the FR-4 layer directly above it. The frequency at which this resonance occurs is also controlled by the same parameter. The second resonance which occurs at 33.1 GHz in the measured results is fixed in magnitude and is caused by the IR-LED itself, which could not be modelled accurately in the simulations.

Following the characterisation of the silicon itself, the reflectarray unit-cell could be modelled and tested. As mentioned in the previous sections, the unit-cell used in this letter only differs in that the PET printed grating is present. The results presented in Fig. 5 (a) highlight a high level of deviation for the reflection magnitude, across a relatively large bandwidth. More precisely, between on and off states, the

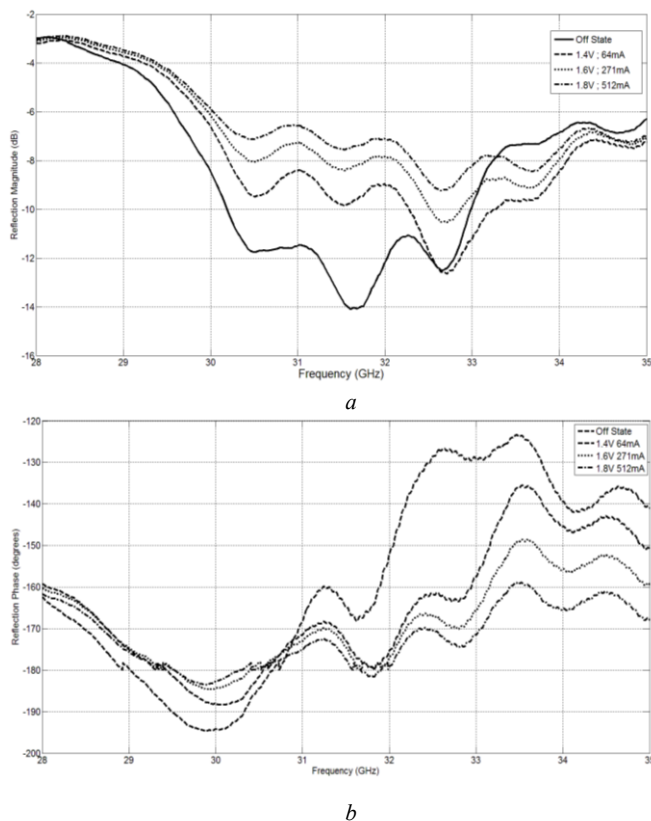


Fig. 5: Measured results for the reflectarray unit-cell
a Reflection magnitude variation with changing LED illumination
b Reflection phase variation with changing LED illumination.

maximum deviation is 7 dB. Furthermore, with each increase in voltage, the reflection magnitude increases by at least 1 dB, with the largest increase occurring between the off-state and 1.4 V. The amount of variation decreases as the power of LED reaches its maximum at 1.8 V and 512 mA.

The phase deviation of this unit-cell is an important aspect which needs to be considered. The reflection phase of this unit-cell should be independent of the illumination intensity of the LED, allowing the phase to be controlled only by the dimensions of the grating on the top layer. Fig. 5 (b) demonstrates that very little phase deviation is present with respect to illumination intensity, particularly at around 31 GHz. Furthermore, away from this frequency, the deviation at a particular frequency is no more than ± 20 degrees. Although this variation is not significant, it will be necessary to adjust the phase distribution accordingly, as these phase alterations will cause phase error which may affect the reflectarray performance negatively.

Conclusion: A novel reconfigurable unit-cell is proposed for sidelobe reduction in reflectarrays, in which the reflection magnitude is controlled by an optically activated semiconductor substrate. Inkjet printing of silver is used for rapid prototyping of the grating layer, allowing quick turnaround in the design process. The chosen silicon substrate is integrated as part of a multilayer structure, along with the inkjet-printed layer. Furthermore, we have used a variation of this unit-cell structure to characterise the conductive properties of silicon under IR-LED illumination. A variation of 14 dB is observed at 30.8 GHz, corresponding to an increase in the conductivity to 80 S/m. Additionally, the full reflectarray unit cell has been measured, and shows good reflection magnitude reconfigurability, meaning this unit-cell design is a good candidate for a reflectarray with variable amplitude unit-cells for sidelobe and pattern modification.

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