Beam steering microwave reflector based on electrically tunable impedance surface

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A periodic resonant texture can transform a conductive sheet into a high-impedance surface. By adjusting the resonance frequency using varactor diodes, the surface impedance and the reflection phase are tuned. The reflection phase can be varied across the surface, to create an electronically tunable phase gradient, which can steer a reflected beam in two dimensions.

Introduction: It has been shown recently that periodic textures can be used to alter the electromagnetic properties of metal surfaces to perform a variety of functions. Some examples are the corrugated structures known as soft and hard surfaces, in which quarter-wavelength corrugations provide high effective surface impedance for one polarisation, but low impedance for the other [1]. These are used in various applications, such as manipulating the radiation patterns of horn antennas, or controlling the edge diffraction of reflectors.

A related structure, comprising a two-dimensional lattice of small resonators, provides high surface impedance for both polarisations [2]. The structure is similar to that shown in Fig. 1 and is typically constructed as a printed circuit board, with a lattice of metal plates on the front side, connected to a solid ground plane on the back by metal plated vias. The surface impedance can be modelled as a resonant *LC* circuit, where the capacitance *C* is provided by the close proximity of the plates, and the inductance *L* is provided by the conductive paths that link them together through the vias and the ground plane.

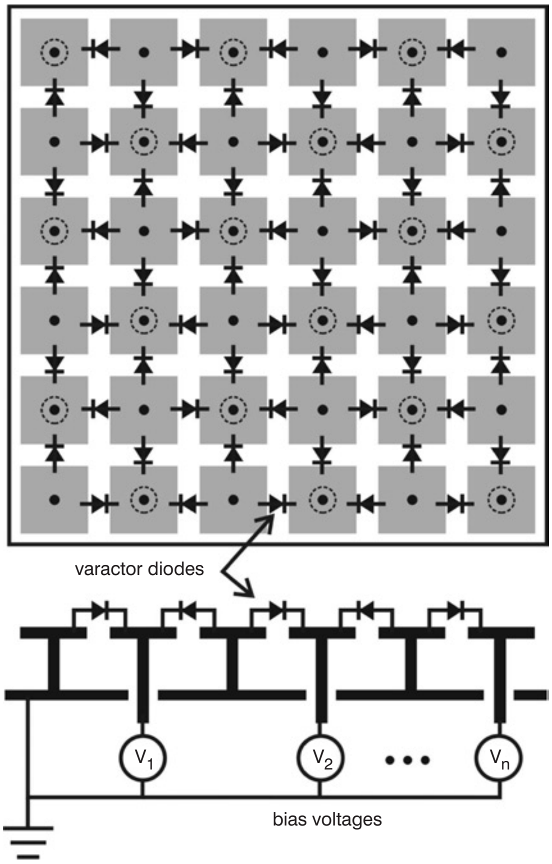

Fig. 1 *Electrically tunable impedance surface*

Built as flat metal sheet covered with raised metal patches. Half of the patches grounded, half connected to bias lines, which drive varactors

For a wave impinging on this textured surface, the reflection phase is a function of the frequency, with respect to the surface resonance frequency $\omega_0 = 1/\sqrt{(LC)}$. The phase varies from π at low frequencies, to $-\pi$ at high frequencies, and passes through 0 at ω_0. The resonance frequency can be tuned with either L or C, thereby tuning the reflection phase for any fixed frequency ω near ω_0. By varying the reflection phase across the surface, we can create a tunable phase gradient, which can steer a reflected beam. This concept has been demonstrated using a mechanically tuned surface, in which the capacitance is adjusted using a layer of tuning plates [3].

In this Letter, we describe an electronically tuned surface, where the capacitance is controlled using varactor diodes. This structure is related to other beam steering devices such as grid arrays [4]. However, the tunable surface presented here provides two-dimensional steering, by addressing internal elements through the vertical vias.

Design: The electrically tuned impedance surface is shown in Fig. 1. It is built as a printed circuit board, with metal plates on the front side, and a solid metal ground plane on the back. Every second plate is connected to the ground plane by a metal plated via, and each alternate plate is connected to a bias line through a hole in the ground plane. The biased and unbiased plates are arranged in a checkerboard pattern, and varactor diodes are connected between each neighbouring pair of plates. The varactors are oriented so that they are reverse-biased when a positive voltage is applied to the bias lines.

Our experimental structure is designed to have a resonance frequency near 4 GHz. The circuit board substrate is 1.6 mm-thick Rogers Duroid 5880, and the square metal plates are 9.2 mm wide, separated by a gap of 0.8 mm. The varactor diodes are Micrometrics MHV500-19-1 devices, which have a useful capacitance range of roughly 0.2 to 0.8 pF. The surface measures 25 cm square, which is about 3.3 wavelengths at the design frequency, and uses 1152 varactors. The period was approximately 1/8 wavelength, so that an effective surface impedance model could be used in the design. It may be possible to use a larger period, with fewer varactors, but the practical upper limit for the plate size has yet to be determined.

Measurements: We began by measuring the reflection phase of the tunable surface against bias voltage and frequency. Fig. 2 shows 11 different reflection phase curves, for bias voltages ranging from 20 to 30 V in 1 V increments. The resonance frequency varies from 3.55 to 4.35 GHz, with higher voltage corresponding to lower capacitance, and higher resonance frequency. Within this range, the reflection phase can be tuned by nearly 2π. By varying the bias voltage across the surface, we can produce a tunable phase gradient, which is equivalent to a virtual rotation of the surface.

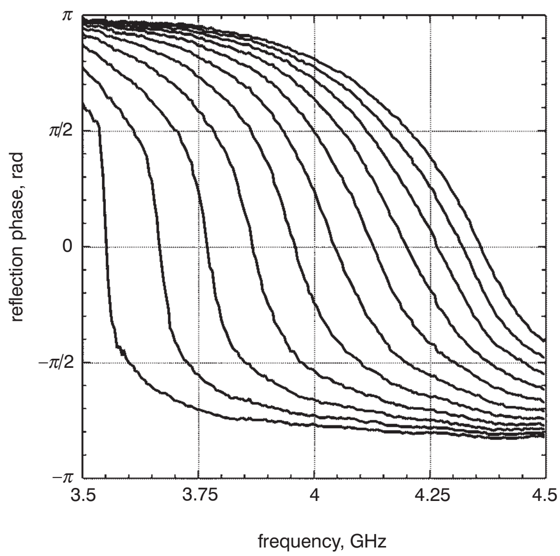

Fig. 2 *Reflection curves*

As uniform bias voltage across varactors is varied from 20 to 30 V, resonance frequency is tuned from 3.55 and 4.35 GHz. For frequencies within this range, reflection phase is varied by nearly 2π

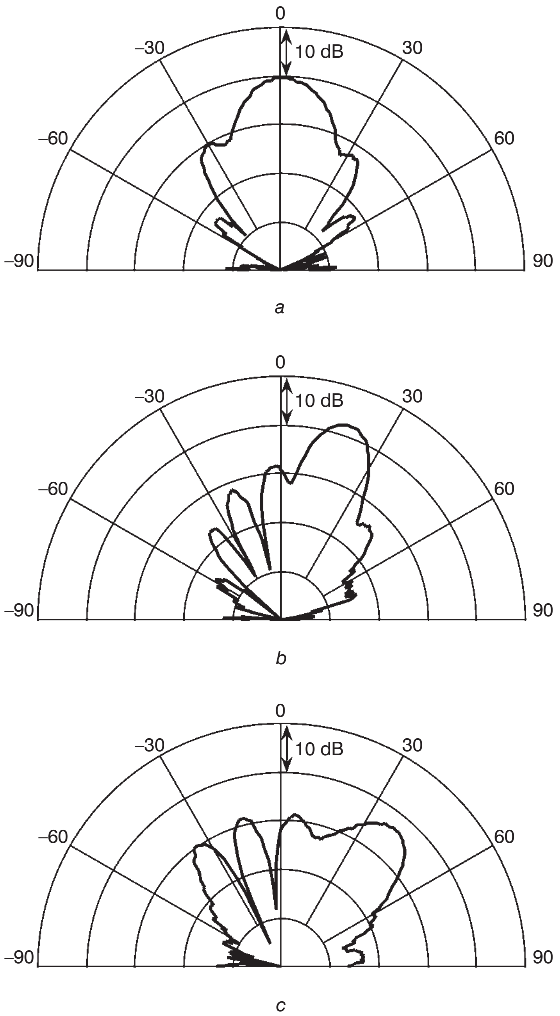

Fig. 3 *Radiation patterns at 4.2 GHz for three different phase gradients, corresponding to 0°, 20°, and 40°*

Antenna can be steered in opposite direction with opposite phase gradients

For the beam steering experiments, the reflection phase was recorded against frequency and bias voltage, to serve as a calibration table. We then selected a frequency steering angle, and applied the corresponding voltages to the bias lines. Steering to large angles required 2π phase discontinuities to produce a sharp phase gradient. The experiment was simplified by addressing the plates in rows, so the reflected beam was only steered in one direction, but two-dimensional steering could be achieved by addressing each plate individually, or by adding a transistor at each bias point, and addressing them by rows and columns.

The surface was mounted above a vertically oriented horn antenna at 45°, so that the reflected radiation was directed into the horizontal plane. The surface and horn were rotated together, and the radiation pattern was measured with a stationary receiving horn. The patterns for three different phase gradients are shown in Fig. 3, corresponding to beam positions of 0°, 20°, and 40°. Steering to the opposite direction is produced with the opposite phase gradients. The frequency of the plots is 4.2 GHz, and the measured bandwidth is about ~5%. The surface produces approximately the expected beamwidth, patterns, and sidelobe characteristics for a 3.3 wavelength reflector. However, the patterns show some dependence on frequency and steering angle, which is likely due to the phase curvature of the horn antenna, and could be removed by adding a compensating curvature to the reflection phase function.

Conclusion: We have described a resonant textured surface with a tunable reflection phase using varactor diodes. With an electronically tunable phase gradient, the surface can steer a reflected beam over +/−40°. This could be a low-cost substitute for conventional phased arrays, because it replaces expensive phase shifters with varactor diodes, and eliminates complicated feed structures by using a free-space feed.

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