Electronic Beam Steering Using a Varactor-Tuned Impedance Surface

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Introduction

Typically, beam steering with reflective apertures is performed using mechanical rotation of the reflecting surface. Limited electronic steering can be accomplished using a focusing reflective surface by changing the feed location or direction of incidence. In this paper we describe a method of electronic beam steering by using a tunable impedance surface. Since there are no moving parts or complicated feed networks, this method of reflective beam steering can have great utility for low-cost and light weight scanning antennas.

Our structure consists of a reflective surface covered by an array of resonant elements, which are tuned using varactor diodes. The resonant elements are created using a series of metal strips printed on a standard microwave substrate, and are intended to represent a one-dimensional high-impedance surface. [1] The strips provide a sheet inductance to the structure, and the varactors provide a tunable sheet capacitance. Thus, the structure can be analyzed as a resonant LC circuit. By varying the reverse bias across the varactor diodes, the sheet capacitance, and hence the resonance frequency of the surface can be varied, resulting in a tunable reflection phase. By programming the reflection phase as a function of position, a phase gradient can be introduced, which can be used to steer a reflected beam. Using commercial off-the-shelf components, we have built a resonant reflector that can be tuned from 2.8 GHz to 5.0 GHz, and can be used to steer a reflected beam over a range of +/-45°.

This tunable impedance surface is similar in concept to work on grid arrays that has been done in the past. [2,3] However, in this work we have made the structure electrically thin, (1/50 wavelength) which provides several important advantages. Since it is electrically thin, it is highly resonant, which means the reflection phase varies rapidly with changes in sheet capacitance. This allows our resonant reflector to achieve a phase turning range of nearly 360°, providing the potential for nearly hemispherical scanning. Furthermore, for low frequency applications, the antenna is not prohibitively bulky. As an added advantage, a full two-dimensional high-impedance surface would allow internal elements to be addressed by vertical vias, providing the potential for two-dimensional beam steering.

Design

The surface design was based on the concept of high-impedance surface, in which a lattice of resonant elements provides a frequency-dependent phase shift. These structures are often modeled using an effective sheet capacitance, and effective sheet
inductance. The structure has a reflection phase of zero at the LC resonance frequency, and by varying the capacitance or inductance, any desired reflection phase can be produced. For additional details on high-impedance surface design, we refer the reader to a prior publication. [1] We designed our structure based on commercially available varactor diodes (Metellics MSV34,000-P55L). The capacitance of these varactors is variable from 0.22 pF to 0.74 pF, and the parasitic capacitance of the package is the 0.13 pF. In order to demonstrate beam steering using a reasonable number of varactors, we designed the surface to be one wavelength square at its lowest operating frequency, which was chosen to be 3 GHz. For a center frequency of 4 GHz, a sheet inductance of 2nH was required, giving a substrate thickness of about 60 mils. For this we chose Duroid 6002 because of its low dielectric constant (2.94). To maintain the validity of the effective surface impedance model, we required that the surface have about 10 periods per wavelength at the highest operating frequency, which was to be about 5 GHz. For the final design we chose 3 mm stripes with a center-to-center spacing of 6 mm. The resulting structure, pictured in figure 1(a), was 9 cm square and contained 196 varactor diodes. The varactors were biased in rows using a series of bias resistors, which can be seen at the top of the structure.

Results

The reflection phase measured normal to the surface is shown in figure 2. As the reverse bias across the entire array is varied from 0 to 32 V, the resonance frequency can be tuned from 2.8 GHz to 5.0 GHz. For any frequency within this range, any desired reflection phase can be obtained by applying the appropriate bias voltage. Furthermore, by programming a voltage gradient across the surface, a phase gradient can be produced, which can be used to steer a reflected microwave beam.

In order to measure the beam steering properties of our small tunable reflector, we mounted it at 45° to a vertical horn antenna, and measure the radiation pattern in the horizontal plane as shown in figure 1(b). This prevented spillover from the horn antenna from interfering with the measurement of the surface reflection properties. Figure 3(a) shows the radiation pattern of the surface with zero bias applied to all varactors. The measured radiation pattern, shown as a red solid line, agrees well with the predicted pattern for a surface of this size, shown as a blue dashed line. When a voltage gradient is applied, the beam is steered to an angle determined by the magnitude of the resulting phase gradient. Measured and predicted radiation patterns for +/-8 V and +/-16 V are shown in figures 3(b)-(e). By tuning the applied bias voltage over +/-16 V, the beam can be steered in an analog fashion over a range of +/-45°.

References


175
Figure 1. (a) Photograph of the varactor-tuned impedance surface. A series of resistors at
the top of the array provide the voltage gradient across the surface. (b) Photograph of the
experimental setup. The surface is illuminated at a 45° angle so that spillover from the
horn antenna does not interfere with the measurement of the small steerable reflector.

Figure 2. Reflection phase of the varactor-tuned surface for various reverse bias voltages.
The resonance frequency of the surface, defined here as the frequency where the
reflection phase crosses through zero, can be tuned from 2.8 GHz to 5.0 GHz by varying
the bias voltage from 0 to 32 volts.
Figure 3. Radiation patterns for various reverse bias voltage gradients across the varactor-tuned impedance surface. Voltage gradients of: (a) 0 volts, (b) -8 volts, (c) +8 volts, (d) -16 volts, and (e) +16 volts are shown. The radiated pattern can be steered in an analog fashion over a range of +/- 45° by tuning the applied voltage gradient. The measured pattern is shown as a solid red line. The theoretical calculated pattern is shown as a dashed blue line. This represents the expected pattern for a surface of the size we measured, with a linear phase gradient.