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A Four Element Phased Patch Antenna Array Using Fluidic Phase Shifter

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Abstract

A phase shifter in microstrip was investigated in which narrow, hollow channels were located under a microstrip line. When the channels were filled with fluids having a dielectric substantially different than that of the microstrip substrate, the change in the wave propagation velocity produced a noticeable phase shift. For this study, water (with a dielectric constant of 78) and air were used to achieve a variable phase shift. The goal of this study was to use water-based fluidic phase shifters to create a four element patch antenna array in microstrip operating at 8 GHz where the beam steering could be controlled by filling a number of water channels per antenna. To achieve this, a series of channels 1 mm wide and 1 mm high, separated by 2 mm, were modeled in the substrate below the transmission line in ANSYS HFSS. These channels were modeled in a 1.52 mm high substrate of Rogers R04003C with a dielectric constant of 3.55. The channels were modeled as being milled from the ground plane side of the microstrip line. The full 4 element array was able to achieve a beam steering angle of up to 18° in either direction from boresight, for a total of 36°.

1 Introduction

Phased antenna arrays are useful for many applications from directed power in communications systems to RADAR systems for military applications. Phased antenna arrays require that the source signal can be phase shifted at each element by some form of phase shifter. Here a passive method of using fluids in microstrip substrate systems was investigated to achieve this phase shift. Prior work on microfluidic microwave circuits has shown tunable resonators using water channels under microstrip lines [1]. In [2] a liquid-metal fluidic arrangement was used in an antenna array feed network. A system was developed in [3] that had a network of tubes under the substrate to change the electrical length of elements in a low pass filter. The results of this paper showed that the water capillaries under the substrate were able to effectively cause a shift in the frequency response of the microstrip filter using only water. The use of microfludic channels with R04003C substrates was also seen for microfludically tunable antennas in [4].

The goal of this study was to use water-based fluidic phase shifters to create a four element patch antenna array in microstrip operating at 8 GHz where the beam steering could be controlled by filling a number of water channels per antenna. To achieve this a series of simulations were setup in ANSYS HFSS (hereafter referred to as HFSS). A phase shifter, patch antenna, patch antenna array, and patch antenna array with the phase shifter were simulated to show how materials with different dielectric constants could be used the achieved a beam steerable antenna array.

2 Creating A Phase Shifter

A phase shifter was modeled in HFSS with 9 channels that were each 1 mm by 1 mm and about 15 mm long. These channels were milled into the bottom of the substrate from the ground plane side of the substrate, the substrate R04003C was 1.52 mm high with the top of the channels 0.52 mm below the top of the substrate. For this simulation, the channels could be filled with either water or air, having dielectric contestants of 78 and 1 respectively. Each channel was located under a 50 Ohm microstrip line. In the substrate a 50 Ohm line was calculated to be 3.45 mm wide. There was 2 mm of space between each channel. The phase shifter was simulated with 9 channels in the middle and two ports on either end. The simulated phase shift was found using the case where each of the 9 channels were air filled as the base line phase shift, and more channels were filled with water to cause a greater phase delay. The phase shift was seen because the phase velocity of a microwave signal in water (or a high dielectric material) is lower than that of air. For this setup, distilled water was used as it has a lower conductivity than tap water and is therefore less lossy. A phase shifter with 9 discrete levels was designed for this investigation so there could be three discrete levels of phase shift between each of the elements in the 4 patch antenna array.

From the simulation results at 8 GHz a phase shift of about 20° was seen per channel, with an insertion loss of between of between -1 dB and -2 dB at the same frequency. This would allow an array setup to have approximately 20° , 40° , or 60° of phase progression between the array elements.

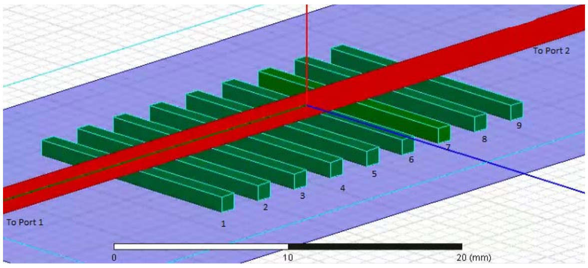


Figure 1. A zoomed image showing the phase shifter channels in green under the red transmission line above the blue ground plane. Each channel is 1 mm by 1 mm and 15 mm long and separated by 2 mm.

3 Combining the Array and Phase Shifter

An antenna array and phase shifter was created as seen in figure 2. The antenna array was simulated in HFSS for the 7 possible increments of phase shift where the antenna array would provide a symmetrical beam steering from a phase progression of up to 3 water channels in one direction, to the opposite direction. The combination where the closest phase shifter channel was 50 mm away from the matching network produced antenna performance for all desired levels of phase shift where the input reflection for any phase shifter and antenna element never went above -10 dB at 8 GHz.

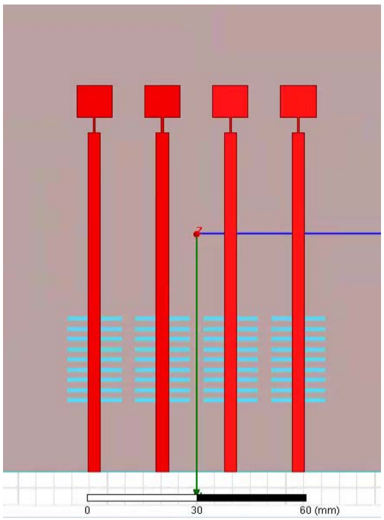
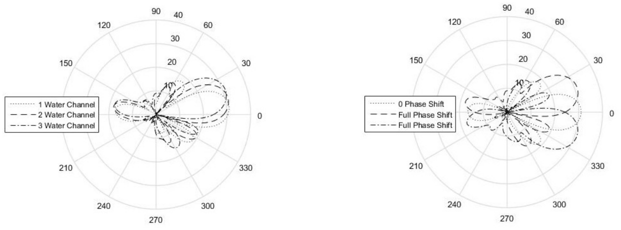


Figure 2. The 4 element array with the phase shifters. The feed lines were this long to make room for the phase shifters and increase array performance.

The radiation beam steering plots are seen in figure 3a and 3b. The zero point for angle is taken directly above the array when all the channels in the array were air filled. As channels were water filled sequentially, the beam would be steered in the direction of the water filling. The HFSS simulation showed that the setup seen in figure 2 was able to steer the output beam from -18° to 18 ° in steps of 6°.



(a) (b)

Figure 3. Both figures show the direction of the emitted E-field above the antenna in dB, for a constant input power. The 0° mark is taken directly above the antenna array along the z-axis. (a) Shows the incremental beam steering of having 1, 2, and 3 water filled channels of phase progression. (b) Shows the maximum beam steering in both directions from the center point. The maximum beam steering of 18° can be seen, as well as the symmetry in the array.

4 Conclusion

The use of channels in the substrate of the microstrip line can successfully be used to achieve a steerable phased antenna array. The higher the dielectric of the fluid, the greater the phase shift seen, but also the greater discontinuity for matching. Using distilled water and air, a 4 element patch antenna array at 8 GHz was able to achieve up to 18° of beam steering in either direction from boresight in a total of 7 discrete steps to the maximum steering using 9 channels in the substrate per antenna array element. The loss in the phase shifter is at a maximum when 1 or 2 channels are water filled. Other than this case, the loss in the phase shifter is less than 2 dB.

References

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