PIN SWITCHED MICROSTRIP SLOT ANTENNA ARRAY FOR 3D MICROWAVE REFLECTION TOMOGRAPHY

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Abstract  The design of microstrip slot antenna array for 3D microwave imaging for the structural assessment of concrete structure is presented in this paper. The array uses microstrip feed network for the ease in the design and PIN diodes as switches to turn on/off antenna elements. Commercially available surface mount PIN diodes are very reliable and possess good isolation up to RF frequencies. Good agreement between simulation and measurement is demonstrated. This array would be later expanded into a larger array.

1. Introduction

The non-destructive evaluation of structural damage such as voids and steel rebars in concrete columns and pavement is critical in civil engineering since most of today’s bridges, dams, and multi-story homes. To fulfill such an important task, the visual inspection to locate and analyze these structural defects on-site is required. In this way, time and money would be significantly saved. Three-dimensional microwave reflection imaging technique that could accomplish such a task is presented here. It is based on the previous work where surface imaging technology using focused microwave for the assessment of bonding condition of Fiber Reinforced Polymer (FRP) jacketed concrete structures was developed [1-2]. The depth and location information of the structural defects between FRP jacket and the concrete were successfully identified for various shapes and sizes of defects. The images were reconstructed from the numerical measurements in two-dimension.

In this paper, the development of the slot antenna array for the three-dimensional microwave reflection tomography based on the previous work is studied. This preliminary array design consists of 4 by 4 microstrip slot antenna elements and uses PIN diodes that replace the mechanical switches used before. These diodes are surface-mounted directly onto the substrate for compactness and portability of the whole microwave image system. This array is to be developed into a larger array for enhanced imaging reconstruction.

2. Microstrip Slot Antenna

Compared to the microstrip-fed microstrip antenna, a microstrip-fed slot antenna offers a better isolation between the feed and the material under measurement [3]. They are more flexible in integration with other active and passive devices in a hybrid MIC and MMIC design. Furthermore, they are capable of producing omni-directional radiation patterns by simply inserting quarter-wave thick foam and reflector. The microstrip-fed slot antenna with its dimension in millimeter is shown in Fig. 1. The dielectric used here is Duroid 5880 ($\varepsilon_r = 2.2$, tan $\delta = 0.0009$) and its thickness is 15 mil. It is coated with 0.5 oz copper on both sides. Rohacell Rigid Foam, whose dielectric constant resembles that of air, by Richmond Aircraft is inserted between the top and bottom dielectrics.

![Fig. 1 Microstrip slot antenna structure](image_url)
microstrip feed is chosen to be 50-ohm for the ease in the designing the rest of the feed network of the array. Center feeding is chosen rather than off-center feeding to efficiently use the limited space in array. Ansoft HFSS 8.0 is used for designing and optimizing the antenna dimension.

The measurement and simulation results reveal very good consistency in return loss and resonant frequency. Simulation shows the return loss of –20 dB at 4.9 GHz whereas measurement has –21 dB return loss with the resonant frequency at 5.2 GHz as shown in Fig. 2.

![Fig. 2 Simulated and measured return loss of microstrip slot antenna](image)

**Fig. 2** Simulated and measured return loss of microstrip slot antenna

3. **Antenna Array**

Microsemi’s MPP-4203 surface mount PIN switch diodes are used as internal switching elements. These diodes are 0402 types and therefore are very small, typically less than one millimeter in both lateral and vertical dimensions. Each package contains single PIN diode and specially treated with photolithographic technique for smaller parasitic capacitance.

The diode was measured by mounting it on the same substrate used for building the array for more accurate characterization of a diode. The diode showed very low insertion loss, less than 0.5 dB, and good isolation up to 6 GHz.

The fabricated microstrip slot antenna array is shown in Fig. 3. The lateral dimension of this prototype array is 65 mm and the height is 55 mm. Fig. 3(a) shows the feed network of the array including the bias lines. The squares around the periphery of the array are the pads for the bias wires.

![Fig. 3 Fabricated slot antenna array](image)

**Fig. 3** Fabricated slot antenna array

At every T-junction of the microstrip feed, PIN diodes are surface-mounted to turn on/off antenna elements. The total number of four PIN diodes is needed to turn on one slot antenna element to radiate. The ground for these diodes is created by drilling 0.5 mm-diameter holes through the dielectric as shown in Fig. 3.

The surface containing the slots, which acts as ground plane, is in physical contact with the concrete block ($\varepsilon_r = 5.3$) for the measurement. DC voltage of 3.6 V and 20 mA DC current were applied to the diodes. Across each diode, roughly 0.9 V was applied. This bias would turn on four diodes
at the same time, establishing low impedance path from the antenna to the input port.

To investigate the effect of loading PIN diodes, a preliminary antenna array that contains only four diodes and the final array with thirty diodes are built. The preliminary array turns on only one antenna element with the rest open circuited, ignoring the off-state diode parasitic components. The final array, however, contains diodes at every T-junction so that those parasitic components of diode are included. The results are shown in Fig. 4, where it is clearly shown that the addition of more PIN diodes degrades the overall impedance matching of the array due to those parasitic components of diodes at off state.

The preliminary array has the resonant frequency at 4.94 GHz with the return loss of –36 dB and the 11% bandwidth whereas the final version’s resonant frequency is 5.0 GHz, return loss is –14.9 dB and the bandwidth is only 8.56% when all the diodes turn on.

![Fig. 4 Measured return loss of preliminary and final antenna array](image)

Fig. 4 shows more measurements of each antenna element. Due to the numerous elements, two plots are provided for better visibility of each return loss plot. As each antenna turns on, different behavior is observed in terms of resonant frequency, return loss and bandwidth as summarized in Table 1, where resonant frequency is defined to be the frequency of the lowest return loss.

![Fig. 5 More measurements of antenna elements](image)

Fig. 5 is the comparison between the simulation and the measurement of the final array. The geometry identical to the fabricated final array was used for the simulation. The diodes were, however, replaced with gap for off diode and perfect conductor for on diode to neglect the effect of the parasitic components of diode when it is off or on. Good consistency exists between simulation and measurement. Momentum result indicates the resonant frequency at 5.2 GHz with the return loss of roughly -18 dB and the bandwidth of 5%.

<table>
<thead>
<tr>
<th>Antenna Element</th>
<th>Resonant Frequency (GHz)</th>
<th>Return Loss (dB)</th>
<th>-10 dB BW (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>5.54</td>
<td>-16.8</td>
<td>8.6</td>
</tr>
<tr>
<td>2</td>
<td>5.33 &amp; 5.76</td>
<td>-12.3 &amp; -12.1</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>5.02</td>
<td>-14.9</td>
<td>8.5</td>
</tr>
<tr>
<td>4</td>
<td>5.52</td>
<td>-12.2</td>
<td>10.7</td>
</tr>
<tr>
<td>5</td>
<td>5.54</td>
<td>-12.2</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>4.81</td>
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<td>7</td>
<td>5.33</td>
<td>-15.3</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>4.95 &amp; 5.54</td>
<td>-14.4 &amp; -13.9</td>
<td>7.2 &amp; 6.4</td>
</tr>
<tr>
<td>9</td>
<td>5.33 &amp; 5.76</td>
<td>-19.7 &amp; -15.6</td>
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<tr>
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<td>-13.4</td>
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<tr>
<td>12</td>
<td>4.81</td>
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<td>6.4</td>
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<tr>
<td>13</td>
<td>5.47</td>
<td>-12.3</td>
<td>10.9</td>
</tr>
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</table>

Table 1. Summary of final array measurements
Simulations were conducted using numerical measurements to verify the resolution of the image reconstruction system. Two point-like objects are placed with the distance of 22.0 mm along each axis at the center of the reconstructing volume. As shown in Fig 7, the results demonstrate that the algorithm is capable of achieving a resolution adequate for image reconstruction of the object.

5. Conclusion

The design of 4×4 microstrip-fed slot antenna array has been presented in this paper along with its applicability in microwave image reconstruction of concrete structure defects. The measurement results show that the each microstrip slot antenna element in the array produces return loss good enough to be implemented in the microwave imaging. Also, the simulation of two point-like objects reveals that the three-dimensional image reconstruction possesses high resolution that could distinguish two closely spaced objects in the concrete structure. This successfully designed and tested array is the prototype of a larger array to be developed soon.

Acknowledgements

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References


