Bandwidth Enhancement of Microstrip Line Slot Array Antenna

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Abstract—In this paper, we propose a wideband microstrip line slot array antenna. A microstrip line slot array antenna is constituted by a slot fed in series using the microstrip line. This antenna has features that the feeding loss is small and it is easy to configure the array antenna of the multi-element. However, the bandwidth is narrow compared with a conventional parallel fed array antenna. To overcome this disadvantage, we propose the method of appropriate placement of the slot operating at different frequencies as the method of enhancement bandwidth of slot array antenna.

Keywords—Microstrip line slot array antenna; microstrip structure; bandwidth enhancement; base station

References:


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1. Introduction

- Currently, dipole array antennas or patch array antennas fed by parallel feeding circuit are used for the base station antenna[1].
- These antennas can be designed radiation elements and feeding circuits separately and have wide band characteristic.
- However, the feeding circuit becomes complicated depending on the number of elements of array antenna, so the overall size of the antenna becomes large and the gain of the antenna becomes low by the loss of feeding circuit.
- Therefore, it is difficult to apply the parallel feed array antenna to the base station antenna that high gain antenna is needed.
- To realize a higher gain antenna, we focus on the microstrip line slot array antenna(MSAA) which is arranged a slot along both edges of the microstrip line.
- This antenna is chosen due to the feature that it can be designed using a simple feeding circuit independent on the number of elements due to series feed.
- However, the slot array antenna has narrow bandwidth characteristic.

We propose the method of appropriate placement of slots to realize the bandwidth enhancement of MSAA.

- The microstrip line with its width $W$ and its thickness $t$ is located in the bottom of dielectric substrate with its height $h$ and having a relative dielectric constant $\varepsilon_r$.
- Slots with its length $a$ and its width $b$ is located on the ground plane.
- Each slot is located at a distance $l_n$ and the length $L$ is the distance between $N$-th slot and open end of microstrip line.

In the design of this antenna, the two important parameters are the resistance value of each slot $r_n$ and an offset position relative to the resistance value $d_n$. 

\[
\begin{align*}
\mathbf{I} & \quad \mathbf{J}_{n-1} \quad \mathbf{J}_n \\
\mathbf{V}_1 & \quad \mathbf{V}_{n-1} \quad \mathbf{V}_n \\
\mathbf{L} & \quad \mathbf{d}_n \quad \mathbf{a}
\end{align*}
\]

For the equivalent circuit of this antenna, the resistance value of each slot $r_n$ is obtained by following equations,

$$
K = \prod_{i=n+1}^{N} \left| \left\{ 1 + (1 - \Gamma_i) \frac{r_i}{2} \right\} e^{\gamma l_{i-1}} \right|^2 \quad (n = 1, 2, \ldots, N-1)
$$

$$
\Gamma_N = e^{-2\gamma L}
$$

$$
\Gamma_{n-1} = \frac{\frac{r_n}{2} + \left(1 - \frac{r_n}{2}\right) \Gamma_n}{1 + \frac{r_n}{2} - \left(\frac{r_n}{2}\right) \Gamma_n} e^{-2\gamma l_{n-1}}
$$

$$
r_n = A_n r_N \frac{|1 - \Gamma_N|^2 1}{|1 - \Gamma_n|^2 K}
$$

\[\begin{align*}
\gamma &= \alpha + j\beta \\
l_n &= \lambda_g, L = \lambda_g / 4 \\
\lambda_g &\text{ is equivalent wavelength } A_n \text{ is amplitude distribution}
\end{align*}\]

1. Substitute the initial value $r_N$ in the above equation
2. Calculate the resistance value of each slot $r_n$ and reflection coefficient $\Gamma_0$
3. Change the value of $r_N$ until $\Gamma_0$ is under a certain value and obtain $r_n$

The offset position relative to the resistance value $d_n$ is obtained by following equations,

$$R_d = 4 \left( \int_{-1/2}^{1/2} \left\{ \frac{1}{2\pi} \int_{-\infty}^\infty \frac{g(\zeta) e^{-j\zeta x}}{e^{j\zeta h}} d\zeta \right\} \cos \frac{\pi}{a} (x + d) dx \right)^2$$

$$g(\zeta) = \frac{\sin \left( \frac{\zeta w}{2} \right)}{\zeta w / 2} - \frac{1}{2} \sin^2 \left( \frac{\zeta w}{4} \right)$$

Obtain the offset position that satisfies the resistance values obtained from the above calculation from the following graph:

<table>
<thead>
<tr>
<th>Resistance value of each slot $r_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset position relative to the resistance value $d_n$</td>
</tr>
<tr>
<td>$/Z_0$</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Uniform</td>
</tr>
<tr>
<td>Taylor</td>
</tr>
<tr>
<td>$/a$</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Uniform</td>
</tr>
<tr>
<td>Taylor</td>
</tr>
</tbody>
</table>

- Design 2×8 elements MSAA
  - The −10 dB bandwidth of these antenna are 4.56 ~ 4.72 GHz
  - The gain of these antenna are 17.2 dBi at 4.65 GHz.
  - 1st sidelobe level using Taylor distribution is lower than one using uniform one

- Uniform distribution

- Taylor distribution

(a=27.0, b=3.2, l_n=48.0 L=10.9, ground: 408×100 [mm])
3. Bandwidth Enhancement of MSAA

Investigate the placement of slots to realize the wideband characteristic

- Use the slot operating at different frequencies as the method of enhancement bandwidth (Pattern 1).
  - Slots operating at one frequency are arranged along one side edges of the line
  - Slots operating at another one are arranged along the other side edges of the line
  - The $-10$ dB bandwidth of this antenna is $4.32 \sim 4.94$ GHz
  - The gain at $4.55$, $4.65$, and $4.75$ GHz are $15.1$, $15.5$, and $16.0$ dBi, respectively

- To improve the radiation pattern at yz-plane, we propose another placement of the slots (Pattern 2).
  - Slots operating at different frequencies are arranged alternately along both edges of the microstrip line.
  - As compared with Pattern 1, the $-10$ dB bandwidth of this antenna has same range and the gain is same level.
3. Bandwidth Enhancement of MSAA

Pattern 1

\( (A1: a=26.2, b=3.2, l_n=47.9 \ L=11.1 \text{ [mm]}), \ (A2: a=25.0, b=3.2, l_n=45.9 \ L=10.6 \text{ [mm]})) \)

<table>
<thead>
<tr>
<th>( l/Z_0 )</th>
<th>( r_1 )</th>
<th>( r_2 )</th>
<th>( r_3 )</th>
<th>( r_4 )</th>
<th>( r_5 )</th>
<th>( r_6 )</th>
<th>( r_7 )</th>
<th>( r_8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.99</td>
<td>1.52</td>
<td>2.62</td>
<td>3.56</td>
<td>3.79</td>
<td>3.16</td>
<td>2.07</td>
<td>1.50</td>
</tr>
<tr>
<td>A2</td>
<td>1.01</td>
<td>1.55</td>
<td>2.66</td>
<td>3.60</td>
<td>3.82</td>
<td>3.18</td>
<td>2.08</td>
<td>1.51</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( l/a )</th>
<th>( d_1 )</th>
<th>( d_2 )</th>
<th>( d_3 )</th>
<th>( d_4 )</th>
<th>( d_5 )</th>
<th>( d_6 )</th>
<th>( d_7 )</th>
<th>( d_8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.695</td>
<td>0.656</td>
<td>0.613</td>
<td>0.593</td>
<td>0.589</td>
<td>0.6</td>
<td>0.63</td>
<td>0.656</td>
</tr>
<tr>
<td>A2</td>
<td>0.705</td>
<td>0.664</td>
<td>0.62</td>
<td>0.6</td>
<td>0.596</td>
<td>0.608</td>
<td>0.639</td>
<td>0.667</td>
</tr>
</tbody>
</table>

\( S_{11} \) [dB]

-30
-20
-10
0

Frequency [GHz]

4.0
4.2
4.4
4.6
4.8
5.0
3. Bandwidth Enhancement of MSAA

Realize bandwidth enhancement of MSAA using the slot operating at different frequencies that are arranged alternately along both edges of the microstrip line.
4. Conclusion

- This paper proposed the method of bandwidth enhancement of MSAA.
- The proposed method is that slots operating at different frequencies are arranged alternately along both edges of the microstrip line.
- The antenna designed using proposed method has wideband characteristic and good radiation pattern.