A Compact Microstrip Patch Antenna Having a 2-Dimentional Grounded-Pad Array Embedded in an LTCC Substrate

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1. Introduction

Microstrip patch antennas have been widely used in mobile and satellite communication systems due to their great advantages of low cost, low profile, lightweight, and easy fabrication. However, the dimensions of a classical patch antenna are on the order of half a wavelength. To reduce dimensions of the antenna, various techniques have been proposed. The use of high permittivity material is the orthodox way. Cutting slits [1] or fabricating a slow-wave structure [2, 3] in the patch is effective. The use of shorting pins or resistive posts is also well known [4]. With these techniques, antenna size can be reduced up to 50%.

This paper proposes a new approach to reduce the size of the patch antenna by embedding a 2-dimentional grounded-pad array in an antenna substrate. Periodically installed grounded-pads are expected to exhibit slow-wave effects. First of all, a microstrip delay line having a 1-dimentional grounded-pad array in its substrate is demonstrated theoretically by the conventional FDTD method, and the slow-wave effect is discussed in section 2. Next, a 2-dimentional grounded-pad array is applied to a microstrip patch antenna to reduce the size of the antenna, and experimental results are shown in section 3 together with the theoretical ones. In the experiment using a prototype model, an LTCC substrate, which is suitable for the multi-layer structure, was adopted.

2. Microstrip delay line having a 1-dimentional grounded-pad array

The basic behavior of a single grounded-pad embedded in a microstrip line substrate has been studied and shown to work as a narrow band elimination filter [5]. In this section, the slow-wave effect of a microstrip delay line having a 1-dimensional grounded-pad array embedded in a microstrip line substrate is discussed. Fig.1 shows the geometry of the delay line. The 50Ω microstrip line with a width of $w = 0.6mm$ is fabricated on a substrate whose relative permittivity of $\varepsilon_r = 7.5$ and thickness of $h = 0.5\,mm$. Five rectangular pads with an edge length of $w_p = 1.6\,mm$ and a height from the ground plane h_p are embedded in a substrate just beneath the microstrip line at the period of $T = 2.1\,mm$. All of the pads are center-connected to the ground plane by a thin metal wire. For the theoretical analysis, this line is modeled on a Yee's mesh constructed by $40 \times 60 \times 200$ uniform cells, and each cell size is assumed to be $0.0625\,mm \times 0.1\,mm \times 0.1\,mm$. All conductors and metallizations are treated as perfect

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conductors with zero thickness. For the absorbing boundary, Mur's 2nd order absorbing boundary condition is adopted.

Fig.2 shows the frequency characteristics of a transmission coefficient $|S_{21}|$ and a reflection coefficient $|S_{11}|$ for the pads' height h_p as a parameter. It is apparent from this figure that the deep and sharpened stopband characteristic with an insertion loss of more than $30\,dB$ is obtained for all models. On the other hand, the $|S_{21}|$ shows a low insertion loss and small ripples in the pass band from DC to $6\,GHz$. To evaluate the slow-wave effect in the pass band, the characteristics of the phase delay are presented in Fig.3. All phase delays are calculated at the output port on the basis of the phase characteristics of the normal microstrip line without any grounded-pads in the substrate. From the graph, the phase delay and the insertion loss observed at $6.0GHz$ are 18.0° and $0.04\,dB$ for $h_p = 0.125\,mm$, 56.3° and $0.30\,dB$ for $h_p = 0.250\,mm$, 168° and $0.12\,dB$ for $h_p = 0.375\,mm$, respectively. These results indicate that the periodically installed grounded-pads work as an effective delay line.

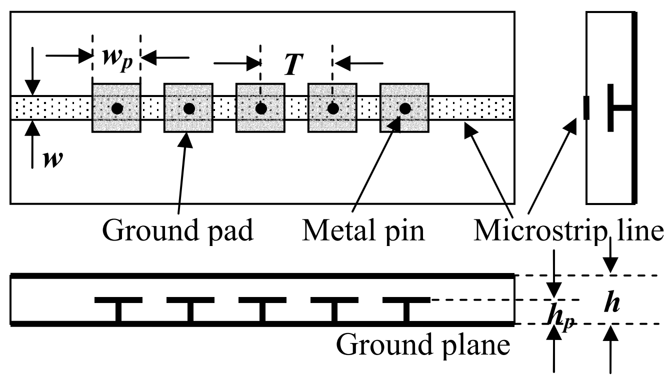

Fig.1 Geometry of a microstrip delay line having a 1-dimentional grounded-pad array in the substrate. The number of pads is five.

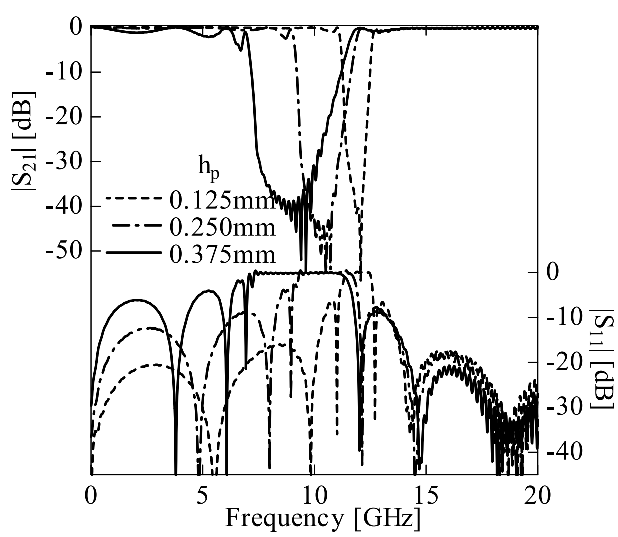

Fig.2 Frequency characteristics of the scattering coefficient of the microstrip delay line.

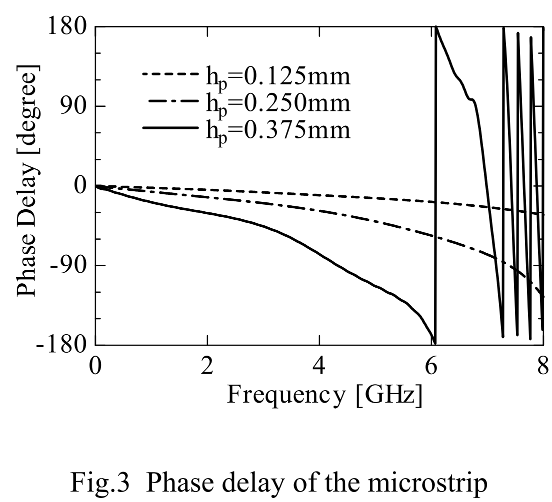

Fig.3 Phase delay of the microstrip delay line. Phase is evaluated at the output of the line.

3. Microstrip patch antenna having a 2-dimentional grounded-pad array

Fig.4 shows the geometry of a rectangular microstrip patch antenna having a 2-dimensional grounded-pad array in an antenna substrate. The microstrip patch antenna with an edge length of $L = 10.0\,mm$ is fabricated on a substrate whose relative permittivity of $\varepsilon_r = 7.5$ and thickness of $h = 0.5\,mm$. The feed line is directly connected to the patch by a 50Ω microstrip line with a width of $w = 0.6\,mm$. For the impedance matching, slits with a length of S_L and a width of $S_w = 0.6\,mm$ are fabricated at the feeding point. The grounded-pad array composed of 25 rectangular pads with $w_p = 1.6\,mm$ each, is embedded in its substrate just beneath the patch at the period of $T = 2.1\,mm$. All of the pads are center-connected to the ground plane by a thin metal wire. In addition to two grounded-pad array models with the pads' height of $h_p = 0.250\,mm$ or $h_p = 0.375\,mm$, a normal microstrip patch antenna without any pads is also calculated for the comparison. Fig.5 shows the calculated return loss characteristics of these models. Slit length S_L is optimized for each model. From the graph, the lowest resonant frequency of the normal microstrip patch antenna can be seen at $5.4459\,GHz$. By embedding the grounded-pad array, this resonant frequency shifts lower to $3.9684\,GHz$ for $h_p = 0.250\,mm$ and $2.8695\,GHz$ for $h_p = 0.375\,mm$, which results correspond to $72.9\,\%$ and $52.7\,\%$ size reduction, respectively.

Finally, experiments have been carried out to confirm the theoretical predictions. Two prototype models, the normal antenna without any pads and the grounded-pad array antenna with $h_p = 0.375\,mm$, were fabricated on an LTCC substrate, and the return loss characteristics were measured by the vector network analyzer HP8719C. Results are presented in Fig.6. Though some ripples were included, the resonant frequency of each antenna was coincident with the theoretical predictions.

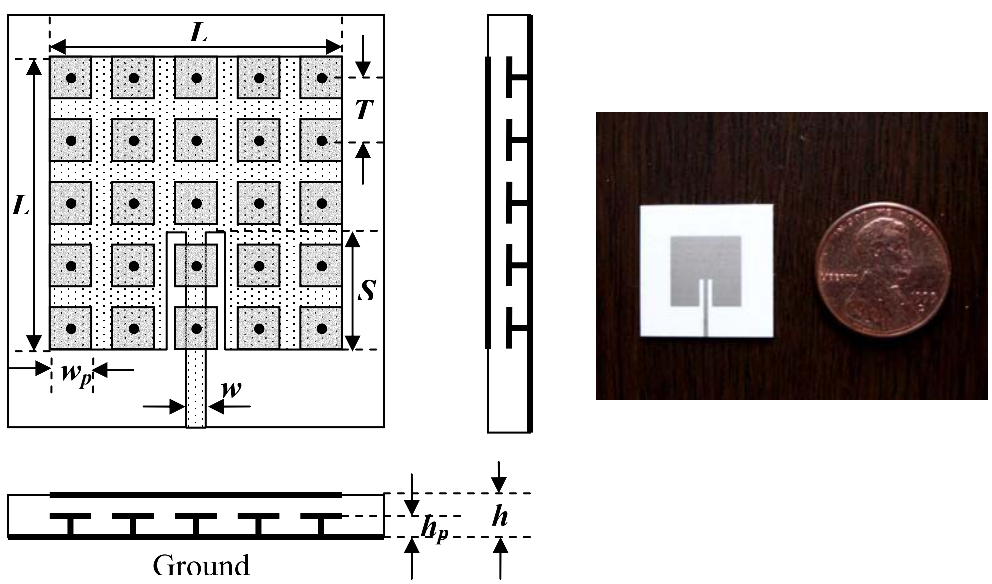

Fig.4 Geometry of a rectangular microstrip patch antenna having a 2-dimensional grounded-pad array in an LTCC antenna substrate. A picture of the prototype model is shown on the right.

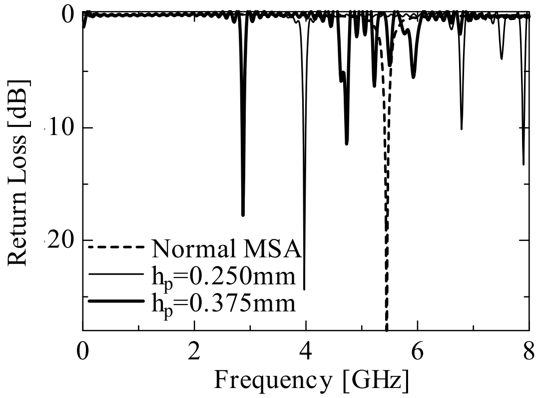

Fig.5 Theoretical return loss characteristics of the microstrip patch antennas.

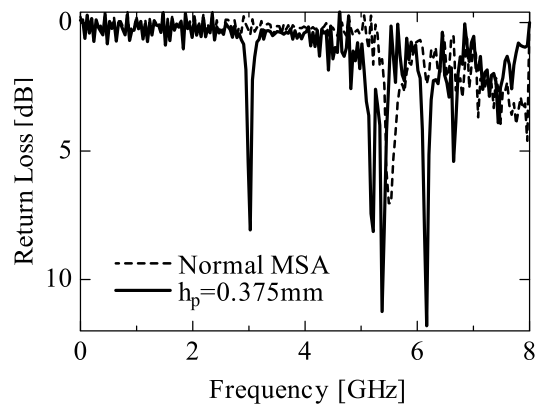

Fig.6 Experimental return loss characteristics of the microstrip patch antennas.

4. Conclusion

A novel approach to reduce the size of patch antennas was proposed by embedding a 2-dimentional grounded-pad array in an antenna substrate. From the demonstration, the lowest resonant frequency shifted from 5.4459 GHz to 2.8695 GHz , a result that corresponds to 52.7 % reduction of the antenna size. To confirm the theoretical predictions, some experiments have been carried out using prototype LTCC antennas, and the behavior of the dominant frequency was coincident with the theoretical predictions.

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Reference

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