LETTER

Novel Periodic Structures for a Slotline : Patch Loaded Slotline

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SUMMARY In this Letter, a dumbbell-shaped patch loaded slotline(PLS) is proposed. Like the conventional defected ground structure(DGS) for a microstrip line, we show that the proposed PLS can provide a wide bandstop characteristic in some frequency bands with only one or small number of unit cells. Also, the equivalent circuit model for a unit section is derived from the analysis of the field distributions in the structure and its circuit parameters are determined by means of full wave numerical simulations. This equivalent circuit is shown to be dual to that of the typical DGS in a microstrip line. A broadband microstrip to slotline transition is incorporated in the PLS in order to measure the characteristics of the structure. The experimental results agree well with the simulations and show the validity of the modeling for the proposed PLS.

key words: *patch loaded slotline(PLS), defected ground structure(DGS), periodic structure*

1. Introduction

For many years, periodic bandgap(PBG) structures for planar transmission lines have been popular due to their extensions to many applications in antennas and microwave circuits [1]–[3]. However, a general PBG structure has so many design parameters affecting the bandgap properties that there have been a lot of limitations in using this structure for microwave devices. Among various researches to improve its utilities, a defected ground structure(DGS) in a microstrip line has been proposed recently [4]. This proposed DGS can be easily designed since its equivalent circuit is very simple and the circuit parameters can be readily derived [5]. Besides, it is able to provide a wide bandstop characteristic in some frequency bands with only one or small number of unit cells. Using these features, the DGS has been applied to designing passive circuits in microstrip lines and coplanar waveguides(CPW) such as a compact low-pass filter with a good rejection band characteristic [5], [6], and enhancing the performance of active circuits, for example, improving the efficiency of a power amplifier [7], and so on.

Most of these periodic structures were proposed for the applications to a microstrip line or a CPW. Although the periodic structure for a slotline, which has periodic defects in a signal and a ground plane, has been proposed recently [8], there are little articles and applications on the slotlines loaded by periodic structures in the open literature. In this Letter, we propose a patch loaded slotline(PLS) as a novel periodic structure for a slotline. The equivalent circuit model is easily conceived from its structure, and the circuit parameters can be determined by using the numerical simulations.

Also, in order to verify the numerical results by measurements, a broadband microstrip to slotline transition is incorporated in the PLS since it is difficult to probe a slotline directly. The bandwidth of this transition is shown to be wide enough to cover the stopband due to a patch loaded in the slotline. Using this transition, the frequency characteristics are investigated for the slotlines loaded by various sized patches and several periodic sections.

2. Structure and Modelling

As shown in Fig. 1, the PLS is composed of a standard slotline on one side of a dielectric substrate and a loaded patch on the opposite side of the substrate. The patch loaded in the slotline has a dumbbell shape like a slot in the typical DGS [4].

The slotline and the narrow microstrip line, which connects two square patches, cross each other at right angles, and thus, the coupling between them will be tight [9]. The magnetic fields along the longitudinal section in the slotline excite large currents in the narrow microstrip line at some frequency as shown in Figs. 2(a) and (b). Since this narrow microstrip line is attached to two wide square patches connecting the signal and the ground in the slotline by parallel plate capacitance, respectively, as in Fig. 2(c), the equivalent circuit for the PLS can be represented as shown in Fig. 2(d).

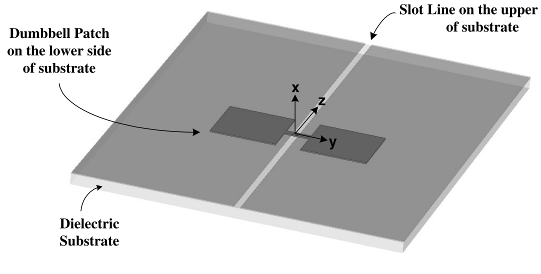

Fig. 1 Three dimensional view of the unit section of a dumbbell patch loaded slotline (PLS).

Manuscript received March 29, 2004.
Manuscript revised June 18, 2004.

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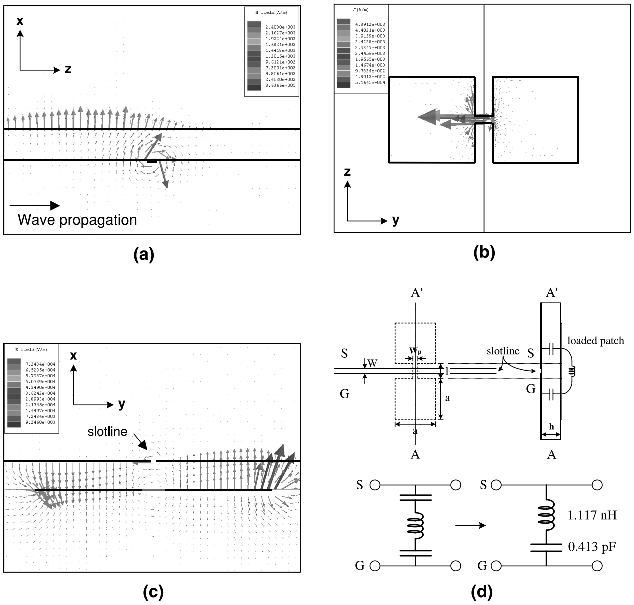


Fig. 2 Field distributions obtained from full wave simulation and extracted equivalent circuit parameters of the proposed PLS unit section which has $a = 2.4$ mm, $w_p = 0.2$ mm, $l = 0.5$ mm, and $w = 0.038$ mm. The substrate with a thickness of 25 mil and a dielectric constant ϵ_r of 10.2 was used in the simulation. (a) Magnetic field distribution along the longitudinal section of the slotline. (b) Surface current density on the loaded patch. (c) Electric field distribution in the cross-section of the slotline. (d) Equivalent circuit and its circuit parameters.

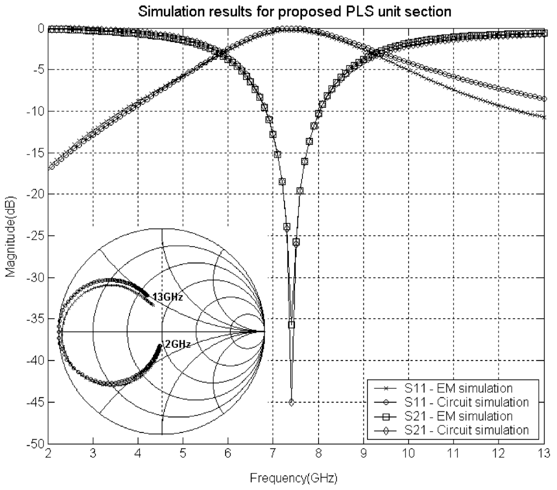


Fig. 3 Simulation results for the proposed PLS unit section. The result of EM simulation is compared with that of circuit simulation using the extracted equivalent circuit parameters.

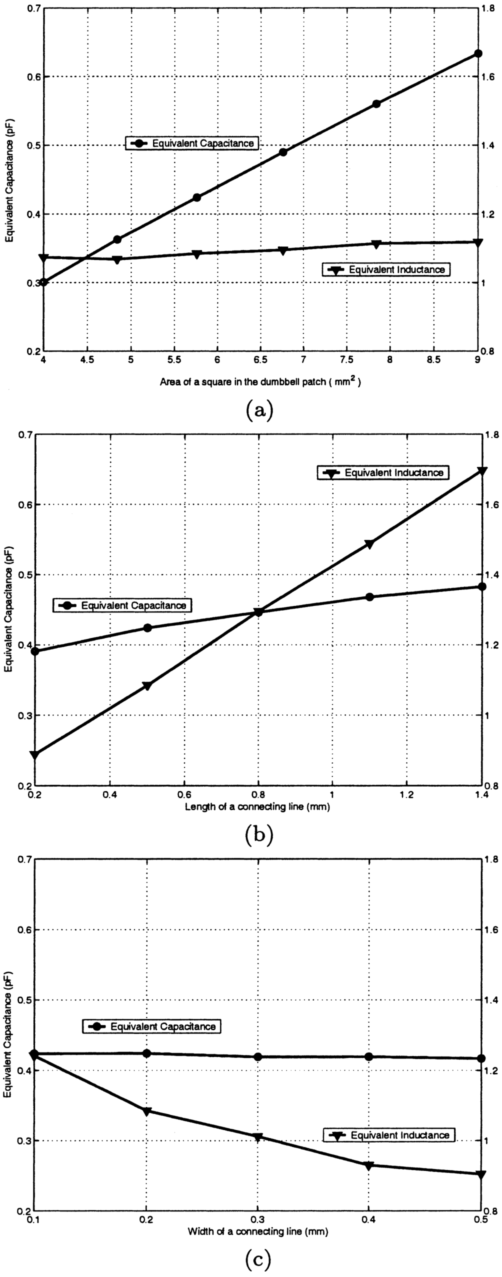


Fig. 4 The relationship between the physical size of the structure and the values of the equivalent circuit parameters. (a) Equivalent circuit parameters versus the area of a square in the dumbbell patch ($w_p = 0.2$ mm, $l = 0.5$ mm). (b) Equivalent circuit parameters versus the length of a narrow connecting line ($a = 2.4$ mm, $w_p = 0.2$ mm). (c) Equivalent circuit parameters versus the width of a narrow connecting line ($a = 2.4$ mm, $l = 0.5$ mm).

In this equivalent circuit, the series L-C connection between a signal and a ground in the slotline can be considered as dual to the case of a typical DGS in a microstip line since the equivalent circuit for a DGS is composed of parallel L and C components which are series-connected to a microstrip line [5]. Hence, the values of circuit parameters can be extracted by the almost same procedure as proposed in [5]. In order to verify the validity of this equivalent circuit, the results between the equivalent circuit analysis and the full wave numerical simulation are compared and demonstrated in Fig. 3. Using a RT Duroid 6010LM substrate with $\epsilon_r = 10.2$ and $h = 25$ mil, a slotline of $w = 0.038$ mm, which corresponds to 50 Ω at the center frequency of about 7.4 GHz [10], is selected, and each dimension of a dumbbell patch used in the simulation is designed at this frequency. As shown in Fig. 3, the result obtained from the equivalent circuit analysis has a good agreement with that from the numerical simulation although the characteristic impedance of a slotline is considerably dependent upon the operation frequency. Also, it is evident that the proposed circuit model represents the actual physical behaviors of the structure since the reflection coefficients follow a nearly constant admittance circle and pass near the short point at the resonant frequency on the Smith chart.

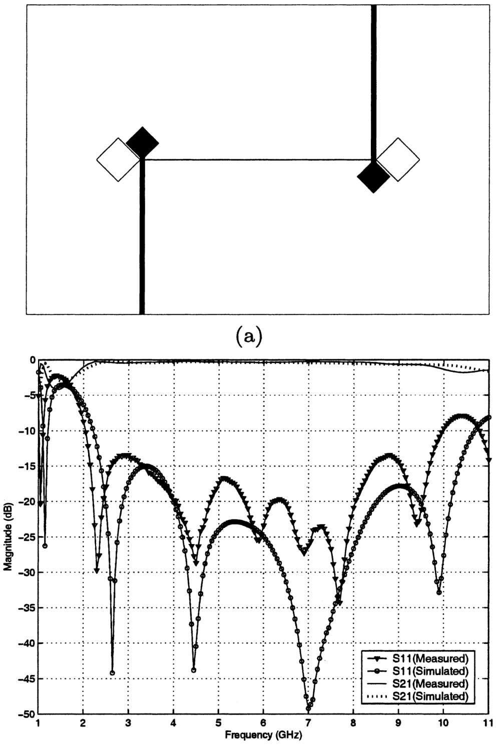
Fig. 4 shows the relationship between the physical size of the structure and the values of the equivalent circuit parameters. As shown in Fig. 4(a), the equivalent capacitance value is found to be linearly related to the area of a square in the dumbbell patch while the inductance value keeps almost constant. In Fig. 4(b), the effect of the length of a narrow connecting line is presented. As expected, the inductance value increases almost linearly as the length l increases. In this case, the reason for the slight increase of the capacitance value is that some capacitance by the extended parts of the narrow connecting line is added to that by the square patches. The last physical parameter is the width of the connecting line. As shown in Fig. 4(c), the inductance value decreases as the line gets wide. However, this parameter is considered to make less effects on the circuit values than the others since the changing rate becomes slow down.

On the other hand, in order to confirm the above results by measurement, a broadband transition is required since it is not easy to probe a slotline directly in general. Therefore, in this Letter, a broadband microstrip to slotline transition is used as shown in Fig. 5. This transition is proved to have a broad transition bandwidth on condition that both the characteristic impedances of a microstrip and a slotline are equal to 50 Ω [11]. However, we used a slotline with $w = 0.1$ mm which corresponds to the characteristic impedance of about 60 Ω at the center frequency since the slotline width corresponding to 50 Ω is too narrow and somewhat difficult to implement. Although the characteristic impedance of the slotline is somewhat larger compared with the optimum value, EM simulation and the experiment show that the designed transition has a fairly good characteristic for a broad frequency band as shown in Fig. 5. Thus, this transition is considered to be useful to verify the characteristic of the proposed PLS.

3. Measurement Results

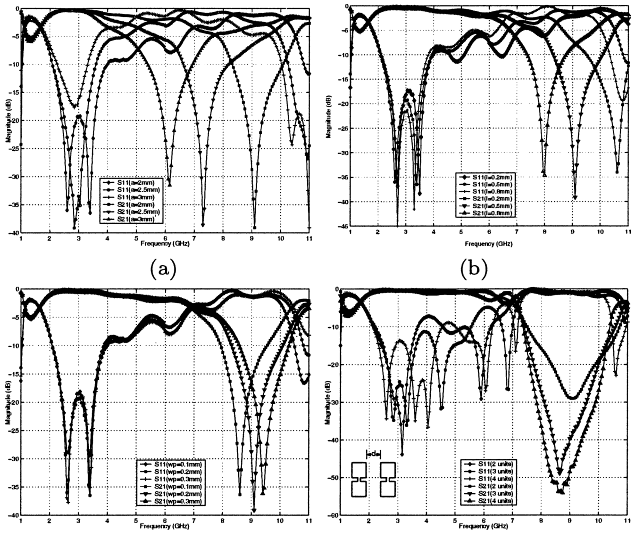
Figs. 6(a)–(c) show the trends of stopbands formed by loading various sized dumbbell patches to the slotline. As mentioned above, large patches and a long and narrow microstrip line lower the center frequency of a stopband by increasing capacitance and inductance between a signal and a ground, respectively. From the results, it is found that the patch size and the line length of PLS have a large effect on the frequency characteristic. This fact is very similar to the case of DGS where the size of defected area is a dominant factor of moving the stopband [4].

In Figs. 6(a)–(c), the passbands are composed of a



(b)

Fig. 5 Broadband microstrip to slotline transition. (a) Back to back configuration. The edge lengths of a square patch and a square slot are 3 mm and 4 mm, respectively. (b) Simulated and measured S-parameters.



(a) (b)

(c) (d)

Fig. 6 Measured S-parameters of the proposed PLS. (a) The length and the width of a narrow microstrip line are set to $w_p = 0.2$ mm, $l = 0.5$ mm in all cases. The size of each square patch is $a = 2$ mm, $a = 2.5$ mm, and $a = 3$ mm, respectively. (b) The size of each square patch and the width of a narrow microstrip line are set to $a = 2$ mm, $w_p = 0.2$ mm in all cases. The length of the line is $l = 0.2$ mm, $l = 0.5$ mm, and $l = 0.8$ mm, respectively. (c) The size of each square patch and the length of a narrow microstrip line are set to $a = 2$ mm, $l = 0.5$ mm in all cases. The width of the line is $w_p = 0.1$ mm, $w_p = 0.2$ mm, and $w_p = 0.3$ mm, respectively. (d) 2 to 4 unit sections are cascaded with a spacing of $d = 2$ mm. The dimensions of each loaded patch are set to $a = 2$ mm, $l = 0.5$ mm, and $w_p = 0.2$ mm in all cases.

lower and a higher frequency band than the stopband of a unit PLS section. As shown in these figures, the insertion loss in the lower passband near 3 GHz is less than 0.5 dB and this value is considered to be small enough to use this structure in many applications. However, the loss in the higher passband is measured to a somewhat high value more than about 2 or 3 dB. This is considered as the radiation loss of a dumbbell patch since two square patches become larger than a quarter wavelength in this frequency band and they are fed by the narrow connecting line coupled by the magnetic field in the slotline. In addition, the fact should be taken into consideration that this band is limited to the passband of a microstrip to slotline transition. Besides, the proposed equivalent circuit model does not work any more, and thus, it seems difficult to find various applications in this frequency band.

Fig. 6(d) represents the results of periodic circuits which are composed of two to four PLS unit sections. The results show that the proposed PLS provides a wide stopband with only a small number of unit sections. In addition, the depth and the bandwidth of the rejection band are inclined to depend upon the number of PLS unit sections. However the center frequency is found to be more dependent upon the size of each patch loaded periodically in the slotline than its periods as in the case of DGS [4].

4. Conclusions

A patch loaded slotline(PLS) is proposed as a novel periodic structure for a slotline and a simple equivalent circuit for a unit section is derived. By means of full wave simulations, the derived equivalent circuit is proved to be valid. Also, the measured result shows that the proposed PLS has a broad stopband with only a small number of unit sections like a conventional DGS in a microstrip line. Therefore, the proposed PLS is expected to be utilized in many applications such as filters, couplers, and other passive or active circuits.

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