Network modelling of periodic patch loaded slotline

J. Park, J.P. Kim and S. Nam

A network model of a patch loaded slotline (PLS) is proposed for the efficient design of related microwave circuits. The unit model is established by combining the network model for a slotline-to-microstrip transition with the equivalent circuits for microstrip step-discontinuities and open-ends. Therefore, this model is useful for the analysis of periodic PLS structures only by cascading it with a uniform slotline. To validate it, the computed results are compared with the EM simulated and measured ones, and they are shown to give good agreement in a wide frequency range.

Introduction: A slotline offers many advantages in the design of planar microwave circuits with components shunted to ground. Effectively incorporated into microstrip circuits, it also provides design flexibility as well as various attractive features [1]. However, although periodic bandgap (PBG) structures have been popular in microwave circuits for several years, most have been proposed in forms of microstrip [2] and CPW [3] structures, and there have been only a few research activities on the slotline loaded by periodic structures [3] reported in the open literature. Recently, we proposed a patch loaded slotline (PLS) as a novel periodic structure of a slotline [4], and the corresponding equivalent circuit parameters were shown to be extracted from the EM simulation. Therefore, several times of EM simulations should be repeated in order to find the required design values.

In this Letter, a simple but accurate network model of the PLS is proposed for the efficient design of its related circuits. Assuming that a dumbbell-shaped patch is loaded on the opposite side of a slotline, it is considered that its network model can be represented by combining the equivalent circuits for a slotline-to-microstrip transition, microstrip-discontinuities and open-ends. Thus, the proper choice of each equivalent circuit can generate the PLS model valid in a wide frequency range.

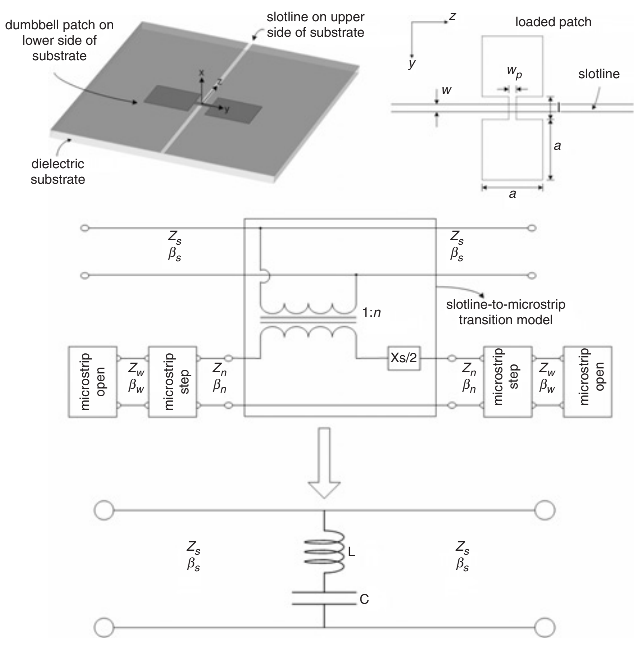

Fig. 1 *Geometry and proposed equivalent network model of unit PLS*

Equivalent circuits of PLS: Consider that the unit PLS is composed of a conventional slotline on one side of a dielectric substrate and a dumbbell-shaped patch on the opposite side. By close inspection, this structure can be represented as shown in Fig. 1, where Z_s, Z_n, Z_w and β_s, β_n, β_w are the characteristic impedances and the propagation constants of a slotline, a narrow and a wide microstrip line, respectively. For a microstrip line, the frequency dispersion model [5] is selected in order to cover the wide frequency range. In most cases, the effective dielectric constant based on this model shows accuracy of less than 0.6%. Although only a few models exist on the slotline [1], they are found to be accurate enough for the present PLS model. For a microstrip step-discontinuity and an open-end, conventional quasi-static models are feasible; however, frequency-dependent models such as the planar waveguide model for the step-discontinuity [5] are adopted to obtain higher accuracy in the wide frequency range. As shown in Fig. 1, the equivalent circuit model of a slotline-to-microstrip transition consists of an ideal transformer and a series reactance element. Their parameters are efficiently calculated using the reciprocity theorem and the spectral domain immitance approach with a finite Fourier transform [6].

This total PLS model can be simplified to a shunt-connected series L-C resonant circuit which coincides with the previous equivalent circuit in [4], since two microstrip arms coupled to the slotline can be considered as an effective $\lambda/4$ open-stub and it shows series L-C resonance near the resonant frequency. Note that the microstrip arms are stepped for design flexibility to obtain independent L and C values.

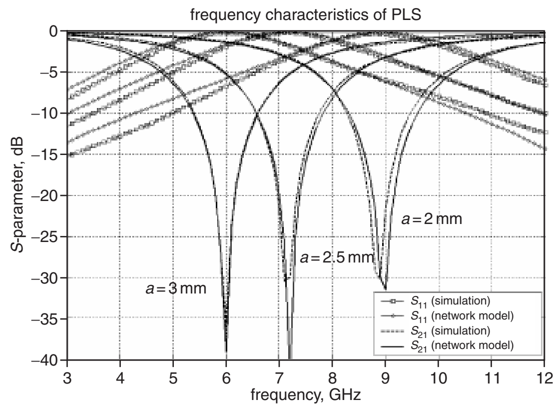

Fig. 2 *S-parameters of PLSs with different patch sizes*

$w = 0.038$ mm, $w_p = 0.2$ mm, $l = 0.5$ mm

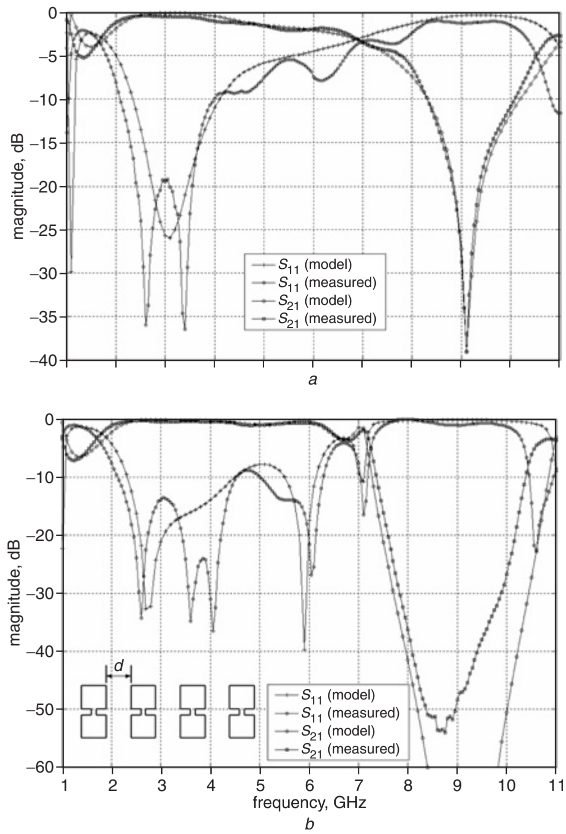

Fig. 3 *Compared S-parameters between network models and measurements*

a Single section
b Four periodic sections
$a = 2.0$ mm, $w = 0.1$ mm, $w_p = 0.2$ mm, $l = 0.5$ mm, $d = 2.0$ mm

Simulation and measured results: To validate the proposed network model several PLSs are considered with different-sized dumbbell patches. The substrate has a thickness of $h = 25$ mil with a dielectric constant of $\varepsilon_r = 10.2$. The computed *S*-parameters based on this model are compared with those from the EM simulation in Fig. 2. As shown in this Figure, good agreement is observed between the two results in a wide frequency range. The present model also estimates the resonant frequency with an error of less than about 1.2%.

To confirm the above results by measurement, a broadband microstrip-to-slotline transition is used, since generally it is not easy to probe a slotline directly. The 50 Ω slotline in the simulation is too narrow and somewhat difficult to implement, and thus a 0.1 mm slotline on the same substrate is used of which characteristic impedance is larger than 50 Ω. From the EM simulation and measurement, the designed transition is found to have a fairly good characteristic for a wide frequency band, enough to include the frequency response of the PLS. The *S*-parameters of a unit PLS model are cascaded with those of this transition extracted from the EM simulation, and then the overall *S*-parameters are compared with the measured ones. Figs. 3*a* and *b* show the results for a single and four periodic PLS sections, respectively. The latter *S*-parameters are obtained by only cascading the unit PLS with a uniform slotline successively. Their frequency responses show very similar trends in a wide frequency range, and the rejection features are also in good agreement with the network models and measurements.

Conclusions: A simple but accurate network model for a patch loaded slotline is proposed. By combining the equivalent networks of the slotline-to-microstrip transition, microstrip step-discontinuities and open-ends, the proposed model is shown to provide an accurate estimate of the frequency response and the rejection band caused by the PLS. Therefore, this model is expected to be very useful for the design of various microwave circuits related to the PLS such as slot antennas, filters, and other passive or active circuits.

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