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Compact broadband multi-way 1:6 power divider

***Abstract**. This paper introduces a design flow of a microstrip multi-way 1:6 power divider incorporating photonic bandgap (PBG) structures. The method proposed has enabled the achievement of considerable miniaturization (15%) together with transmission characteristics enhancement (141% bandwidth). Measured results show significant similarity to theoretical characteristics, which proves the attractiveness of presented design methodology.*

***Streszczenie.** W pracy zaprezentowano metodykę projektowania szerokopasmowego, wielodrożnego dzielnika mocy typu 1:6 wykonanego w technologii niesymetrycznych linii paskowych. Zaburzenie ciągłości metalizacji paska sygnałowego poprzez implementację struktur PBG (ang. Photonic Bandgap) umożliwiło osiągnięcie zarówno 15% miniaturyzacji, jak i poszerzenia pasma pracy do 141% dla częstotliwości środkowej 4 GHz. Wyniki eksperymentu wykazujące dużą zgodność z charakterystykami teoretycznymi potwierdzają zasadność zaproponowanej metodyki projektowania. (**Szerokopasmowy, zminiaturyzowany, wielodrożny dzielnik mocy typu 1:6**).*

Keywords: microstrip line, miniaturization, PBG, power divider.
Słowa kluczowe: linia mikropaskowa, miniaturyzacja, PBG, dzielnik mocy.

Introduction

Planar power splitters are vital components widely used in a huge variety of radio frequency and microwave systems, e.g. antenna feeding systems [1], power amplifiers [2] or multiplexers [3], in order to achieve signal power division or its combination. Nowadays RF/microwave components intended to meet the requirements of novel wireless communication systems are continuously challenged with ever more severe specifications concerning their performance, size, weight and cost. Generally, high frequency circuits can be characterized by considerable physical dimensions (especially at the low radio band operating frequency) and thus become a major obstacle for the design of compact mobile devices. Moreover, modern RF/microwave components are often required to present broadband characteristics, hence, a multi-section configuration is usually considered to design a power divider suitable for broadband applications. However, such a solution results in an additional component's size enlargement, which makes the miniaturization of RF/microwave circuits a crucial and a challenging problem.

Several schemes of power divider size reduction have been suggested by a number of authors for the past years [4-6]. An interesting approach to miniaturization of power splitters is based on the implementation of space-filling fractal curves efficiently shaping the geometry of the circuit [4]. Such a method enables the achievement of a notable scale of size reduction, however, it considerably increases the complexity of the circuit, simultaneously creating severe design and fabrication problems. Another concept has been proposed by etching various defects on the ground plane metallization leading to minimization on considerable scale [5], however, such a technique hinders the fabrication process and can also cause difficulties in terms of electromagnetic compatibility. Recently, it has been reported [6] that photonic bandgap (PBG) structures can be used to obtain the slow-wave phenomenon creating a chance of a significant size reduction. Modification of the metallization with PBG cells in the signal line alone is a promising method because of the simplicity of the fabrication process and a significant scale of miniaturization.

The following article introduces a concept of application of PBG cells in the process of a broadband multi-way 1:6 power divider design flow aimed at its miniaturization.

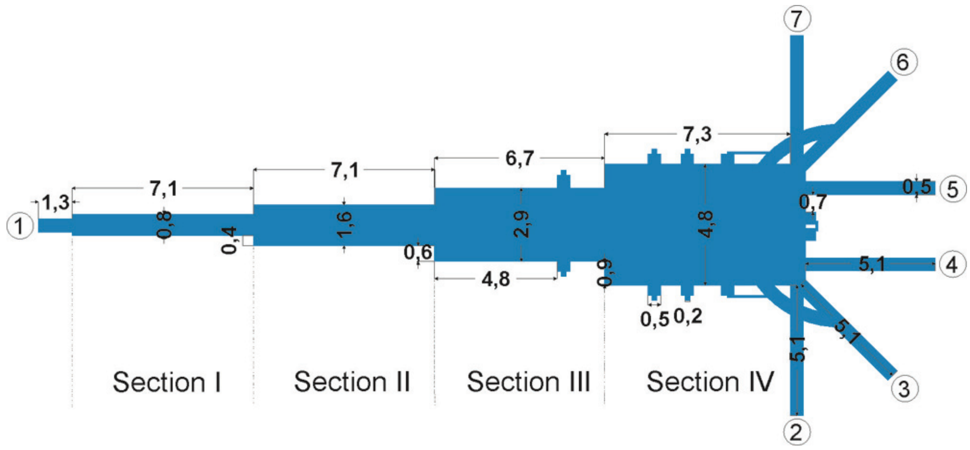

Fig.1. Layout of a conventional multi-way 1:6 power divider (unit: mm)

Design of a conventional 1:6 power splitter

A conventional multi-way power divider has been designed in microstrip technology on Rogers RO3210 substrate (ε_r = 10.2, h = 0.635 mm, tanδ = 0.0023) and designated for 1.5 ÷ 6 GHz frequency band with the input return loss ≤ -10 dB. The topology of a conventional multi-way 1:6 power splitter has been constructed following the conclusions from [7], in which such a component has been based on the concept of a microstrip multi-section impedance transformer. The layout depicted in Figure 1 has been designed and optimized using ADS Momentum EM solver [8]. Additionally, the classic topology has been adequately modified through the implementation of a series of open stubs disturbing the current distribution on the edge of the 3rd and 4th section of the multi-way power divider.

Reflection and transmission characteristics of the designed conventional circuit have been presented in Figure 2.

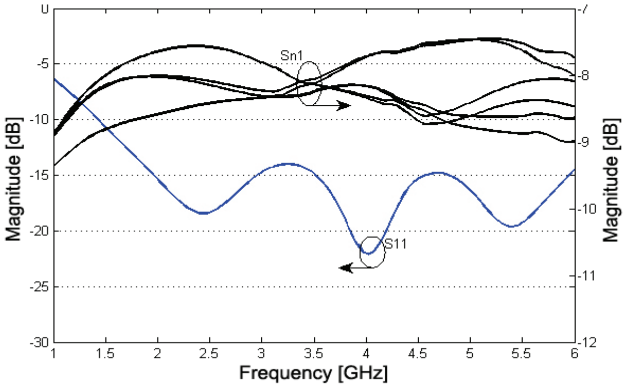

Fig.2. Transmission characteristics of a conventional multi-way 1:6 power divider

Design of a 1:6 power splitter incorporating PBG cells

In order to abbreviate the 4-section power splitter (see Fig. 1), two separate PBG cells have been proposed: (i) the first one constituted by the two C-shaped gaps (see Fig. 3a and Fig. 3b) and (ii) the second one built of the two C-shaped gaps together with two rectangular slots (see Fig. 3c). The PBG cells from Figure 3 present several advantageous features: negligible transmission losses, relatively small width and a slow-wave effect enabling the realization of a shortened microstrip section (maintaining its electrical length). Every PBG cell proposed has been optimized using the algorithm depicted on the block diagram in Figure 4. A time-saving semi-automatic optimization process has been utilized to design the compact 1:6 multi-way power divider.

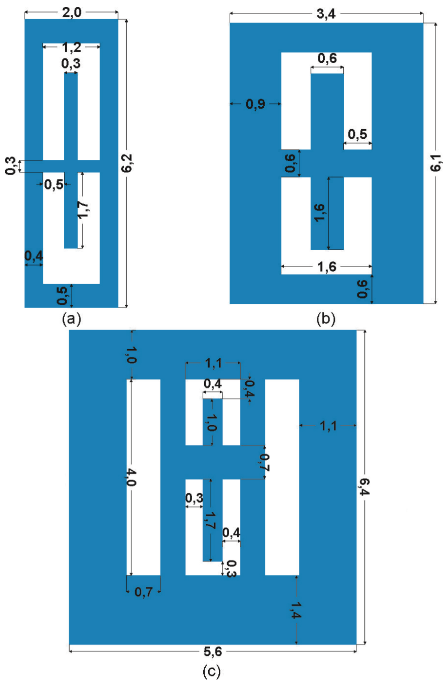

Fig.3. Layouts of proposed PBG cells (unit: mm): (a), (b) structures with two C-shaped slots implemented in the 2nd and the 3rd section of the conventional power divider, respectively; (c) structure with two C-shaped and two rectangular slots used to abbreviate the 4th power divider section

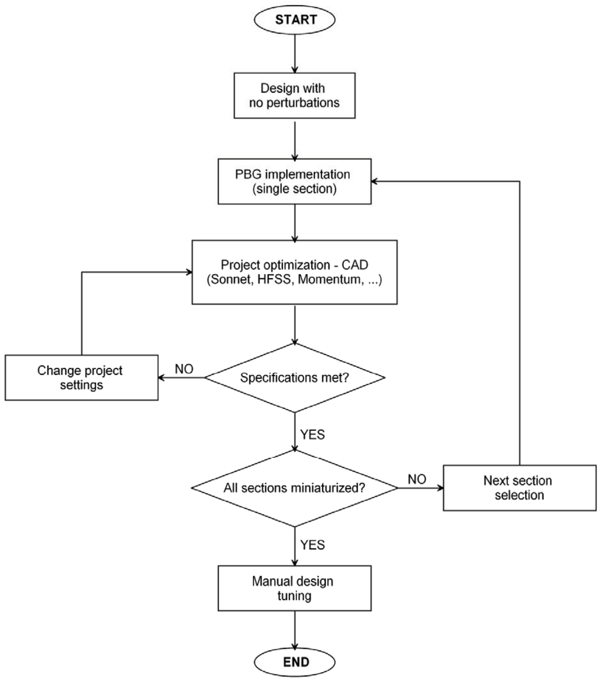

Fig.4. Optimization procedure block diagram used to find key geometric parameters of the designed component

A topology of the miniaturized multi-way 1:6 power splitter incorporating PBG cells has been presented in Figure 5, while its full-wave transmission characteristics derived by means of Momentum EM solver [8] have been portrayed in Figure 6.

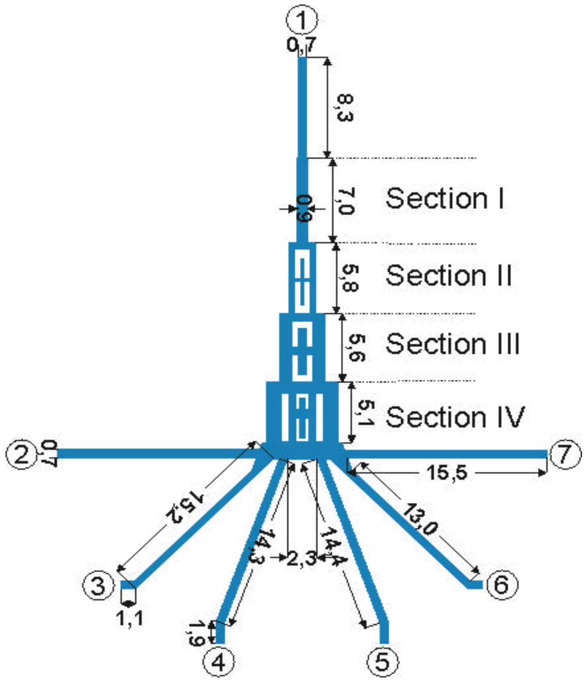

Fig.5. Layout of the miniaturized multi-way 1:6 power divider

Experimental results

The final design of miniaturized PBG-based power splitter has been successfully replicated in Sonnet EM solver [9]. Subsequently, a prototype circuit has been manufactured on Rogers RO3210 dielectric substrate and measured. A photograph of the fabricated component together with its measured characteristics (magnitude and phase) have been collected in Figure 7.

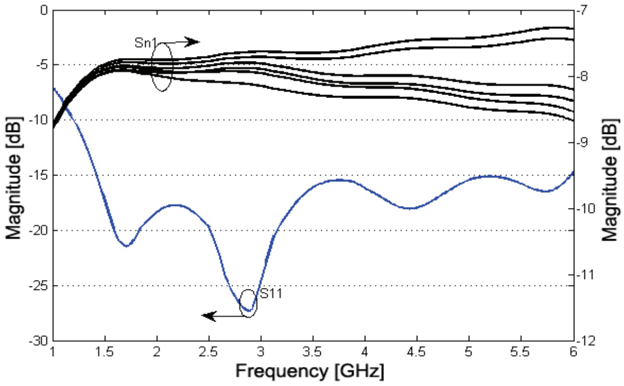

Fig.6. Transmission characteristics of the miniaturized multi-way 1:6 power divider

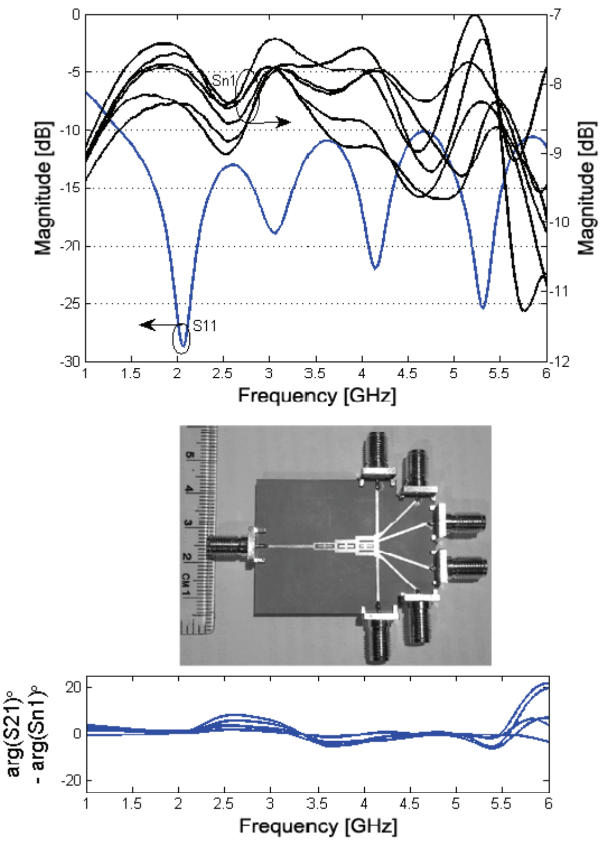

Fig.7. Measured transmission characteristics of the miniaturized power divider prototype

The measured characteristics are in great accordance with the theoretical (simulated) results. Lossless conductor used during E-M simulations as well as fabrication inaccuracy (±0.05 mm) are accounted for the minor performance differences. The intentional perturbations implemented in the microstrip sections constituting the multi-way 1:6 power splitter enabled the achievement of 14.8% length reduction with negligible additional insertion loss. The manufactured prototype circuit also exhibits broadband performance (141% bandwidth assuming 4 GHz operating frequency). The maximum phase difference determined for the separate output ports equals 6˚ in the given frequency range 1.36÷6 GHz. Key parameters of the designed power dividers as well as the fabricated prototype have been collected in Table 1. In reference to Table 1, BW stands for the bandwidth, circuit I corresponds to the circuit with continuous metallization (see Fig. 1), circuit II refers to the circuit with PBG cells (see Fig. 5).

Table 1. Collection of key parameters corresponding to both the conventional and the miniaturized power divider designs (simulations) as well as to the miniaturized multi-way 1:6 power splitter prototype (measurement)

Design	Dimensions [mm]	Area [mm^2]	BW for S_{11}< -10dB	BW for $\Delta arg(S_{n1})$ < 6˚
Circuit I (design)	35.2 x 15.1	531.5	128.7%	57.0%
Circuit II (design)	30 x 15.2	456	134.0%	97.0%
Circuit II (prototype)	30 x 15.2	456	141.0%	101.8%

Conclusions

The following article introduces a design flow of the multi-section multi-way 1:6 power divider aimed at its size reduction. The miniaturization of the circuit proposed has been achieved through the implementation of PBG cells in the adequate microstrip sections, whereas the design procedure has used the time-saving semi-automatic optimization process of key geometric parameters, which enabled the achievement of the goal characteristics. The design method proposed has led to the realization of the broadband multi-way power splitter exhibiting enhanced performance (141% bandwidth at the 4 GHz operating frequency) and a certain scale of size reduction (14.8%). The significant accordance of the measured results to the theoretical characteristics proves the utility of the proposed design procedure. Summarizing, the method reported has been found to be a very effective and a promising tool for achieving novel compact RF/microwave components.

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