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Miniaturized Broadband Multisection Coupled-Line Wilkinson Power Divider Designed with the Use of Quasi-Lumped Element Technique

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***Abstract*—The design of a miniaturized broadband Wilkinson power divider has been presented. To achieve broadband frequency response a three-section coupled-line structure has been used. All coupled-line sections have been realized with the use of a quasi-lumped-element approach, which allowed for significant miniaturization of the resulting network. Each coupled-line section has been designed with the use of a three-section equivalent circuit for which analytical expressions describing the required values of the lumped elements are given.**

Index Terms – **Wilkinson power dividers, coupled-lines, quasi-lumped element technique.**

I. INTRODUCTION

In lower microwave frequency range the conventional distributed passive components such as branch-line couplers, Wilkinson power dividers, Gysel power dividers, coupled-line directional couplers, etc. consume large area of a microwave integrated circuit (MIC) or a monolithic microwave integrated circuit (MMIC). Therefore, size reduction techniques of microwave passive components have been the subject of intensive research over the last years. In applications, where size reduction is required, lumped or quasi-lumped element devices that require only a small area are very attractive [1]–[3]. In addition, a recent rapid development of micromachining technology makes utmost miniaturization of microwave components possible. The development of lumped-element devices is also important in this sense. On the other hand modern trends for integration of multisystem hardware requires broadband operation of the developed circuits and systems. In terms of possible bandwidth enhancement of three-way power dividers, coupled-line multisection Wilkinson power dividers are very attractive [4], [5].

In this paper we present the design of a broadband 3-dB miniaturized Wilkinson power divider operating in 0.6-2.5 GHz frequency range. The broadband frequency characteristics have been achieved with the use of a three-section coupled-line structure. Each coupled-line section has been designed with the use of a quasi-lumped element approach, in which a three-section equivalent circuit has been assumed which allows for achieving both good electrical properties of the power divider and small size of the network.

II. TEORETICAL ANALYSIS

A schematic diagram of the considered power divider is shown in Fig. 1, and consist of three sections of coupled lines, and single resistor used for achieving high isolation between output ports [5]. The electrical parameters of the considered network are listed in Table 1. Fig. 2 presents the calculated frequency response of the ideal 3-dB Wilkinson power divider, and as it is seen, the designed divider operates within 0.6-2.5 GHz frequency range in which both isolation and return losses are better than 20 dB.

To achieve compact size of the Wilkinson power divider each section can be designed with the use of a quasi-lumped element approach. However, the realization of each section with the use a single-section equivalent circuit results in poor electrical performance, as it was shown in [6]. To find the values of the required quasi-lumped elements, at first the expressions for capacitance and inductance elements of the *[C]* and *[L]* matrices, which describe the properties of coupled lines have to be derived, having known coupling k and characteristic impedance Z_0 of each section. These parameters can be found as:

$$C_{11}'=\frac{1}{\sqrt{v^2 Z_0^2\left(1-k^2\right)}} \tag{1}$$

$$C_m'=C_{11}'k \tag{2}$$

$$C_1'=C_{11}'-C_m' \tag{3}$$

$$L_1'=\frac{C_{11}'}{\left(C_{11}^2{}'-C_m^2{}'\right)v^2}\,. \tag{4}$$

Having found the values of *[C]* and *[L]* matrices one can calculate the values of elements of the coupled-line section as

$$C_1=C_1'\frac{x}{2n} \tag{5}$$

$$C_m=C_m'\frac{x}{2n} \tag{6}$$

$$L_1=L_1'\frac{x}{n} \tag{7}$$

where $x=\dfrac{v}{4f_0}$ is the length of the coupler, v = c is the free space velocity of light, k is the coupling of coupled-line section and n is the number of sections used in the equivalent circuit of each coupled-line section.

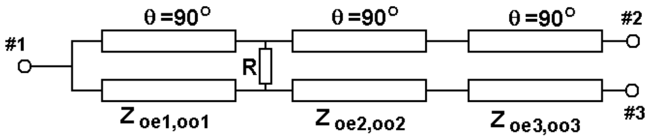

Fig. 1. Schematic diagram of the broadband 3-dB coupled-line three-section Wilkinson power divider.

TABLE I.
VALUES OF EVEN- AND ODD-MODE CHARACTERISTIC IMPEDANCES, COUPLING COEFFICIENTS AND TERMINATING IMPEDANCES OF THE COUPLED-LINE SECTIONS FOR THE CONSIDERED BROADBAND 3-DB COUPLED-LINE THREE-SECTION WILKINSON POWER DIVIDER

	section #1	section #2	section #3
Z_{oe} [Ω]	84.3	70.7	59.3
Z_{oo} [Ω]	68	28.15	39.85
k	0.1	0.43	0.19
Z_0 [Ω]	75.7	44.6	48.6
R [Ω]	50		

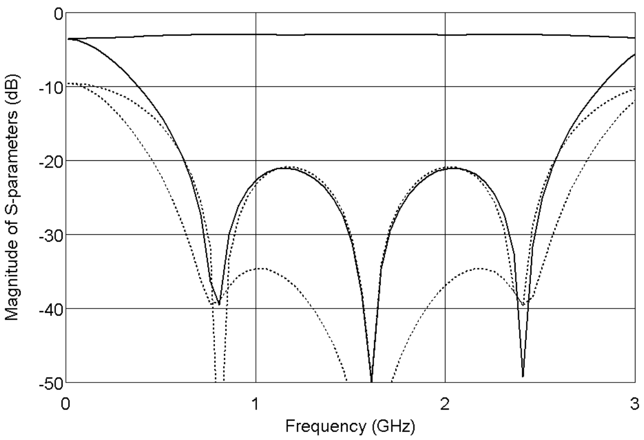

Fig. 2. Frequency response of the considered broadband 3-dB coupled-line three-section Wilkinson power divider. Transmissions, and isolation – solid lines, reflection coefficients – dashed lines. Results of circuit calculations.

The calculated values of lumped elements of the three-section Wilkinson power divider, in which each section is designed with the use of a three-section equivalent circuit are shown in Table II. Fig. 3 presents the results of circuit simulations of such a power divider. As it is seen the achieved isolation and return losses are better than 20 dB within the operational bandwidth. This is due to the assumed number of subsections of each coupled-line section. As it was shown in [6], n = 3, provides the return losses and isolation of a single coupled-line section better than 20 dB over broad frequency range, which is an optimum trade-off between the possible overall size and electrical performance of the resulting network.

TABLE II
VALUES OF LUMPED SELF AND MUTUAL CAPACITANCES, SELF INDUCTANCES, AND COUPLING COEFFICIENTS FOR COUPLED-LINE SECTIONS OF THE THREE-SECTION WILKINSON POWER DIVIDER SHOWN IN FIG. 1 IN WHICH A THREE-SECTION EQUIVALENT CIRCUIT IS ASSUMED FOR EACH COUPLED-LINE SECTION

section	parameter	value
	C_1 [pF]	0.309
	C_m [pF]	0.037
1	L_1 [nH]	3.97
	k	0.107
	n	3
	C_1 [pF]	0.638
	C_m [pF]	0.278
2	L_1 [nH]	2.57
	k	0.43
	n	3
	C_1 [pF]	0.44
	C_m [pF]	0.107
3	L_1 [nH]	2.58
	k	0.19
	n	3

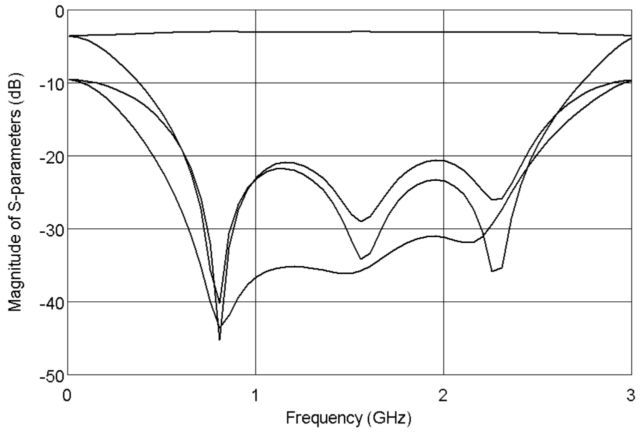

Fig. 3. Frequency response of the considered broadband 3-dB coupled-line three-section Wilkinson power divider. Transmissions, and isolation – solid lines, reflection coefficients – dashed lines. Results of circuit calculations in which values of lumped-element equivalent circuit shown in Table II are used.

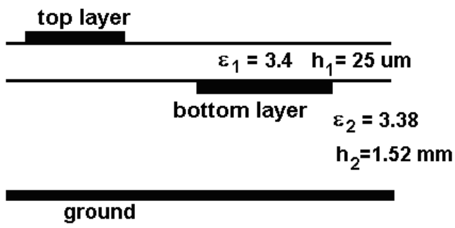

Fig. 4. Cross-sectional view of the dielectric structure used for the design of a compact broadband quasi-lumped 3-dB coupled-line Wilkinson power divider.

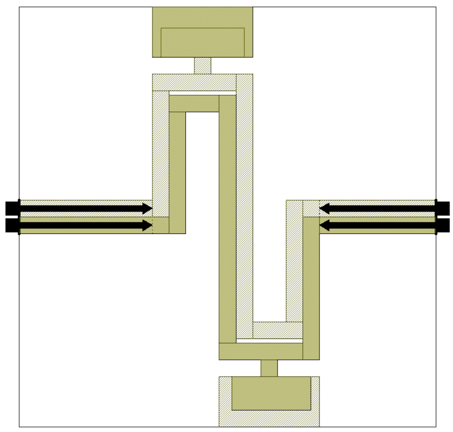

Fig. 5. Exemplary view of a subsection of coupled lines analyzed electromagnetically using Microwave Office simulator.

III. Experimental Results

The major difficulty in the design of quasi-lumped coupled-line section is the realization of coupled inductors. In more advanced technologies such as LTCC or monolithic – where it is possible to realize multilayer circuits – coupled spiral inductor can be designed in order to achieve high inductance per unit sq [6]. In this design we have focused on planar realization of coupled-line sections, therefore coupled inductors are designed as short sections of broadside coupled lines.

The miniaturization with the use of the quasi-lumped approach is efficient only, when a dielectric structure is appropriately chosen, so that it is possible to realize a coupled-line section having the inductive coupling k_L equal to the chosen nominal coupling k (C in dB) and having the characteristic impedance Z_0 much higher then Z_0 of the resulting coupled-line section.

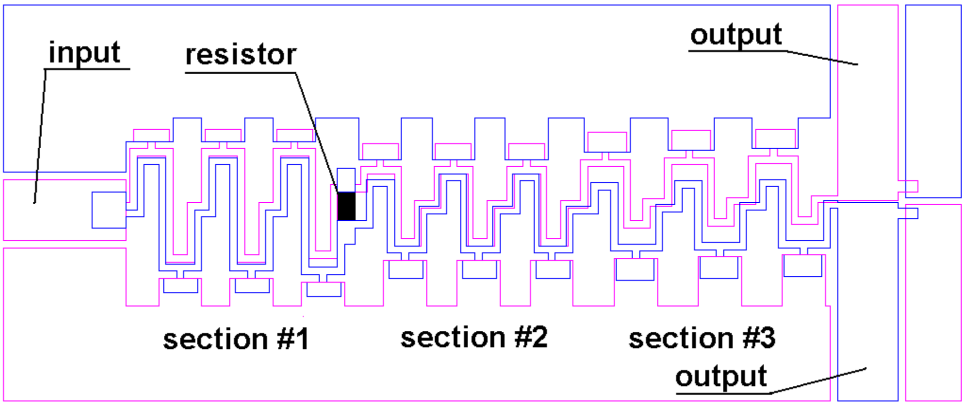

Fig. 6. Layout of the developed broadband quasi-lumped 3-dB coupled-line Wilkinson power divider. Top layer – blue color, bottom layer – pink color.

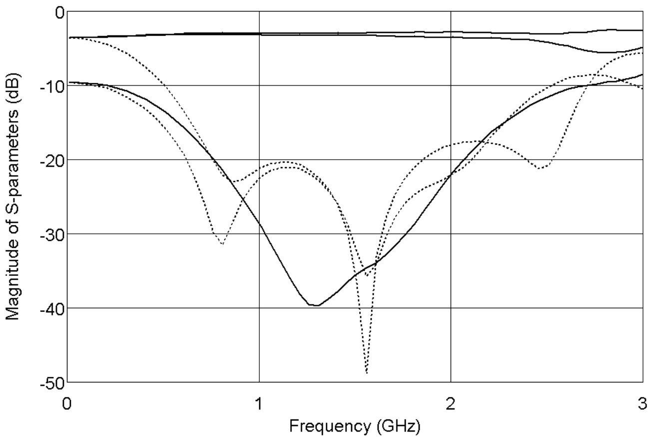

Fig. 7. Frequency response of the considered broadband 3-dB coupled-line three-section Wilkinson power divider. Transmissions, and isolation – solid lines, reflection coefficients – dashed lines. Results of electromagnetic calculations.

In practical application the limitations on miniaturization of the coupled-line section come from the minimum thickness of the dielectric layer and the minimum width of the realizable strip. To ensure significant miniaturization of the quasi-lumped coupled-line sections it is required to select a dielectric structure and technology having: To ensure significant miniaturization of the quasi-lumped coupled-line couplers it is required to select a dielectric structure and technology having:

- large layer thickness ratio, i.e. the thickness of the dielectric layer on which the traces of coupled lines are placed needs to be much smaller then the ground-plane separating layer(s),
- possibility of realization of narrow metallization strips.

In order to physically realize the designed quasi-lumped Wilkinson power divider a dielectric structure shown in Fig. 4 has been chosen. The chosen structure consists of a thin dielectric layer (h = 0.025 mm, εr = 3.4) placed above a thick (h = 1.52 mm, εr = 3.38) substrate. Such a structure allows for achieving relatively large self-inductance of the thin metal strip due to the large ground distance. On the other hand it also allows for easy realization of large mutual capacitance due to the thin top dielectric layer. In order to realize the needed large self capacitances a grounded pads have been provided on both sides of the thin dielectric layer.

In order to maximally miniaturize each coupled-line section the coupled strips' width has been chosen as narrow as possible (technological limitations) to obtain the highest self-inductance per unit length which gives the shortest length l of the coupled lines. The dielectric thickness of the thin layer allows for achieving coupling k per unit length greater than desired. The strip offset was tuned in a way to achieve appropriate coupling (tuning the offset does not influence the self-inductance). In the presented design the width w = 0.2 mm of coupled lines was assumed. The designed directional coupler has been electromagnetically analyzed and optimized in order to reduce the overall size - meandering of the coupled line sections as it is seen in Fig. 5. Fig. 6 shows the layout of the designed coupler in which all elements are clearly marked. The overall area of the designed Wilkinson power divider equals 120 mm^2. This is much smaller size than the standard coupled-line Wilkinson power divider designed in a microstrip technique using laminate with dielectric constant ε_r=3.38 and thickness 1.52 mm. For such a case the area of only coupled lines equals ~700 mm^2. Fig. 7 shows the electromagnetically calculated frequency response of the designed 3-dB power divider, whereas the corresponding measured results are shown in Fig. 8. It is seen that a good agreement has been obtained and the broadband operation of the circuit is achieved. The proposed approach is suitable for designing passive components in more advanced technologies allowing for further miniaturization.

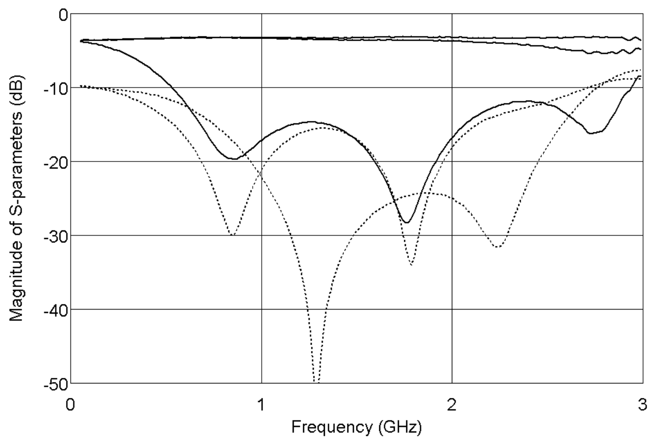

Fig. 8. Measured frequency response of the designed quasi-lumped broadband 3-dB Wilkinson power divider. Transmissions, and isolation – solid lines, reflection coefficients – dashed lines.

IV. CONCLUSIONS

The design of a broadband 3-dB miniaturized Wilkinson power divider operating in 0.6-2.5 GHz frequency range ha been presented. In order to achieve broadband frequency characteristics a three-section coupled-line structure has been selected. Each coupled-line section has been designed with the use of a quasi-lumped element approach, in which a three-section equivalent circuit has been assumed. The chosen number of sub-sections the allows for achieving both good electrical properties of the power divider and small size of the network. The coupled-line Wilkinson power divider has been optimized electromagnetically, manufactured and measured. The obtained results are in good agreement, proving the correctness of the proposed approach for miniature power divider design.

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