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A New Approach to Analytical Calculation of Microstrip Directional Couplers with Full Structure Symmetry

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Abstract—A new approach to analytical calculation of directional couplers that have two symmetry planes, which is based on using input impedances of co-phase (symmetrical) and opposite-phase (asymmetrical) partial two-poles is suggested. Examples of using such approach for calculations of directional couplers on the basis of a coupled lines segment with three directivity types are discussed.

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Directional couplers (DC) in microstrip implementation are an essential part of most integral microwave devices including power dividers, balanced amplifiers, modulators, phase-shifters, pattern-shaping circuits, etc. Out of a rich multiplicity of directional couplers constructions versions with one or two symmetry planes are often used: stub DC and bridges, DC on two- and multi-coupled transmission lines, tandem DC. At the first stage of designing such devices electrical parameters of their equivalent circuit (wave impedances and electrical lengths of common and coupled line segments, parameters of discrete elements that are a part of the coupler). Calculation methods developed for this purpose are based on using T-approximation, i.e. an assumption that a transverse wave propagates in the device. In the majority of cases the calculations expressions are written using a well-known method of co-phase-opposite-phase excitation [1] and further matrix description of the obtained in this way equivalent circuits. This approach is used for developing methods for calculating stub DCs, where the questions of widening the frequency range by increasing the number of stubs [2, 3], decreasing wave impedances of segments and their lengths by introducing additional reactive elements (discrete or microstrip-type) [4–11] are considered.

An important problem, which needs to be solved when developing calculation methods for DCs on coupled lines consists in the necessity to compensate the influence of different phase velocities for even and odd modes, which takes place in case of using layered dielectric filling of the strip structure. Classical calculation methods [1, 2, 12, 13] are based on choosing specific values of modes' wave impedances to satisfy the condition of their phase velocity equality or equality of average impedance values. Leveling of phase velocities is accomplished by technological means due to covering the coupling region with an additional layer of dielectric [14], application of multi-layered dielectric substrate [15], making periodic profile of the coupling region [16, 17], introducing perforation to the screen below the coupling region [18]. Circuit compensation techniques assume adding one or two capacitive elements between the coupled lines [19, 20], connecting inductive stubs in parallel to the coupled lines [21, 22] or connecting inductive elements in series [23]. Expressions for calculating such couplers are obtained using matrix technique under specific assumptions, for example, for the allowed level of transient attenuation [19], for the point of placing discrete elements [20], for input impedance matching [23], which is primarily caused by complexity of deriving analytical dependences. It is worth noting that the well-known calculation methods do not allow accounting for the influence of heterogeneities at junctions between input and coupled lines, which appear under certain conditions [22].

The next stage of design is connected with numerical analysis of the device using electrodynamic methods and optimization of its characteristics. Electrical parameters of directional coupler obtained at the first stage of design serve as initial data for computer modeling. Since the second stage results directly depend on the value obtained at the first stage, requirements to precision of electrical parameters calculation methods increase. Hence this paper aims to develop and study a theoretical approach, using which it would be possible to obtain calculation methods of fully symmetrical (with two symmetry planes) directional couplers without the aforementioned limitations with maximum achievable in T-approximation consideration of the influence factors.