Slot-Coupled Directional Coupler for Application in K-Band 4x4 Butler Matrix

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Abstract – In this paper, an application of recently developed slot-coupled directional couplers in 4x4 Butler matrix is presented. The circuit is composed of 3-dB slot-coupled directional couplers, in which by insertion of two uncoupled transmission lines between slot-coupled lines, isolation and coupling characteristics have been improved. An exemplary directional coupler and Butler matrix operating in K-band at center frequency of 24 GHz has been designed and its performance in context of practical applications has been verified.

Keywords: slot coupler, coupled-line directional coupler, Butler matrix

I. INTRODUCTION

Butler matrices are important class of microwave networks, which are widely used for many applications. Such circuits have been introduced for the first time in [1]. Generally, an N x N Butler matrix is a circuit, which has N inputs and N outputs – a signal is applied to one of its input ports and then appropriately equally divided between output ports. Therefore, Butler matrices are used for many years as beamforming networks of multibeam antennas [2]-[4] as well as direction finding systems [5] or as it has recently been shown in multiport measurement systems [6]. In order to obtain a network operating in a wide frequency range using strip transmission line technique, the Butler matrix needs to be designed using coupled-line directional couplers instead of branch-line couplers, which are narrowband. However, it is difficult to realize coupled-line directional couplers providing coupling equal to 3 dB and operating at higher frequencies such as K-band. To realize such tight coupling, multilayer Lange [7] or tandem coupler [8] can be used, however they require wire crossovers, which are difficult to realize, especially at higher frequencies. Due to this fact, slot-coupled directional couplers might be suitable for realization of Butler matrix [9]-[10].

In this paper, we propose an application of recently developed slot-coupled directional couplers in realization of 4x4 Butler matrix. The network is composed of 3-dB directional coupler, in which isolation and coupling characteristics have been improved by insertion of uncoupled transmission lines in between slot-coupled lines. An exemplary circuit operating in K-band at center frequency of 24 GHz has been designed and experimentally verified. The obtained results prove the usefulness of the presented approach to the design of 4x4 Butler matrices operating in higher frequencies.

II. SLOT-COUPLED DIRECTIONAL COUPLER DESIGN

The isolation improved slot-coupled directional coupler has been presented in [9], where a section of uncoupled transmission lines has been placed in between two slot-coupled lines. Such an approach allowed to improve isolation and, therefore also coupling characteristics of the circuit. Layout of the 3-dB slot-coupled directional coupler realized as shown in [9] has been presented in Figure 1. The coupler has been designed in a dielectric structure presented in Figure 2 where cross-section of the structure is shown. For the design of 3-dB slot-coupled-directional coupler, the uncoupled transmission lines matched to 50 Ω and having length equals 2 mm have been inserted in between two slot-coupled sections: strips’ width w = 1.24 mm, slot width s = 1.32 mm. The designed directional coupler has been electromagnetically (EM) verified and its performance optimize at that stage using AWR Microwave Office software. The results of EM calculations are presented in Figure 3. In the next step the proposed coupler has been manufactured and measured. Measurement results are presented in Figure 4, whereas photograph of the physically realized structure is shown in Figure 5.

Figure 2. Layout of the proposed slot-coupled directional coupler.

Figure 1. Cross-sectional view of the utilized dielectric structure: layer 1 and layer 2 are the dielectric laminates having thickness 0.3 mm and permittivity 3.38, w and y are the strips’ and slot width respectively.
As seen, the circuit features almost equal power split. However, measured transmission and coupling characteristics have been decreased due to the utilization of long input lines, required for circuit measurement purpose. Such long signal lines introduce power loss, which significantly influences performance of the circuit. Moreover, the center frequency of the manufactured coupler has slightly shifted towards higher frequencies due to the manufacturing of the circuit. At such frequencies, circuits are highly sensitive on manufacturing process accuracy.

realization of lines cross-over is application of tandem connection of directional couplers and appropriate modification of the phase shifters in order to maintain output differential phases. Such an realization is proposed in this case. Final, layout of the designed Butler matrix is presented in Figure 7. The circuit has been designed and analyzed using AWR Microwave Office software. The results of electromagnetic calculation of the structure have been presented in Figure 8 to Figure 9. The transmission imbalance is equal 0.8 dB at the center frequency 24 GHz, isolation and ports matching are better than -20 dB over the entire band of operation while differential phases error is lower than 4°. Obtained performance is at satisfactory level for some practical applications.

III. 4X4 BUTLER MATRIX DESIGN

An exemplary 4x4 Butler matrix has been realized using the presented in previous Section (Section II) slot-coupled directional coupler. A schematic diagram of such a circuit has been shown in Figure 6. Such circuit is composed of four 3-dB directional couplers and two -45° phase shifters in case of ideal circuit. Moreover, lines cross-over is required in-between two sets of directional couplers. One of the practical
IV. CONCLUSION

A novel approach for realization of 4x4 Butler matrix with the use of slot-coupled directional couplers has been proposed. Such approach is particularly useful for circuit operating in higher frequency ranges, e.g. K-band. An exemplary directional coupler and Butler matrix operating at center frequency of 24 GHz has been designed and its performance in context of practical applications has been verified.

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REFERENCES