Design of an Un-Conventional Butler Matrix

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In this paper, a novel design of 4x4 Butler matrix is presented, which can realize flexible phase difference at the output ports. Different from the conventional Butler matrix where quadrature couplers are used, the proposed Butler matrix employs couplers with arbitrary phase-difference. Butler matrix as a passive feeding network has a symmetrical structure with identical number of input and output ports. It has been widely used in beam-forming antenna arrays for both civil and military applications, including search and rescue, remote sensing, imaging, and respiration measurement.

Up to now, the design of Butler matrix has been focused on improving bandwidth and size reduction [H. T. Nguyen et al., Proc. Asia-Pacific Microw. Conf., 753-756, 2011; G. Tian et al., IEEE Microw. Wireless Compon. Lett., 24, 306-308, 2014]. It is highly desired to design un-conventional Butler matrix with arbitrary progressive phase difference to meet the requirement of advanced wireless systems. To address this issue, a modified Butler matrix has been investigated recently [N. Sutton et al., Proc. Antennas and Propagation Conf., 521-524, 2010]. However, it can only be implemented by using multilayer structures, which increase the complexity of the whole system. In this paper, a new Butler matrix featuring flexible progressive phase difference is proposed. It can be implemented in a planar structure. Novel couplers with arbitrary phase-difference are applied to achieve the flexible progressive phase difference among output ports. To facilitate the design, closed-form design equations are derived. Based on the derived equations, an experimental prototype is designed at 5.8GHz. Numerical simulations have been carried out. The simulated return loss and isolation are better than 17dB at the design frequency. The generated phase differences are -30°, +150°, -120°, and +60° when the signals are input from different input ports (note: these phase differences can be changed by controlling the phase differences of the applied couplers). To verify the design concept, the designed Butler matrix has been fabricated and characterized. The measurement results match well with the simulation results.