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Single-Layer Waveguide Circuit to control Sidelobe and Crossover Levels in Butler-Matrix Beam-Switching Antenna

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1. Introduction

The Butler matrix [1] is a beam-forming network for a multi-beam array antenna. The main-beam direction can be switched according to the input port. Conventional Butler matrix suffers from high crossover levels between adjacent main beams of -3.7dB and high sidelobe levels of -11.4dB independent on the number of ports, theoretically. In order to solve these problems, the configuration of a circuit has been proposed to control the crossover and sidelobe levels by using two-way dividers with 180-degree difference [2]. This paper presents this circuit configuration by single-layer post-wall waveguides [3] to integrate with a Butler matrix and a slotted waveguide antenna by complete single layer.

2. Single-Layer Waveguide Configuration

Figure 1 shows the single-layer waveguide configuration of the circuit for a 4-way Butler matrix. The circuit consists of four two-way dividers with 180-degree difference and crossings. The divider consists of a short-slot coupler [4] and a 90-degree phase shifter inserted in one of the two output ports (port 2 and port 4). The short-slot coupler enables to realize single-layer structure. It gives 90-degree phase difference between the two output ports in principle. It controls the divided amplitudes $\cos\theta$ and $\sin\theta$ to port 2 and port 4, respectively, where θ is the argument defined by multiplying the effective length of the coupled region with the difference in phase constant between two propagating modes when the reflections to the two input ports (port 1 and port 3) are suppressed. The four dividers have different arguments θ chosen $90-\alpha$, $90-\beta$, β, α $(0 \leqq \alpha \leqq \beta \leqq 45)$ from the top to the bottom. The original short-slot coupler [4] has two posts in the coupled region for suppressing the reflection, which is applied for the bottom two dividers with small argument in Fig.1. On the other hand, in the top two dividers with large argument, the two posts can be removed with keeping the reflection suppression to halve the length of the coupled region in comparison with the original coupler [5]. The crossings are also realized by the short-slot couplers in full single layer. The amplitudes at the output ports 5 - 12 are symmetrical with respect to the center and tapered to the edges.

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3. Pattern control by the Circuit

Figure 2 shows the crossover and sidelobe levels in the array factor of the eight output ports in Fig.1, when α and β are independently changed with the spacing of $0.5\lambda_0$. Taper distribution of amplitude can control the crossover level of -3.7dB or below and the sidelobe level in the range of -12.8～-26.7dB. The array factor for the lowest sidelobe level and the lowest crossover level is shown in Fig.3 (a) and (b), respectively. In Fig.3 (a), the crossover level is -9.6dB. In this case, each beam is not orthogonalized to the other beams at the direction of the main beam. In Fig.3 (b), the crossover level is null, and the sidelobe level is -12.8dB.

4. Design of Short-Slot Couplers

Each short-slot coupler is designed to have different dividing ratio with reflection suppression at 22GHz. Fig.4 shows the values of *l*, *w*, *d*, *p* for the dividing ratio. We confirm that the dividing ratio S_{41}/S_{21} can be in a range of -14dB～14dB . The short-slot coupler with the reflection-canceling posts is applied for the dividing ratio less than -4dB while that with the steps for the size reduction is adopted for the ratio larger than -4dB. In the former coupler, the posts are arranged symmetrically with respect to the structure in the longitudinal direction. The design parameters are the coupled length *l* and post spacing *p*. The dividing ratio becomes small with decrease of *l*. In the latter coupler, the design parameters are the length *l* and the width *w* of the coupled region and the step offset *d*. The dividing ratio is mainly dominated by *l*, and the reflection is suppressed by choosing proper values of *w* and *d*. In this case, the dividing ratio becomes large with increase of *l*, as is the case with the former. But the variation of *l* for the dividing ratio is not so much as large as that of the former case. Instead of this, the value of *w* changes very much. The argument θ is sufficiently changed even for small variation of *l*, because the difference in the phase constant between the two propagating modes in the coupled region becomes large for smaller w. In Fig. 3(a) for the lowest sidelobe level, the four short-slot couplers have the arguments of 12.88deg, 28.81deg, 61.19deg and 77.12deg respectively.

5. Conclusions

We have proposed the single layer configuration of the additional circuit to control the crossover and sidelobe levels in the Butler matrix. The circuit consists of four two-way dividers with 180-degree difference and crossings. The dividers and the crossings are realized by short-slot couplers in the single layer. We have confirmed that the dividing ratio can be in a range of -14dB～14dB. By a proper taper distribution of amplitude from eight output ports, the crossover and sidelobe levels in the array factor can be controlled -3.7dB or below and in the range of -12.8～-26.7dB, respectively.

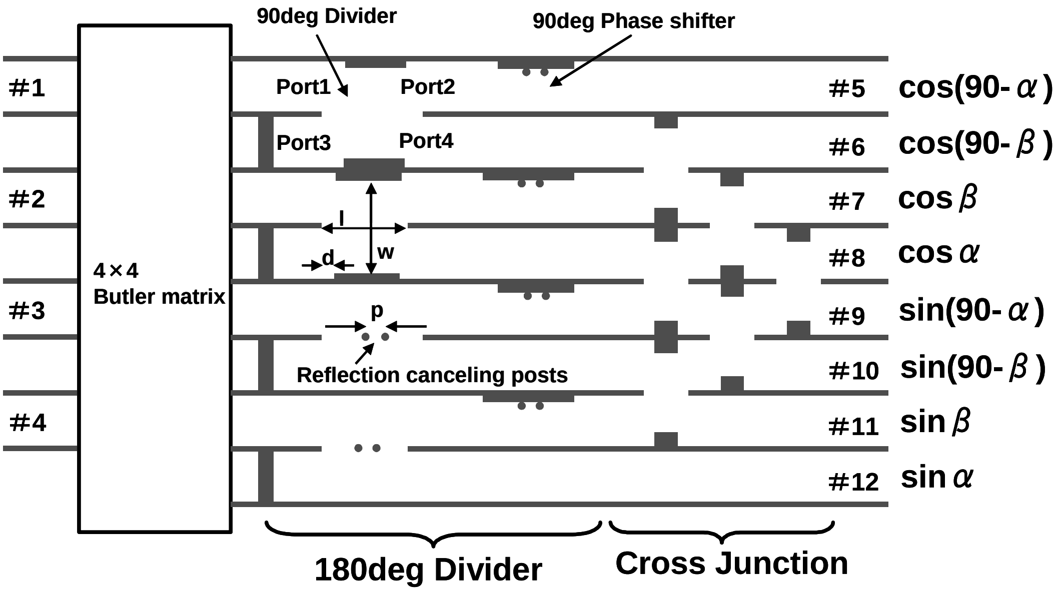
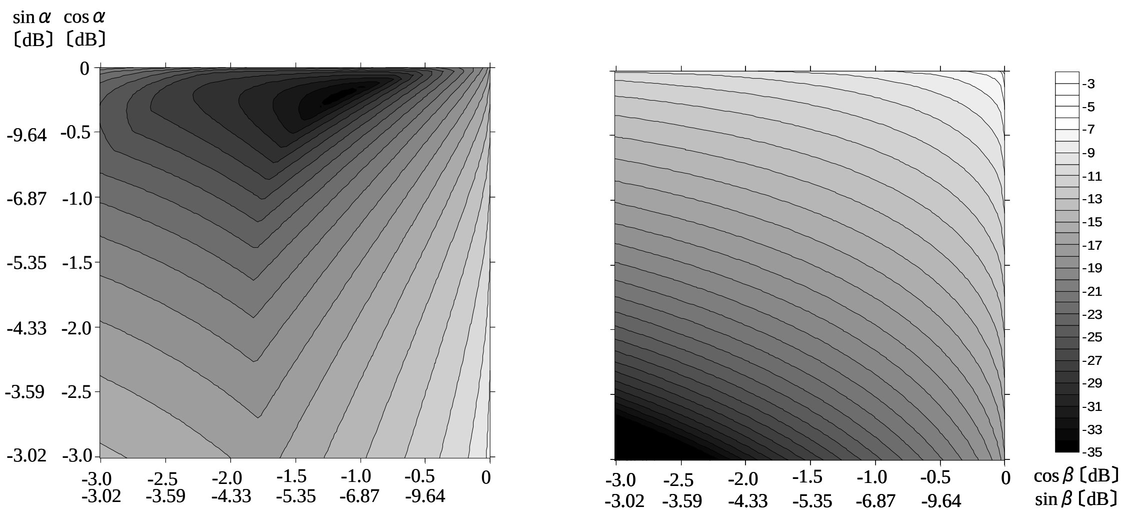
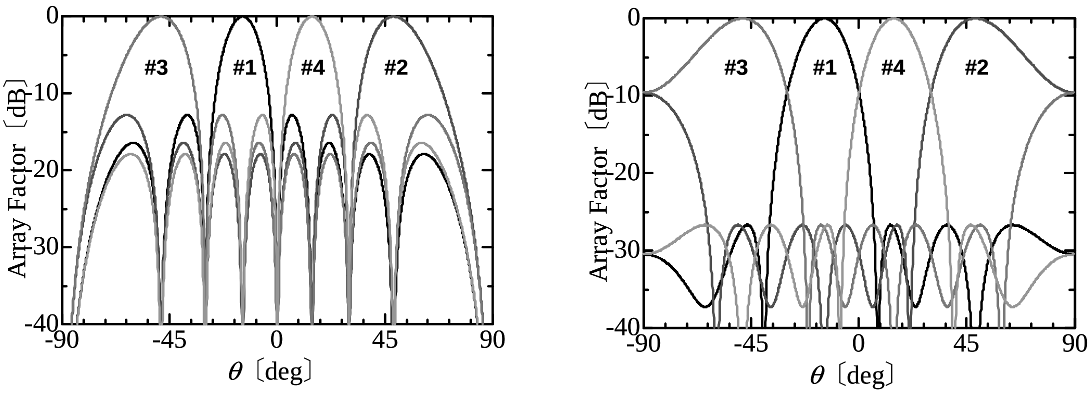


Fig.1 Modified Butler matrix



(a) sidelobe level (b) crossover level

Fig.2 The range of sidelobe level and crossover level when α and β are changed



(a) The lowest sidelobe (b) The lowest crossover level

Fig.3 Array factor of modified Butler matrix

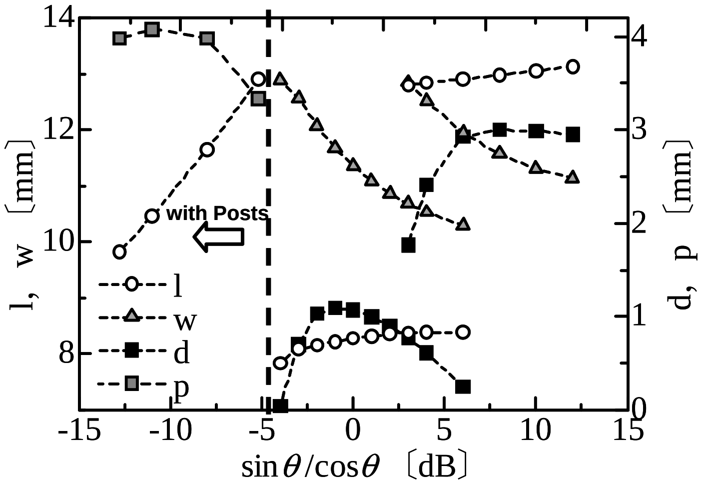


Fig.4 The dividing ratio versus the design parameters

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