International Conference on Antenna Theory and Techniques, 6-9 October, 2009, Lviv, Ukraine pp. 328-330

COMPARATIVE ANALYSIS OF NOVEL COMPACT AND USUAL SMOOTH 90-DEGREE TWISTS

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Abstract

Two types of compact 90-degree twists whose transformer sections are square waveguides with two square or stepped ridges are considered. Twist electromagnetic models are based on the mode matching and generalized scattering matrix techniques. Good agreements between calculated and experimentally measured characteristics of manufactured prototypes of the both type twists in the 23×10 mm waveguide are demonstrated. On the base of specially studies carried out, it is shown that, at close or even better performance, the lengths of proposed twists are ten and more times less than the ones of conventional smooth twists.

Keywords: Corner-ridged square waveguides, rectangular waveguides, twists, waveguide components.

1. INTRODUCTION

Waveguide twists are widespread components of microwave and millimeter-wave systems based on rectangular waveguides. Usual 90-degree twists formed by a mechanical rotation of a rectangular waveguide cross-section along its longitudinal axis have the best matching at the length close to several half-wavelengths in the twisted waveguide [1]. To achieve an acceptable standing wave ratio (SWR) level over a broad frequency band, the twists lengths should be increased. This decreases the possibilities of such twists usage under conditions of a limited volume that is typical, e.g., for satellite systems.

Alternative to smooth 90-degree twists can be stepped (see, e.g., [2] and [3]) or more compact twists based on waveguides of complicate cross-sections that play a part of transformer regions rotating a polarization plane of the TE_{10} mode incident from the input waveguide [4-6]. Compact twists with transformer sections in the form of a square waveguide with two stepped ridges of different shapes have been proposed and considered in the papers [5, 6].

In the present paper, the results of calculations and measurements of compact optimized twist configurations reported in [5, 6] and their comparison with the measured data for two smooth twists of different lengths in the waveguide 23×10 mm are presented.

2. TWIST CONFIGURATIONS AND MODELS

In Fig. 1a, the twist configuration, considered in [6], is shown. It consists of input and output rectangular waveguides of the $a \times b$ cross-section oriented by the angle of 90 degrees and transformer section of the length l.

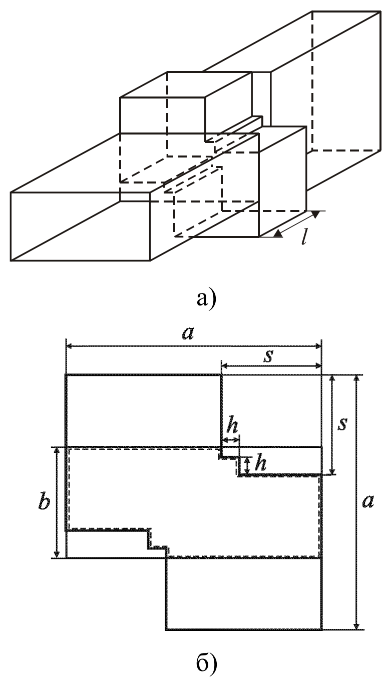

Fig. 1. Compact twist configuration (a) and cross-sections of input rectangular waveguide and transformer section (b).

The studied twist is symmetrical relative to the longitudinal axis. Cross-sections of input rectangular waveguide and transformer section are shown in Fig. 1b. Here, the dashed line outlines a common aperture of these waveguides. The section represents the $a \times a$ square waveguide with two diagonally opposite identical stepped corner ridges. The $s \times s$ corner ridges have the additional $h \times h$ cuts. At h=0 the twist configuration corresponds to that considered in [5]. We will call configurations with h=0 as twists of the first type and with h>0 as ones of the second type.

Electromagnetic models of the considered twists are built with using the mode matching and generalized scattering matrix techniques. These methods are realized within the system of electromagnetic simulation [7] oriented on a wide class of waveguide devices with coordinate boundaries. The system recognizes the twists as a sequence of waveguide plane junctions. The mode matching technique is used to calculate their generalized scattering matrices in terms of the TE and TM modes.

A number of the TE and TM modes, taken into account in the connected waveguides, determines the calculation accuracy of the generalized *S*-matrices of the appearing key waveguide junctions. The system allows calculating orthonormalized basis of the TE and TM modes in rectangular and complex cross-section waveguides whose cutoffs do not exceed the given limiting value f_{max}.

The twist design has been carried out with the aid of the optimization procedure based on the steepest descent method. The used cost function requires a minimum reflection over the specified frequency range. The ridge size *s* and the length *l* of transformer waveguide section are considered as objective variables for the first-type twist. The parameters *s*, *h*, and *l* are the objective variables for the second-type twist. Design results discussed below are obtained at f_{max} =100 GHz.

3. Results of Numerical and Natural Experiments

3.1. Performance of Compact Twists

The comparative analysis showed that the twists differ in their characteristics depending on their type, operating bandwidths, and the relation between the sizes of waveguide narrow and wide walls, namely, when b/a=0.5 or b/a<0.5. Such relations are typical for standard rectangular waveguides. It has been found that the first-type twists with the wall relation b/a=0.5 are able to provide the 36.5% bandwidth at the level of SWR=1.1 and the second-type ones – 44.5% with SWR<1.02. For the standard rectangular waveguides with b/a<0.5, each twist configuration has to be considered individually.

To confirm the results of numerical experiments, the twist of both types in the 23×10 mm rectangular waveguide have been designed and manufactured and their characteristics have been measured. The dimensions of twists of the first (*s*=9.47 мм, *l*=1.5 mm) and second (*s*=9.0 мм, *l*=15.5 mm) types have been found by the results of optimization over the 8 – 12 GHz bandwidth.

The twist prototypes were manufactured in different ways. The first-type twist block was manufactured using a brass plate of the thickness *l*=6.8 mm. Due to the small plate thickness, it was possible to make the corner-ridged square waveguide channel using the electrospark discharge machine. The second-type twist brass prototype was manufactured from two separated half parts using the milling machine. To provide a flange connection to the input and output rectangular waveguides, the holes for the fixing bolts and dowels were bored in the twist block.

The calculated frequency responses of the optimized twists are shown by solid curves in Figs. 2 and 3, respectively. The first twist provides the 31% bandwidth and the second one – the 43% bandwidth at the level SWR<1.065 that corresponds to the return loss of 30 dB. Point-to-point measurements of the frequency responses have been carried out with using a noncomputerized scalar network analyzer R2-61.

The measured responses of twists of the first and second types are shown by black circles in Figs. 2 and 3, respectively. As one can see, the simulated and measured results are in reasonably good agreement. The observed discrepancies in the simulated and measured results can be attributed to manufacturing uncertainties, an amplitude ripple of the used waveguide termination as well as a limited dynamic range of the analyzer.

3.2. Comparison of Performance of Compact and Smooth Twists

A more comprehensive idea of compact twists possibilities can be obtained by results of the comparative analysis of their performance and those for conventional smooth configurations. Two smooth twists with the distances of 100 mm and 200 mm between output flange plane faces were chosen for this analysis.

The measured frequency response for the smooth twist of the length 100 mm is shown in Fig. 2 by the curve with squares. It has an oscillating character that is inherent for lengthy waveguide discontinuities. Comparing the characteristics presented in Fig. 2, one can conclude that the 100-mm smooth twist ranks below the first-type twist in the matching level within a greater part of the waveguide operating range (8.15 – 12.04 GHz).

The dashed line with triangles in Fig. 3 is obtained by measurements of the 200-mm smooth twist having a flute in one of flanges to provide a coupling with a circular choke groove. The solid line with squares corresponds to the same twist but with the reduced thickness of the mentioned flange by the groove depth. This allows one to eliminate a coupling with the choke when connecting with a plane flange.

The frequency responses of such a smooth twist, in the presence and in the absence of a coupling with the choke, have a strongly oscillating character due to a large twist length but their behavior is different. In the first case, oscillations are sufficiently even within the lower and middle parts of the frequency band, whereas, in the second case the oscillations decay with increasing the frequency.

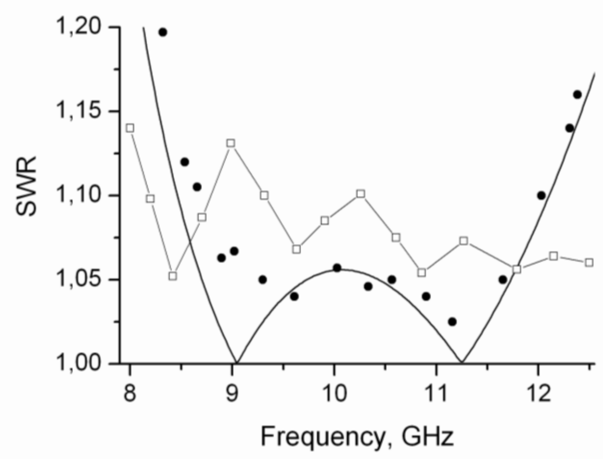

Fig. 2. Theoretical (solid curve) and measured (circles) responses of the first-type twist. The line with squares corresponds to the 100-mm smooth twist.

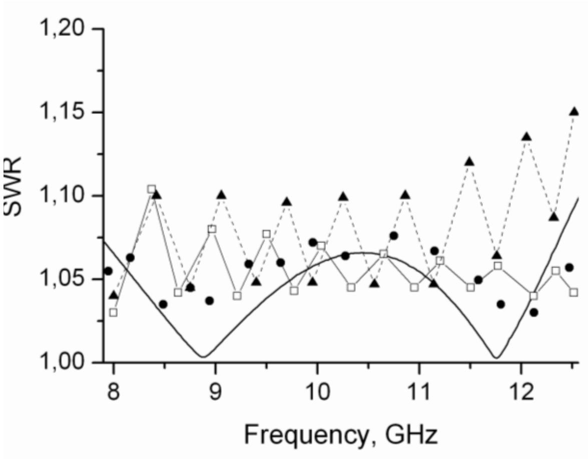

Fig. 3. Theoretical (solid curve) and measured (circles) responses of the second-type twist. The lines with triangles and squares correspond to the 200-mm smooth twist.

In whole, from the comparison of results presented in Fig. 3 one can draw a fundamental conclusion that both variants of the long smooth twist have no advantages over the second-type twist at the matching level throughout the waveguide operating range.

4. CONCLUSION

The presented results show that the novel compact configurations of 90-degree twists, formed by sections of square waveguides with two square or stepped ridges, provide a high matching level throughout the waveguide operating range or over its specified part. The comparison of theoretical and measured responses of the manufactured twist prototypes of two types for the 23×10 мм rectangular waveguide confirms their good agreement. It is significant that, at close or even better performance, the lengths of proposed twists are ten and more times less than the ones of conventional smooth twists.

ACKNOWLEDGMENTS

The authors thank the workers at the Yuzhnoye State Design Office, Dnieperpetrovsk for help with carrying out measurements.

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