Combined twist-bend with compact-size and broad bandwidth

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Abstract: A novel combined twist-bend with compact-size and broad bandwidth is proposed in this letter. It provides an interconnection of two waveguides with 90 degrees oriented cross-sections and a perpendicular alignment of their axes. The basic structure consists of a multi-step central waveguide and two transformer sections, which made the twist-bend with compact size and broad bandwidth. For verification purpose, a prototype has been manufactured and measured. Measurements of a WR28 combined twist-bend exhibit a return loss greater than 24 dB and a insertion loss better than 0.1 dB over the full waveguide bandwidth. Also the good agreement has been found between the simulated and measured results.

Keywords: broad bandwidth, compact-size, twist-bend, waveguide

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

Modern communications equipment is focusing at integrated waveguide subsystems for easy handing and interfacing within the overall system [1]. Mostly the waveguide parts like bends, twists and transformers are required for the interconnection of the components and the interfaces of the system. So compact twist-bend with broad bandwidth is very useful in the waveguide subsystems. And high performance over a wide operating band and suitable implementation based on the general production method of the twist-bend are aspired.

A variety of bend configurations are discussed in [2, 3, 4, 5] and different twist designs have been provided in [6, 7, 8, 9, 10], but few designs have been demonstrated at combined twist-bend suited for machining in integrated waveguide structures. J. A. Ruiz-Cruz et al. [11] have reported a combination of a separate twist and bend. It provides good matching properties over a full waveguide band, but it lacks of compactness and it is a non-planar structure so that expensive to manufacture and not suited for machining in integrated waveguide structures.

This letter describes a combined twist-bend that is based on a design investigated by U. Rosenberg et al. [1] The main difference between the structure in [1] and the structure this paper used is that a multi-step central waveguide has been introduced and it connected via two transformer sections without irises, as illustrated in Fig. 1. It provides orthogonal rotation of both direction and polarization. Some characteristics of this twist-bend are presented, as well as design process. A prototype is presented with measured data. In a frequency range from 26.4 GHz to 40 GHz, corresponding to the full bandwidth of a WR28 waveguide, the return loss and insertion loss are better than 24 dB and 0.1 dB, respectively. To the authors’ knowledge, no such compact combined twist-bend with full bandwidth and good return loss has ever been reported before. A comparison of this twist-bend with some other reported is summarized in Table I.
The configuration with port nominations of the proposed combined twist-bend is shown in Fig. 1. It includes a central waveguide and two transformer sections. To obtain broad bandwidth and good return loss, multi-step central waveguide has been assumed. For ease of fabrication and assembling, all the upper sides of the transformer sections are aligned with the upper sides of the central waveguide. The idea of introducing such multi-step central waveguide came from our attempts to improve the main performance parameters of the twist-bend, such as bandwidth and return loss, through optimization tool from the well-known commercial simulator CST Studio. In order to obtain good return loss and compact-size of the twist-bend, one, two, three, four and five steps in the central waveguide were studied, respectively, with all the configuration parameters of the transformer sections fixed. The best results from each case are shown in Fig. 2. It can be seen that the performance will improve when number of steps increases. As a compromise, we choose 5-step central waveguide in our prototype combined twist-bend.

| Technology | Bandwidth | Return Loss | Insertion Loss | Fabrication |
|------------|-----------|-------------|----------------|-------------|
| Combined twist-bend [1] | 20%-35% | 38 dB | Not given | easy |
| combination of a separate twist and bend [10] | 40% | 30 dB | Not given | difficult |
| The proposed twist-bend | 40% | 24 dB | 0.1 dB | easy |

2 Configuration

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3 Design and simulation results

In order to explain the design process of such a compact combined twist-bend with full bandwidth, as an example, we will design a twist-bend in the bandwidth between 26.4 GHz and 40 GHz. For measurement purpose, both ports are tapered to WR28 waveguide size. Since all the structures are manufactured by computer numerical controlled (CNC) milling techniques, the assigned twist-bend designs have to consider appropriate milling radii to facilitate the overall production. Here we let all respective radii that are prerequisite for the application of CNC milling techniques as a optimization variable $r$. Through optimization, it was found that the compromise must be taken between bandwidth and good return loss. Modeling of the twist-bend is done using commercial simulator CST Studio with lossy silver material and the simulation results obtained from modeling with CST are shown in Fig. 5, together with the measured results.

Table II. Value of variable dimensions of the combined twist-bend

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|------------|------------|------------|
| $A$        | 7.328      | $B$        | 1.771      |
| $A_1$      | 1.486      | $H_1$      | 4.016      |
| $A_2$      | 1.841      | $H_2$      | 4.984      |
| $A_3$      | 1.568      | $H_3$      | 5.592      |
| $A_4$      | 1.567      | $H_4$      | 6.115      |
| $A_5$      | 0.866      | $H_5$      | 6.522      |
| $a$        | 7.112      | $b$        | 3.556      |
| $l_{10}$   | 1.005      | $b_{10}$   | 2.163      |
| $l_{11}$   | 3.078      | $b_{11}$   | 2.836      |
| $l_{12}$   | 2.068      | $b_{12}$   | 3.301      |
| $l_{20}$   | 0.928      | $b_{20}$   | 2.346      |
| $l_{21}$   | 2.496      | $b_{21}$   | 2.888      |
| $l_{22}$   | 2.608      | $b_{22}$   | 3.500      |
| off        | 0.361      |            |            |
In a frequency bandwidth from 26.4 GHz to 40 GHz, corresponding to the full frequency bandwidth of a WR28 standard waveguide (a = 7.112 mm, b = 3.556 mm), the return loss is more than 24 dB. The final parameters are listed in Table II. And all the milling radii \( r = 0.83 \) mm, which is not labeled in Fig. 3.

An important point need to be noted here. The combined twist-bend not only has good return loss over the full bandwidth of a standard waveguide, but also its basic part can completed with a flat lid, thus only one part needs to be precisely machined facilitating overall low implementation cost.

![Diagram of twist-bend](image)

Fig. 3. Top view (a) and side view (b) of the proposed twist-bend.

### 4 Measured results

A sample combined twist-bend with full bandwidth was fabricated according to the configuration parameters given in the above Section. The material used to fabricate the design is silver-plated aluminium alloy and the machining accuracy is \( \pm 0.02 \) mm. Fig. 4 shows the photograph of the sample twist-bend with its inner structure by CST in detail. Its over sizes are \( 24 \times 25 \times 21 \) mm.

Scattering parameter measurements were performed using an Agilent E8361A network analyzer and the measured results are shown in Fig. 5, together with the corresponding result from simulations for comparison purpose. From Fig. 5 we can see that, over the full waveguide bandwidth from 26.4 GHz to 40 GHz, the return loss is more than 24 dB, corresponding to a VSWR of 1.13, and the insertion loss is better than 0.1 dB. We can also see relatively good agreement between the measured and simulated results. The discrepancies between the measured and
simulated results are mainly due to the fabrication errors. We believe that the agreement between measured and simulated results in Fig. 5 would be even better if the machining accuracy was enhanced.

![Figure 4](image1.png)
(a) (b)

**Fig. 4.** Photograph of the sample combined twist-bend (a) and its inner structure (b).

![Figure 5](image2.png)

**Fig. 5.** Measured and simulated results from the sample twist-bend.

## 5 Conclusion

A compact combined twist-bend has been proposed, which has good return loss over the whole bandwidth of a standard waveguide. As an example, a prototype twist-bend has been designed, fabricated and measured. Tested results from the prototype twist-bend shows that the return loss is more than 24 dB and the insertion loss is better than 0.1 dB in the full bandwidth of the WR28 standard waveguide. It is easily designed, and can be fabricated at low cost with excellent repeatability.