An X-band single-layer waveguide directional filter with compact size and low insertion loss

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Abstract: A novel waveguide directional filter with compact-size and low insertion loss is proposed in this letter. The basic structure consists of a pair of rectangular waveguides placed parallel to each other along their narrow side and two identical band-pass filters connect them via two coupling slots. For easy of fabrication and assembling, all the band-pass filters and waveguides have a uniform height, that is all the components of the directional filter are in a single-layer waveguide. It is easy machining by standard computer numerical controlled (CNC) techniques to match the requirement for low cost. For verification purpose, an X-band single-layer waveguide directional filter has been manufactured and measured. The measured results show a insertion loss better than 0.1 dB, a return loss lower than $-17.5$ dB and a isolation better than $-22.5$ dB, good band-pass and band-elimination responses are also obtained over the frequency range from 7.25 GHz to 9.75 GHz. The good agreement has been found between the simulated and measured results.

Keywords: compact-size, low insertion loss, single-layer, waveguide directional filter, X-band

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

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1 Introduction

A directional filter is a well matched four-port device which can be used as a absorptive filter or a complementary diplexer in a transmit-receive system. A variety of directional filter configurations and theory are discussed in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. R. L. Williams [1] has reported a waveguide directional filter by using magnetic coupling with the field configuration for the TE111 mode in circular cavity. Kumazawa. H [2] has reported a pill-box-type directional with low-loss and lightweight, but they are three-dimensional structures and they are difficult for fabrication and assembling. Traveling-wave loop [3, 8, 9] and half- or full-wavelength strips [4] belong to the stripline or microstripline type, they have attractive compact-size characteristics, but they are affected by significant losses and low power-handing capabilities.

In this letter, a novel and simple waveguide directional filter with compact-size and low insertion loss is proposed and investigated. The main differences compared with the conventional ones are that all the components of the directional filter are in a single-layer waveguide to obtain compact size and easy fabrication. Also it is simple in realization and has acceptable band-pass and band-elimination responses. A comparison of this directional filter with some other reported is summarized in Table I.

2 Configuration

The configuration and the port nominations of the proposed directional filter are shown in Fig. 1. It includes a pair of rectangular waveguides and two identical band-pass filters. They are coupled to each other by two identical coupling slots.

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To simplify the design process, all the components are assumed with the same height, corresponding to a single waveguide layer, and the whole structure are symmetric with respect to the middle plane normal (BB’) and parallel (AA’) to the axis of the waveguides.

The idea of introducing such directional filter configuration came from our attempts to obtain a waveguide directional filter with compact-size and low insertion loss. It is also simple and easy machining by standard computer numerical controlled (CNC) techniques to satisfy low equipment costs.

### 3 Design and simulation results

In order to explain the design process of such a single-layer waveguide directional filter with compact-size and low insertion loss, as an example, we will design a directional filter in the bandwidth between 7.25 GHz and 9.75 GHz. Through optimization tool from the well-known commercial simulator CST Studio, it was found that the compromise must be taken between good band-pass response and low return loss. At first, the structure was optimized without all the ports tapered to the rectangular WR112 (a = 28.499 mm, b = 12.624 mm). For measurement pur-
pose, four three-section transformers are then added to the structure to convert all ports to WR112 waveguide size, in order to facilitate the measurements.

The directional filter with all transformers is shown in Fig. 2. Since all the structures are manufactured by computer numerical controlled (CNC) milling techniques, the assigned directional filter 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 $r$. The calculated results from which is shown in Fig. 3 with its inner structure by CST in detail, where $S$-parameters $S_{11}$, $S_{21}$, $S_{31}$, $S_{41}$ represent the power coming out from port 1, port 2, port 3 and port 4, respectively, when power is injected into the input port (port 1). In a frequency bandwidth from 7.25 GHz to 9.75 GHz, the insertion losses are lower than 0.1 dB in their band-pass responses, the return loss and the isolation are both better than 18 dB. The final parameters of the directional filter are listed in Table II. All the milling radii $r = 3.31$ mm, and the uniform height of the whole structure $b = 12.62$ mm, which are not labeled in Fig. 2.

![Fig. 2. Top view of the proposed directional filter with transformers.](image)

![Fig. 3. Simulation results of the proposed directional filter.](image)
An important point need to be noted here. The directional filter not only has good band-pass and band-elimination filter responses with compact size and low insertion loss, 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.

4 Measured results

A sample directional filter 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 ±0.02 mm. Fig. 4 shows the photograph of the sample directional filter. Its over sizes are 151 mm * 95 mm * 48 mm. The volume have been reduced by approximately 40%, compared with the three-dimensional waveguide directional filter [1, 2] in the same frequency band.

| Parameters | Value (mm) | Parameters | Value (mm) |
|------------|-----------|------------|------------|
| $a_0$      | 24.20     | $w_1$      | 24.20      |
| $a_r$      | 25.27     | $w_1$      | 24.20      |
| $w$        | 31.39     | $a_1$      | 28.50      |
| $w_r$      | 7.85      | $a_2$      | 26.86      |
| $l$        | 5.60      | $l_0$      | 11.07      |
| $l_{r1}$   | 24.29     | $l_1$      | 2.88       |
| $l_{r2}$   | 22.50     | $l_2$      | 1.70       |

Table II. Value of variable dimensions of the directional filter

Fig. 4. Photograph of the sample directional filter.

Scattering parameter measurements were performed using an Agilent E8361A network analyzer and the measured results are shown in Fig. 5, together with the corresponding results from simulation for comparison purpose. From Fig. 5 we can see that, over the bandwidth from 7.25 GHz to 9.75 GHz, the return loss (S11) is lower than −17.5 dB, corresponding to a VSWR of 1.3, the insertion losses (S21 and S31) are lower than 0.1 dB in their band-pass responses, the isolation (S41) is
better than $-22.5$ dB, good band-pass (S31) and band-elimination (S21) responses have been obtained from port 3 and port 2, respectively. 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.

![Graphs of S11, S41, S21, and S31](image)

Fig. 5. Measured and simulated results from the sample directional filter: (a) S11 and S41; (b) S21 and S31.

5 Conclusion

A simple single-layer waveguide directional filter with compact size and low insertion loss has been proposed, which has good return loss, isolation, band-pass and band-elimination responses in X-band. As an example, a prototype directional filter has been designed, fabricated and measured. Tested results from the prototype directional filter shows that the insertion loss, return loss and isolation are better than 0.1 dB, $-17.5$ dB and $-22.5$ dB, respectively, good band-pass and band-elimination filter responses are also obtained in the required bandwidth. It is simple and can be fabricated at low cost with excellent repeatability.