Analysis and Design of Grooved Circular Waveguide Dual-Mode Filters

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ABSTRACT

This paper presents a novel type of circular waveguide dual-mode filter with grooves for coupling orthogonal resonant modes and correcting resonant frequency. The presented dual-mode filter is suitable for realizing high performance without tuning elements in Ka-band and above because of the simple structure. A Ka-band elliptic function type dual-mode filter has been designed by accurate and fast full-wave analysis performed using mode-matching techniques.

INTRODUCTION

In general, circular waveguide dual-mode filters are useful in antenna feed systems aim at low loss response and high selectivity between adjacent channels. Dual-mode filters, which provide orthogonal resonant modes in a physical cavity, have several elements for coupling orthogonal resonant modes and correcting resonant frequency of respective modes. Typical examples of coupling and correcting element are a screw, a metallic post, a rectangular waveguide iris, and a circular waveguide iris [1-4]. Dual-mode filters with the above-mentioned elements are suitable for realizing high performance under Ku-band. In Ka-band and above, however, these filter types have the serious degradation in the performance due to manufacturing inaccuracy because of complex coupling structure. In addition, they have the difficulty of setting up tuning elements, because the dimensions of waveguide cross sections should be designed very small to avoid excitation of higher order propagation modes. Consequently, for circular waveguide dual-mode filters operated in the Ka-band and above, low complexity of the physical coupling structure is required to reduce influence of manufacturing inaccuracy. And further, the design is in need of an accurate analysis to realize high performance without tuning elements.

In this paper, we present a novel type of dual-mode filter that is composed of grooved circular waveguides. The presented dual-mode filter is suitable for realizing high performance and low fabrication cost in Ka-band and above because of simple structure without screws, metallic posts, and waveguide irises. And further, we propose accurate analysis and design techniques of the dual-mode filter with grooves, which is performed using full-wave mode-matching techniques for circular-to-rectangular waveguide junctions [5-8]. As a design example, a Ka-band elliptic function type dual-mode filter has been designed by the above analysis techniques.

CONFIGRATION

Fig.1 shows a structure of the proposed grooved circular waveguide dual-mode filter. The dual-mode filter is composed of circular waveguide cavities, apertures located at top/bottom wall of the cavities, and several grooves situated partially at side wall of the cavities. In Fig.1, the grooves arranged 45degree offset with regard to the H-plane of input/output rectangular waveguides are coupling elements between orthogonal resonant modes in the cavity, and the grooves arranged vertically are

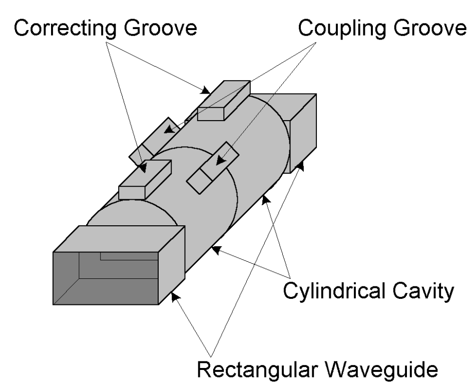

Figure 1: Grooved Circular Waveguide Dual-Mode Filter

elements for correcting resonant frequency of horizontally polarized mode.

The grooved circular waveguide dual-mode filter has the advantage of reducing the degradation in antenna feed performance due to manufacturing inaccuracy, because the filter has the coupling and correcting grooves in the sparse electromagnetic field (i.e., in the wall of the circular waveguide) instead of arranging any salient posts and thin irises in the dense electromagnetic field (i.e., inside of the circular waveguide). And further, an accurate design of the filter can be performed by fast full-wave analysis on account of the simple structure.

ANALYSIS

Fig.2 illustrates the concept for full-wave analysis of grooved circular waveguide, which is the most important component of the proposed dual-mode filter. As shown in Fig.2, the grooved circular waveguide is composed of two key-building block elements, that is, a circular-to-rectangular waveguide T-junction and a short-circuited rectangular waveguide. Therefore, analysis of the grooved circular waveguides is performed using mode-matching method for circular-to-rectangular waveguide H-plane and E-plane T-junctions associated with the generalized S-matrix techniques [5,6]. The full-wave analysis techniques have the capability of including high-order mode influences and the advantage of shortening the computing time as compared with other numerical techniques. Finally, accurate analysis and design of the presented dual-mode filter can be realized by cascading the generalized scattering matrices of H/E-plane T-junctions, short-circuited rectangular waveguides, double-plane step in rectangular waveguide, and rectangular-to-circular waveguide steps [5-8].

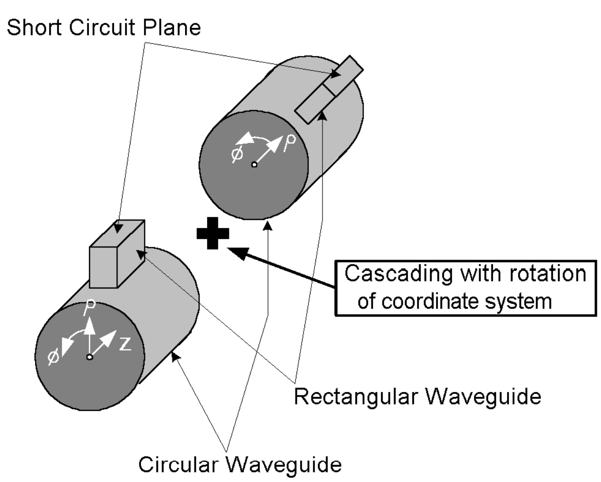

Figure 2: Analysis Concept of Grooved Circular Waveguide

Fig.3 shows calculated coupling characteristics between orthogonal resonant modes in Ka-band grooved circular waveguide cavity. The computed data are obtained by simulating well-known measurement model of coupling coefficient between resonant modes using the above-mentioned full-wave analysis techniques [9]. In the simulation model, the groove is situated along the half-length of the cavity and arranged 45degree offset with regard to the H-plane of the input rectangular waveguide. As shown in Fig.3, calculated characteristics vary in coupling coefficient from 0 to 0.04 with the size of the groove. The results indicate that the proposed dual-mode filter can be used for various applications require bandwidth of less than 4%.

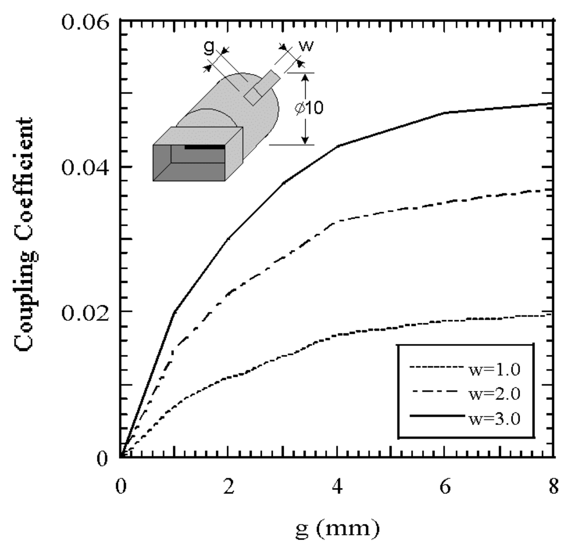

Figure 3: Calculated Coupling Characteristics between Orthogonal Resonant Modes in the Grooved Circular Waveguide Cavity

Fig.4 shows calculated resonant frequencies of orthogonal modes in Ka-band grooved circular waveguide cavity. Similarly, the computed data are derived from simulating well-known measurement model of resonant frequency in a cavity [9]. In the simulation model, the groove is situated along the half-length of the cavity and arranged 0degree or 90degree offset with regard to the H-plane of the input rectangular waveguide. In the case of assigning 0degree offset groove, calculated resonant frequencies of the cavity vary suitably with the size of the grooves. On the other hands, calculated resonant frequencies in the case of assigning 90degree offset groove little vary with the size of the grooves. The above results indicate that resonant frequencies of orthogonal dual modes can be corrected independently using 0degree or

90degree offset grooves. Consequently, the presented grooves are regarded as appropriate correcting elements in the dual-mode filter.

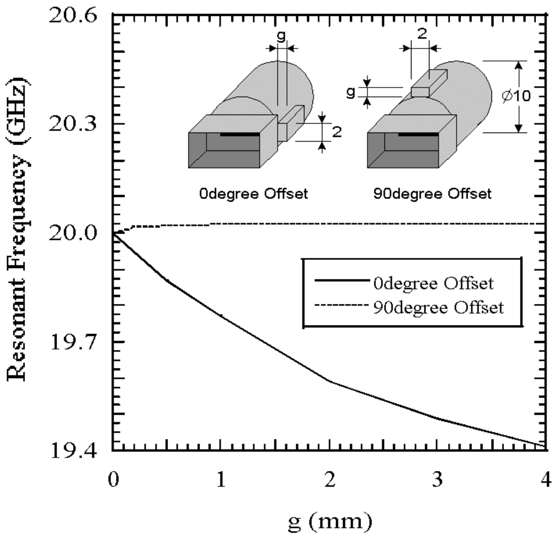

Figure 4: Calculated Resonant Frequencies of the Grooved Circular Waveguide Cavity

DESIGN

As a typical design example, a 4-pole/2-cavity elliptic function filter is designed in Ka-band with the aid of the above-mentioned analysis techniques and a mathematical model [1]. The total length of the designed filter is 31mm, and the diameter of the circular waveguide cavities is 10mm. The coupling and correcting grooves are situated along the half-length of the cavity as shown in Fig.1. The width and depth of coupling grooves are 2mm and 4mm respectively, and the width and depth of correcting grooves are 2mm and 0.4mm respectively. The size of the input/output rectangular waveguides is 10.7mm*4.3mm, and the size of the slots between the input/output waveguide and the cavities is 7mm*1.5mm. And further, the width and length of the slot between the cavities are 2.5mm and 5.2mm respectively. Incidentally, the slot width is determined in consideration of bypass coupling. Fig.5 shows the reflection and the transmission characteristics of the designed Ka-band grooved circular waveguide dual-mode filter. The refection characteristics computed by full-wave analysis prove a good match (VSWR 1.15) over the frequency range between 19.7GHz to 20.2GHz and well coincide with the elliptic function responses derived by mathematical model. Moreover, Fig.6 shows the degradation in the reflection response due to manufacturing inaccuracy, that is, giving errors (+/-0.02mm) to all dimensions of the designed coupling and

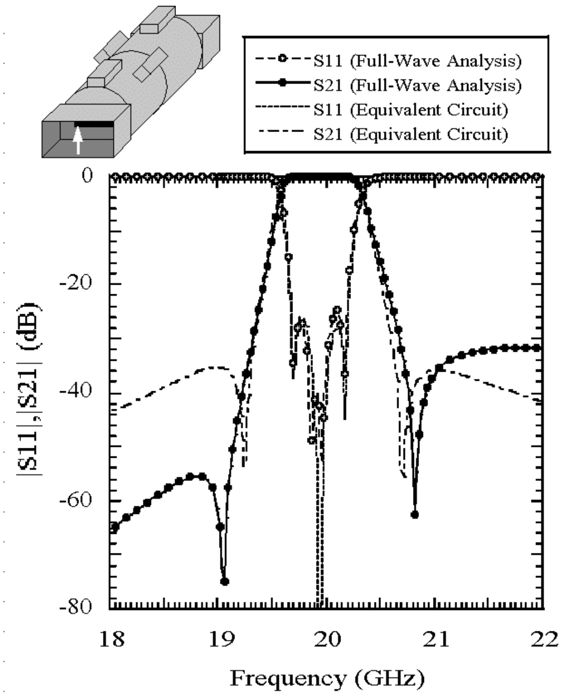

Figure 5: Computed Frequency Response of the Ka-band Grooved Circular Waveguide Dual-Mode Filter

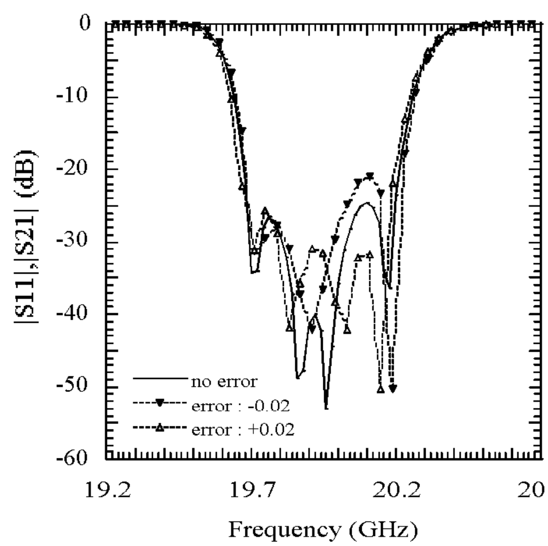

Figure 6: Calculated Reflection Characteristics of the Ka-band Grooved Circular Waveguide Dual-Mode Filter: The Degradation in Performance due to Giving Errors to All Dimensions of the Designed Grooves

correcting grooves. The error 0.02mm is practical manufacturing tolerance. Therefore, the results of the error analysis indicate that excellent performance (i.e. the VSWRs less than 1.2 over the frequency range between

19.7GHz to 20.2GHz) can be obtained without tuning elements. The above results verified the high efficiency of the presented grooved circular waveguide dual-mode filter.

CONCLUSIONS

A configuration, analysis and design of a grooved circular waveguide dual-mode filter have been introduced. The presented dual-mode filter is suitable for realizing high performance and low fabrication cost in the Ka-band and above because of the simple structure. The accurate design of the dual-mode filter has been performed by the full-wave analysis of circular-to-rectangular waveguide H-plane and E-plane T-junctions using mode-matching techniques. A Ka-band dual-mode filter has been designed with the aid of the above-mentioned analysis techniques, and excellent elliptic function responses have been calculated by full-wave analysis. And further, the results of error analysis have verified the high efficiency of the presented grooved circular waveguide dual-mode filter.

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