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Co-channel interference analysis at faulty K band waveguide joints

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Research Paper

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Abstract

Channel interference is a significant issue for many applications such as satellite communication, mobile communication, and RADAR communication. This paper presents co-channel interference analysis at faulty K band waveguide joints using the multi-cavity modeling technique. Numerical data obtained from multi-cavity modeling technique analysis has been compared with CST microwave studio simulated data and verified with measured data.

Introduction

Rectangular and circular waveguides have been used since World War II and are still used. These waveguide-based elements have wide applications in various frequency bands ranging from 1 to 1000 GHz. Phased array antennas are used in RADAR, satellite communication, broadcasting, space probe communication, weather research, human-machine interface, 5G and Wi-Fi. Multiport power dividers or combiners are used as a feeding network for phased array antennas. As multiple input multiple output techniques are used in many applications, channel interference has become a significant issue.

A literature survey on channel interference reveals that many authors have described it in coaxial cables, microstrip lines and optical fiber cables [1–3]. Coupling of power at waveguide joint has been analyzed for X-band and Ku-band only [4–6]. Many research studies are going on longitudinal waveguides for high power transmission and radiation. For high-frequency applications, it is necessary to use a waveguide-based component. When a two-dimensional array with a power divider through flange is joined, there may be a gap due to faulty workmanship. This gap is unwanted, may cause coupling of power to an adjacent channel. So, at higher frequency bands, channel interference should be analyzed.

An excellent technique for the analysis of waveguide-based components is multi cavity modeling technique (MCMT). It was proposed by Vengadarajan [7]. This technique analyzes slot antenna, open-ended waveguide, to estimate EMC/EMI at faulty joint and directional coupler. Further, E-plane Tee, H-plane Tee, power dividers and combiners have been analyzed using the multi-cavity modeling technique by Das, Chakraborty and Panda [8–12]. More work has been done to analyze waveguide-based networks for high frequency [13].

This paper presents the analysis of coupling at E-plane waveguide joints using the multi-cavity modeling technique. Generally, in this technique, the equivalent magnetic current density replaces all the opening and gaps of the waveguide structure. So it becomes easy to analyze the structure using magnetic field integral equation (MFIE). Here four waveguides are used to model this structure, and the gap is considered as a cavity. Further, the tangential component of the magnetic field scattered inside the waveguide and cavities are determined using the procedure outlined in [12], and the continuity of the tangential component of the magnetic field at coupling aperture is also considered. Now to solve for the electric field at the window aperture, the method of the moment is used. By using basis functions, this method converts all the integral equations into matrix equations. By knowing the aperture fields, reflection and transmission coefficients are being estimated. As coupling regions are of arbitrary dimension, the cross-polarization component has been considered in the analysis. Other higher bands can also be analyzed using MCMT.

Theory

At the beginning for the analysis of co-channel interference, a theoretical model has been prepared using two-channel E-plane waveguides, shown in Fig. 1. The CST simulated three-dimensional view is shown in Fig. 2. It shows that the structure has four waveguide regions wvg-1 to wvg-4 and one cavity gap. It also has four interfacing apertures (A_1-A_4).

When the structure is fed at its input port, field distribution is established on the apertures. The equivalent magnetic current densities replace the interfacing apertures between different regions. There are four magnetic current densities M_1 to M_4 as per four apertures A_1 to A_4 [14]. These are considered sources and can be obtained by modal expansion method for waveguide regions (Wvg-1 to Wvg-4) and using cavity Green's function for cavity region. By

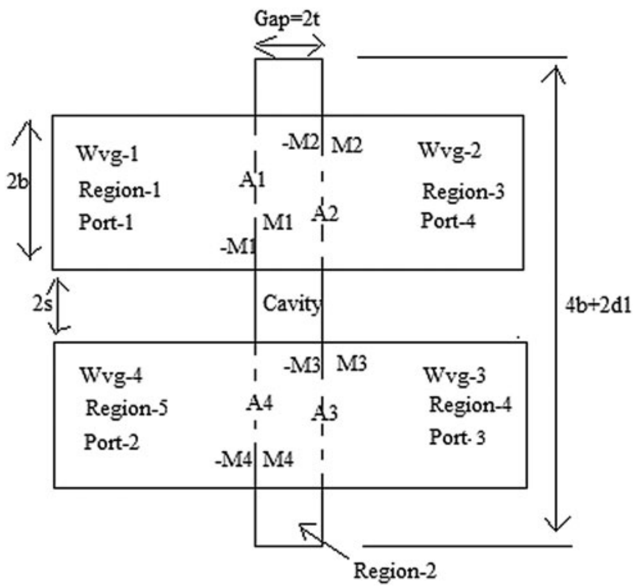

Fig. 1. E-plane two-channel waveguide joint in terms of cavity, waveguides, different regions, and magnetic current at the apertures.

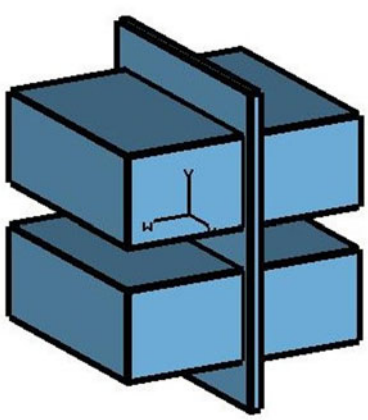

Fig. 2. CST simulated a 3D view of two-channel E-plane waveguides with a gap.

applying the continuity of the tangential component of the magnetic field across the apertures, boundary conditions can be found between different regions as given in [6].

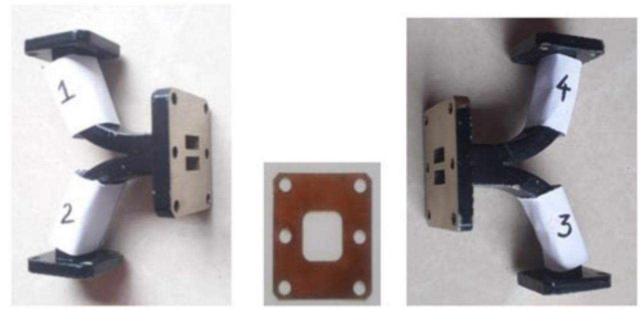

Fig. 3. Image of two-channel E-plane waveguide bends and a copper plate.

Table 1. Different dimensions of the gap for measurement.

Structure no.		d (mm)	d 1 (mm)	2t (mm)
K band	1.	0.66	3.184	0.3
	2.	0.166	2.182	0.5
	3.	0.6	6.18	0.3

Fields are represented over Y-Z plane. Here Y-component of the incident magnetic field at the aperture is a dominant TE_{10} mode and is given by

$$H_Y^{in} = -Y_0 \cos\left(\frac{\pi y}{2a_i}\right) e^{-j\beta x}$$

As electric field distributions are unknown, but can be expressed as a weighted sum of sinusoidal basis functions, which can be given as

$$e_p^{i,z} = \begin{cases} \sin\left\{\frac{p\pi}{2L}(y - y_w + L)\right\} & \text{for } y_w - L \le y \le y_w + L, \\ & z_w - W \le z \le z_w + W \\ 0 & \text{elsewhere} \end{cases} \quad (1)$$

Here $E_p^{i,y/Z}$ are the unknown weights and $e_p^{i,y/z}$ are the sinusoidal basis function which is given by:

$$e_p^{i,z} = \begin{cases} \sin\left\{\frac{p\pi}{2L}(y - y_w + L)\right\} & \text{for } y_w - L \le y \le y_w + L, \\ & z_w - W \le z \le z_w + W \\ 0 & \text{elsewhere} \end{cases} \quad (2a)$$

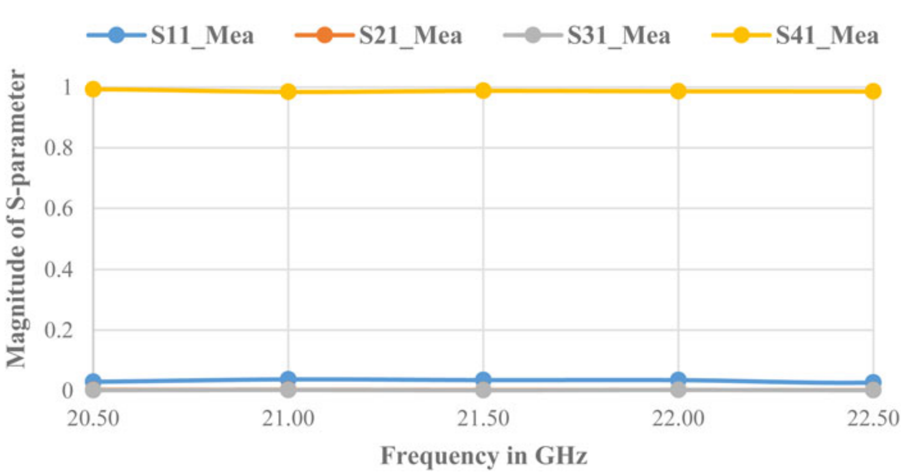

Fig. 4. Graph of measured S-parameters for E-plane WR-42 waveguide two-channel joints for K-band without a gap.

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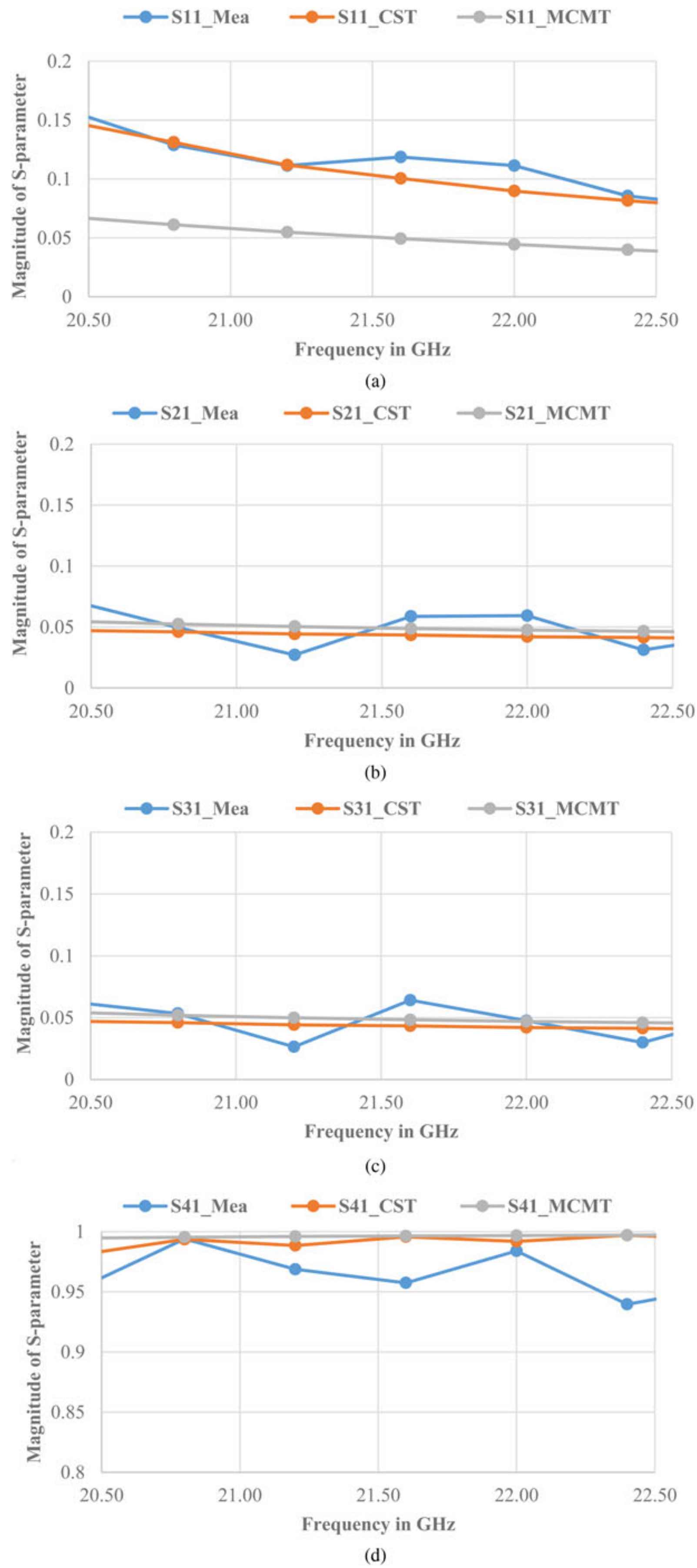

Fig. 5. Comparison of scattering parameters (a) S_{11}, (b) S_{21}, (c) S_{31} and (d) S_{41} of MCMT, CST microwave studio simulated data and measured data for E-plane WR-42 waveguide two-channel joints for K-band with a gap of 2t = 0.3 mm, d = 0.6 mm and d1 = 6.18 mm.

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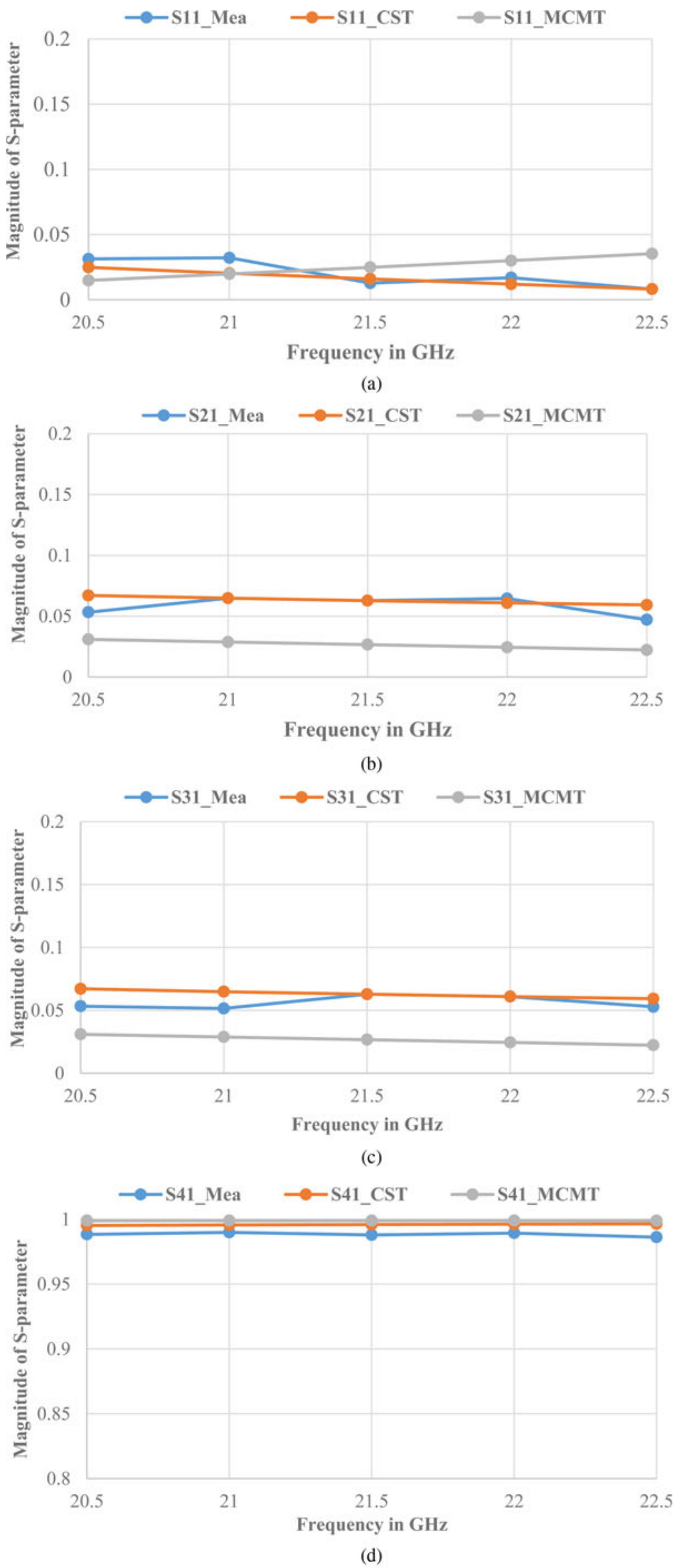

Fig. 6. Comparison of scattering parameters (a) S_{11}, (b) S_{21}, (c) S_{31} and (d) S_{41} of MCMT, CST microwave studio simulated data and measured data for E-plane WR-42 waveguide two-channel joints for K-band with a gap of 2t = 0.5 mm, d = 0.166 mm and d1 = 2.182 mm.

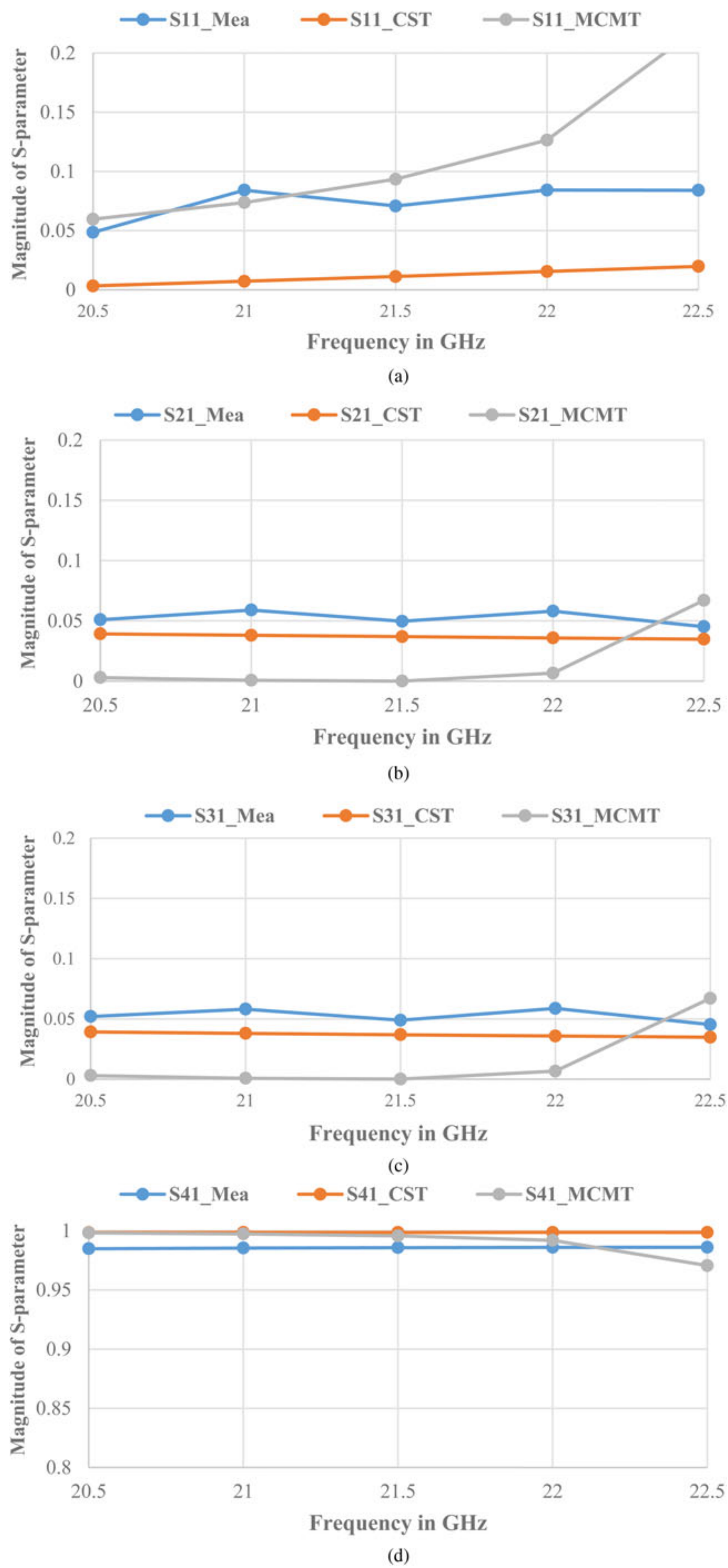

Fig. 7. Comparison of scattering parameters (a) S_{11}, (b) S_{21}, (c) S_{31} and (d) S_{41} of MCMT, CST microwave studio simulated data and measured data for E-plane WR-42 waveguide two-channel joints for K-band with a gap of 2t = 0.3 mm, d = 0.66 mm and d1 = 3.184 mm.

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$$e_p^{i,y} = \begin{cases} \sin\left\{\frac{p\pi}{2W}(z - z_w + W)\right\} & \text{for } y_w - L \le y \le y_w + L, \\ & z_w - W \le z \le z_w + W \\ 0 & \text{elsewhere} \end{cases} \tag{2b}$$

In the above expressions $L = a$, $W = b$, where 2a = 10.668 mm and 2b = 4.318 mm, s = 1.02 mm and 2s is the distance between wvg-1 and wvg-4.

The aperture field distributions can be determined by the knowledge of unknown weight $E_p^{i,y/z}$. Apertures are representing the boundary between different regions as shown in Fig. 1. For each aperture, there are two boundary conditions, corresponding to the two tangential components (Y and Z). These boundary conditions have been solved using Galerkin's specialization of the method of the moment [15]. In this method, weighting functions $w_q^{i,y/z}(x, y, z)$ are assumed to be the same as basis functions $e_p^{i,y/z}$. Reflection and transmission coefficient has been derived as the procedure outlined in [12].

Result and discussion

Based on theory, for the analysis of co-channel interference, MATLAB codes have been written, and simulation has been done using CST microwave studio. For validation of theory, measurement has been carried out. During the measurement two-channel E-plane bends are joined together with a common flange and a copper plate, as shown in Fig. 3. Scattering parameters data obtained from MCMT analysis for E-plane WR-42 two channels waveguide joint at K-band has been compared with CST microwave studio simulated data as well as with measured data.

In the beginning, measurement of the magnitude of S-parameter for frequency range 20.5–22.5 GHz without metallic plate has been done by VNA (Agilent Technologies, E8363B) which is shown in Fig. 4. Further, different dimensions of the gap have been taken, shown in Table 1.

One after another measurement of the magnitude of S_{11}, S_{21}, S_{31} and S_{41} for K-band E-plane WR-42 waveguide two-channel joints with different gap sizes has been done as shown in Figs 5–7. From Figs 5(a) to 5(d), it depicts that the maximum value of coupling of power is 0.33% at 21.6 GHz while in Figs 6(a) to 6(d) it is 0.36% over the frequency range 21 to 22 GHz. From Figs 7(a) to 7(d), It shows that the highest value of coupling is 0.25% at 22 GHz.

Conclusion

Different dimensions of the gap have been taken to analyze the co-channel interference. The comparison of scattering parameters shows excellent matching of CST simulated data, measured data and MCMT data. It has been seen that the maximum value of coupling of power to neighboring port is 0.36% over the frequency range 21 to 22 GHz when the gap size is 2t = 0.5 mm, d = 0.166 mm and d1 = 2.182 mm. MCMT technique can be used for other higher frequency bands. This analysis is helpful to give insight for multiple input and multiple output applications.

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