Analysis on a Waveguide Mode Converter

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Abstract—There is a mainly two types of waveguide which are mainly used in microwave transmission. A Rectangular waveguide and a circular waveguide. Microwave Propagation is being through these waveguides via different modes at different frequencies. But in practical implementation many problems arise like an ascetic excitation method, efficiency of particular mode, complex calculation etc., and an alternation is used. It is called a waveguide converter. In this paper different types of methods are analyzed and describe an output of these methods**.**

Key words: Rectangular waveguide, circular waveguide, Mode converter, Excitation method

I. INTRODUCTION

Waveguide is a metallic structure which is used for a transmission of an electromagnetic energy between two points. There are basically two types of waveguide. A metal waveguide and a dielectric waveguide. Metal waveguides are typically one enclosed conductor in which an insulating medium is filled while a dielectric waveguide consists of multiple dielectrics. For analysis of Waveguide we can use appropriate coordinate systems according to geometrical structure. For Example Rectangular wave guide is analogies with Cartesian coordinate system and a circular waveguide is analogies with cylindrical coordinate system

Electromagnetic wave consists of two components one is electric field and other is magnetic fields. Direction within a waveguide or transmission line decides a mode of Propagation. If both E and H field are transverse to the direction of propagation it called a TEM (Transverse electric and magnetic) mode, if only E field is transverse to direction of propagation it is a TE (Transverse Electric) mode and if only H field is transverse to direction of propagation it is TM (Transverse Magnetic)mode. This transverse component can determine only from axial component of E and H using "Maxwell's Wave Equations". Using these equations, in a waveguide when E and H both field are transverse All component of E and H become a Zero means there is no TEM mode in a waveguide only TE and TM mode are exist .one more important thing is that in unbounded transmission we can consider a Component Ex, Ey, Hx and Hy to be infinite or a long enough, but in a Bounded transmission means in a waveguide this could not be assumed so propagation constant which is consist of attenuation constant and phase constant ($\Upsilon=\alpha+j\beta$) can describe in terms of some frequency limit, so frequency below these make a propagation constant Υ pure real so wave are completely attenuate means there is no propagation in short low frequency cannot be transmit through waveguide and a frequency limit is called a "Cut-Off frequency $f_{c,mn}$" of that waveguide. And for each specify waveguide structure by putting a value of m and n we can determine a cut-off frequency for an each mode. Out of number of mode available a mode which is first to propagate is called a "dominant mode".

II. NECESSITIES OF CONVERSATION

Base on geometry structure we are differentiating a waveguide like Rectangular waveguide, square waveguide, circular waveguide, elliptical waveguide, truncated waveguide, flexible waveguide etc. each of these have a different operating mode .it means it's not true always that operating mode of one waveguide is same for any other waveguide. So as per requirement, performances criteria, and application point of view we need to convert this mode.

Some of the reasons for mode conversation are listed below.

The mode transformation from the fundamental TE10 mode in rectangular waveguide to the TE01 mode in circular waveguide is of practical importance especially where there is a necessity for long transmission runs or in the case where high frequency operation is required [2].

In an application like a VLA (very large array) radio telescope prime requirement is of level of losses attenuation is very low. Therefore helical coupler can utilize for direct conversation of TE01 mode of circular waveguide from standard millimeter Rectangular waveguide [3].TE01 mode in circular waveguide have a very low loss.

The generation of high order modes in circular waveguide is useful for some applications. For example, TM01, TE21 and TE01 modes excited in circular waveguide are used in tracking feed subsystem for producing deference pattern. In addition, several high power microwave (HPM),Generators such as the oscillators of virtual cathode (vircators), the Relativists backward wave oscillators from reflected waves (BWOs) and The magnetically insulating transmission-line oscillators (MILOs),Generate azimuthally symmetric output modes with the TM01 circular Waveguide mode and even the coaxial line transverse electromagnetic Mode TEM. If these modes are directly radiated to the space from The waveguides output, a doughnut-shaped radiation pattern will be Produced, with a clear absence of signal in the axis (bore-sight) Due to the fact that the transverse electric field is null in the axis (Undesirable conical radiation pattern)[1]

One of the available methods for converting a mode from TE10 in Rectangular waveguide to Circular waveguide is Marie converter. Reason to implication of Marie converter is that, Marie converter was predominantly based on ease of fabrication as fundamentally the geometric inner structure of the device is merely a series of straight lines allowing it to be formed using the technique of wire erosion [2].

Mode transformers are also used in antenna applications for multimode antennas. These antennas have different properties depending on spectra and phase shift of radiated modes such as side and main lobe suppression, directivity and polarization change [4].

A Travelling wave Tube (TWT) is a vacuum tube that is used to amplify a signal at a high frequency. Input coupling system is an important part of the gyro-TWT. Its main function is that the input signal is coupled to Gyro-TWT interaction circuit, while the operating mode transition from input mode. Input coupling circuit will have a direct impact on gyro-TWT performance [5].

A wideband input coupling system is presented which realize the conversion from the input rectangular waveguide TE10 mode to operating mode TE11 (circular polarized) [5].

Due to the problem of circular waveguide in the excitation process, in this paper, a rectangular to circular waveguide converter is proposed as an alternative method to excite the circular waveguide from rectangular transducer [6]

An ULTRA-HIGH-POWER RF system such as linear colliders where hundreds of megawatts of pulsed RF power is manipulated, over-moded waveguides are widely used to increase the power-handling capacity. Losses in the system are minimized by transporting power in circular waveguides in azimuthally symmetric modes such as the mode. In many instances, the RF power is easier to manipulate in rectangular waveguides than in circular waveguides [7].

Due to the development of high-power, high-frequency gyrotrons, there was considerable interest in mode converters to transform the higher order modes of a circular waveguide to the lower order, lower loss H01mode. Mode H01in, its turn, can be transformed into the first mode H11which has the radiation pattern with good directivity [4].

Transitions from square to circular waveguides are required in measurement of ceramic used in gyrotrons beam tunnel and RF window [9].

The TM01 circular waveguide (CWG) mode is generated by sources with axial Electron beams, which are most of the very high power (>Megawatt) sources. This mode has a Transverse electric field null on the axis, producing a donut-shaped beam when radiated rather than the preferred solid beam. The desired mode is the TEl1.In order to best use these power sources, it is necessary to convert the TM01 mode to theTE11 CWG mode. [10]. Transmission loss of the oversize Waveguide is lower than that of the beam Waveguide at 141 Gc [11].

III. DESIGN METHODOLOGIES

As discussed above each specific waveguide can operate over many different available TE and TM mode. Out of these dominant modes of Rectangular wave guide has a TE10 and circular waveguide has a TE11 mode.

A. *Method: 1*

Due to the fact that in a circular waveguide the TM01 mode has a higher cutoff frequency higher than the fundamental TE11 mode, it is impossible to make the direct conversion without any reaction in the signal to be transmitted. The mechanical alternative proposed in this work initially allows the conversion of the TM01 mode of the circular waveguide to the TEM coaxial transmission line mode, which has a cutoff frequency equal to zero. This philosophy divides the design into two parts: the first part transforms the TM01 circular mode towards the TEM coaxial mode, and the second one transforms the TEM mode to the TE11 circular mode. Unfortunately, the conversion TEM-TE11 cannot be obtained.

In wide band, due to the proximity between The cutoff frequencies of the two modes, TM01 and TE11 circular waveguide modes. Therefore, the second part was realized using an intermediate mode TE10 of rectangular waveguide; therefore, it was necessary to design an axial intermediate TEM-TE10 converter that was feeding a later TE10-TE11 [1]. Subsequently, a transition between the coaxial line and rectangular waveguide will be designed using a septum of at least three sections, which allows a high TEM-TE10 conversion efficiency in a frequency bandwidth superior to 55%.an octagonal intermediate Transition from a rectangular to a circular waveguide, which allows a TE10-TE11 conversion in a frequency bandwidth of an octave with no evidence of higher order mode excitation [1].

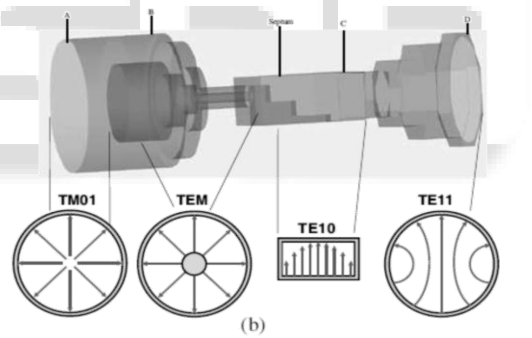

Fig. 1: Mode converter internal view and the propagated fundamental mode in various waveguide sections [1]

B. *Method: 2*

For converting a mode from TE10 of Rectangular to TE01 of Circular waveguide can perform by a Marie converter .The Marie converter comprises of three main sections and this model can simulated in the VE Studio, The decision to model a Marie converter was predominantly based on ease of fabrication as fundamentally the geometric Inner structure of the device is merely a series of straight lines allowing it to be formed using the Technique of wire erosion [2].

C. *Method: 3*

The TE10 rectangular waveguide mode is converted to the circular polarization TE11 circular waveguide mode, the pill-box window of the vacuum envelope is used, A common technique for producing circular polarization mode is that two equal amplitude but 90°phase shifted linear polarization signals simultaneously injected from two directions perpendicular to the circular waveguide.

The main difficulty of this approach is that two signals is hard to maintain the same size and phase to maintain 90 ° in a certain bandwidth [5].every mode converter has a main task to design a transaction region which convert a mode of input to output. But here output mode have a circular polarization so to obtain this, Mode converter circuit of this design consist of a rectangular waveguide, Elliptical waveguide section and electron beam channel [5].

D. Method: 4

Conversion of mode between a TE10 of rectangular to TE11 mode of a circular waveguide can be possible by constitution of a metallic geometric structure. Its one end will be open at an output port of a rectangular waveguide and second end would be at input port of a circular waveguide. This is called a transition region. 5. The minimum length of transition should be quarter wavelength to avoid abrupt dimensional changes and generation of higher order modes [6].

E. Method: 5

Fig. 1 shows a photograph of a Marie transducer next to the Compact mode converter developed at SLAC. The compact Mode converter shown in Figure I.2 is made of five sections and Converts a circular waveguide mode to a rectangular waveguide mode. The first section of the compact mode converter is a height taper that connects a standard rectangular waveguide with dimensions 3.05 cm 2.32 cm. Section 2 is straight section rectangular waveguide that connects to a nonuniform waveguide made of three sections. The design methodology of sections 1 and 2 is given in [6]. The three-section nonuniform waveguide shown schematically in Fig. 2 converts a rectangular waveguide mode to a circular waveguide mode. Due to structural symmetry, these three sections can also convert a rectangular waveguide mode to a circular waveguide mode. The length of these three-section part of the mode converter is less than 7.63 cm in), while a corresponding Marie mode converter, which can convert the same modes, will be around 0.457 m (18 in) long [7].

Fig. 2: Compact mode converter fabricated at SLAC and the Marie mode [7].

F. Method: 6

The basic transformer in Figure 3 contains an on-axis Connection of one square and one circular Waveguide section. The other circular section is introduced for further return-loss improvement. Although the relationships of the fundamental mode cut-off frequencies in square and circular waveguides generally vary for different designs, the following initial dimensions have been broadly tested and will commonly yield a return loss of better than 20 dB. In the design procedure of square-to-circular transitions, we first assume that all transformer sections be Circular as shown in the Figure 3. The diameters of the circular sections can now be related to a. where a is the dimension of square waveguide. The diameters can equal the width/height of the square design, i.e., d $=a$. combination of *a (i)* and *b (i)* can be used to determine the diameters. In order to limit the influence of the rather large *b* dimensions, we choose the diameter of circular waveguide equal to the diagonal of the square Waveguide [9]. The fine optimization is carried out using the Mode-Matching Technique (MMT), the diameters and lengths of the circular sections between the square input and the circular output guide are optimized using a Mini-Max based algorithm the function to be minimized is given by [9]

$$F = \sum_i \left[\frac{R_n}{R(f_i)}\right]^2 \tag{3.1}$$

Where *Rn* and R (*f*) are the desired and actual Return loss, respectively, at frequency *fi* [9].

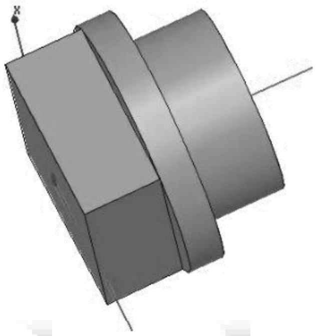

Fig. 3: 22.86X22.86 square to 13.5 mm diameter circular transition with 4.4 mm transformer length [7].

IV. COMMENTS ON PERFORMANCES

As discussed above out of available many methods, selection of method depends on application point of view. Because every method has its own merits and demerits.

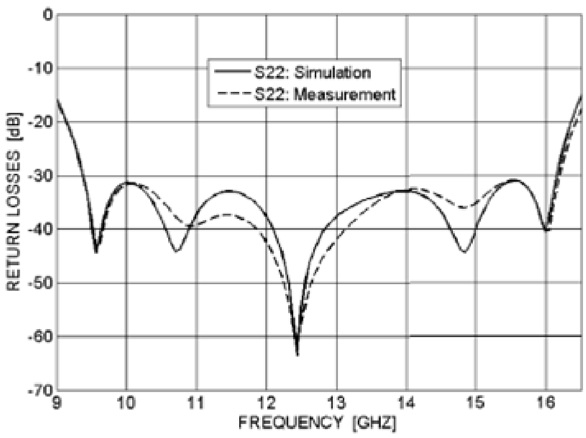

Fig. 4: Simulated and measured output TE11 circular reflection of The TM01 to TE11 mode converter [1]

For Example if larger bandwidth is require method 1 is suitable. it give a the return losses are in the order of 28 dB in both modes TM01 and TE11 along with measured insertion losses less than 0.1 dB, giving rise to a conversion efficiency of 98.8% in a fractional bandwidth superior to 55% [1].S-parameter are as shown in below diagram Figure 4 and Figure 5. Technique used in method 3 has conversation efficiency of 83% and more in frequency range of 34-36 GHz [5] as shown in figure 6.

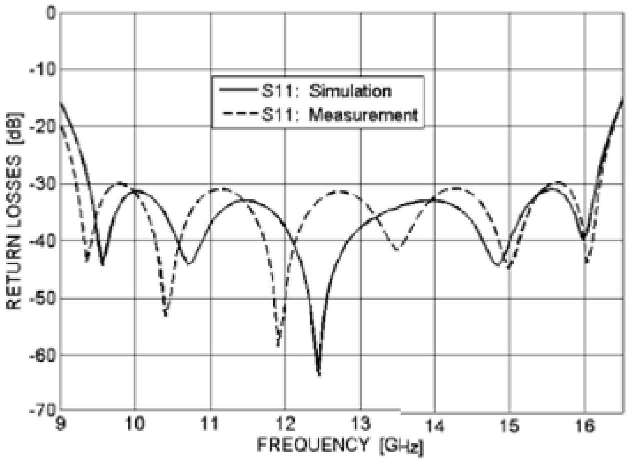

Fig. 5: Simulated and measured input TM01 circular reflection of the TM01 to TE11 mode converter [1].

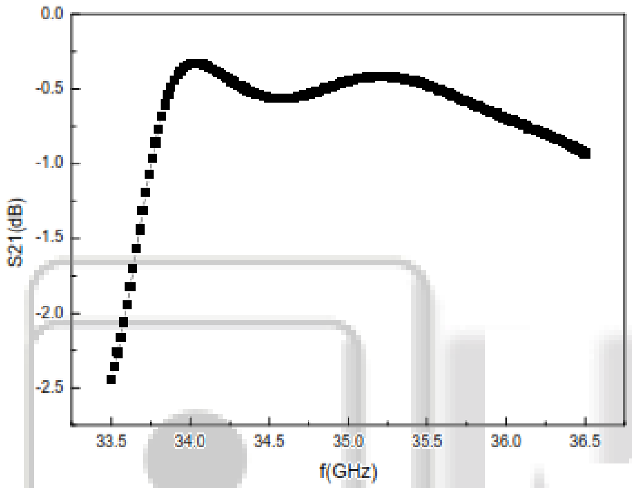

Fig. 6: Transmission Coefficient versus frequency obtained from a HSFF simulation [5].

Minimum length of transaction should be quarter wavelength to avoid abrupt dimensional change and generation of higher order mode [6]. Return loss for different length of transition region is as a shown in figure 7.

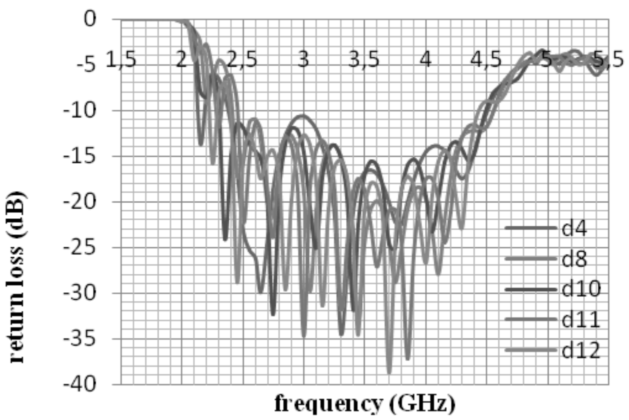

Fig. 7: Return loss of different lengths of transition segment [6].

Figure 8 shows the scattering parameters of the two mode converters tested back to back. This is design by a help of method 5. Indeed, the device has a near-perfect performance at the design frequency of 11.424 GHz [7].

In a particular application where prime requirement is a higher bandwidth can go through a method describe in [10].because it give typical insertion loss of 0.25 dB and less than 0.5 dB over a 30% bandwidth [10] as shown in Fig. 7.

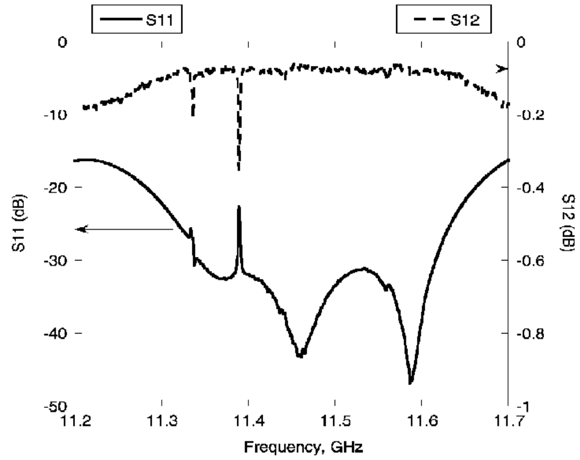

Fig. 8: Parameters for two compact mode converters connected back to back [7].

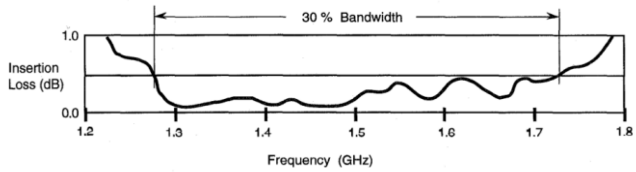

Fig. 9: Measured Insertion Loss for the L-band Mode Convertor [10]

Square to circular waveguide mode converter which design based on method 6 describe above has a 30 dB return loss is achieved with transformer length is 4.4 mm [9].

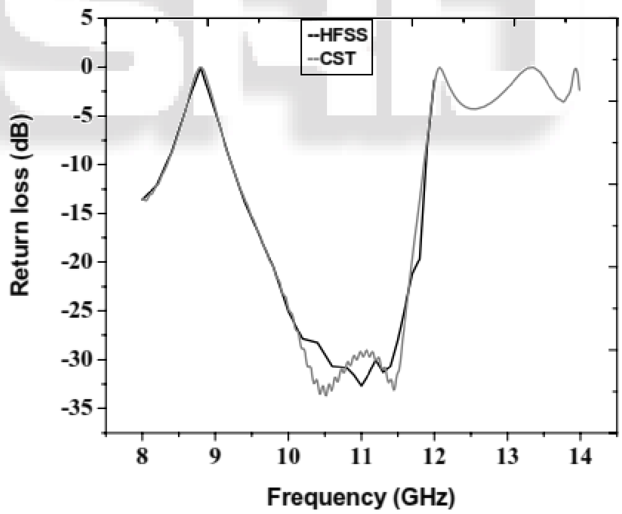

Fig. 10: Performance of square to circular waveguide Transformation according to Figure I.3 [9]

V. CONCLUSIONS AND FUTURE WORK

This paper is reported on study of different method of converting a mode in waveguide, its Requirement and application along with performances. This paper also includes results of s-parameter diagram based on CST microwave studio and HFSS. Based on application point of view and requirement of performance enhancement of particular parameter we can select a various method. In future study we will try to derive a mathematical formula for length transition region as a function of wavelength for C band.

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