International Journal on Recent and Innovation Trends in Computing and Communication
Volume: 5 Issue: 2
ISSN: 2321-8169
163 – 167

# Literature Review: Study of Various Techniques for Beam and Polarization Splitting for mm Waves

Mistry Pooja
Department of Electronics & Communication
L.J. Institute of Engineering & Technology
Ahmedabad, India
*poojamistry1815@gmail.com*

Anil K. Sisodia
Department of Electronics & Communication
L.J. Institute of Engineering & Technology
Ahmedabad. India
*ak_sisodia@yahoo.co.in*

***Abstract***—In this paper, we present the techniques used for splitting the radiation beam and polarization of mm and sub-millimeter waves. First technique is based on H-plane section which splits the square section pipe into two rectangular.Second technique is based on a confocal quasi optical system with wire grid beam splitter. Another is based on grounded Frequency Selective Surface (FSS) array as millimeter wave beam splitter which demonstrates that the reflection phase of coherent mm-wave can be altered by using FSS array with different slot lengths. Last technique is based on Mylar beam splitters over the range of wavelength between 0.08 mm to 2 mm for angles of incidence between 45$^0$ and 80°.

***Keywords****-Beam splitter, polarization splitter, waveguide, millimeter waves.*

*****

## I. Introduction

The rapid development in terahertz (THz) technology has led to a vast range of applications, such as terahertz time-domain spectroscopy, terahertz imaging, and atmospheric remote sensing. To suit for various applications, many devices for THz generation and detection are widely utilized, such as waveguide component, quasi-optics, sensing device and frequency selective surface. [4] Active free-space millimeter wave (mm-wave) systems have gained more and more attraction during the last few years due to their various applications. Front-end components are of an essence to any millimeter waves subsystem, such as transreciever modules, medical instruments, and imaging devices. Hence, a tremendous effort is relentlessly placed to enhance their electrical performance while maintaining a compact size, reasonable fabrication complexity, and above all cost. Power dividers (equal division and unequal division) are important front-end components in many millimeter wave systems. Hence, the advanced designs and miniaturization of these components are ongoing research topics. Scholars strive to achieve set of targets (e.g., broadened bandwidth, suppressed harmonics, less transmission losses) while minimizing size and fabrication cost. Generally, various techniques can be used for power splitting such as, microstrip Lines, directional couplers, magic tee, and waveguidebased, etc. but all these techniques have their advantages as well as limitations. Various techniques for beam and polarization splitting in mm and sub-millimeter waves applications are discussed below. Their advantages, limitations and special features have been analyzed in this paper.

## II. Analysis of various techniques

### A. *P. Buratti et.al*

In this papera 16 m long, square pipe is used links the power splitter system with the spectrometers. The size of the light pipe has been determined under the requirement of keeping the resistive losses of the fundamental waveguide mode below 3 dB at $\lambda$=0.5mm (600GHz). The size of 7.6 cm for the waveguide. The power splitter system includes H-plane wave front divider which splits the square section pipe into two rectangular ones connected to the Fourier transform spectrometer and to grating polychromator respectively. [1]As shown in the Figure 1 low mm wave power is splitted using mirror placed at the center of the square pipe. Further transmitted to FTS and Polychromator having rectangular pipes. Here the waveguide is not an oversized waveguide. Thus final beam splitter was configured with the total predicted loss at lambda = 0.7 mm to be 5.5 dB; 2.5 dB for resistive losses in the 16 m long waveguide and 3 dB for area reduction at the final beam splitter. [1]

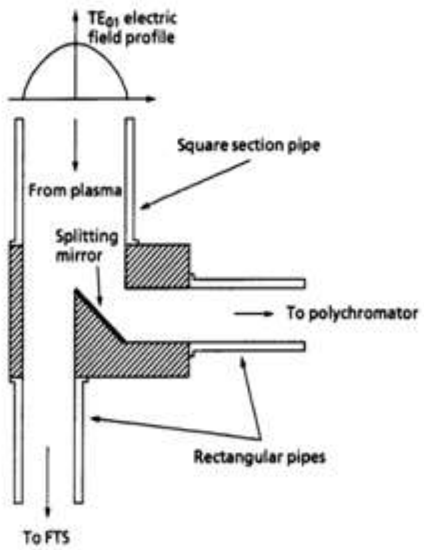


Figure 1: Wave front beam splitter used to connect a single light transport system to two spectrometers at the same time.**[1]**

### B. *Simonetto et.al*

Joint European Torus's (JET) new Microwave Access system requires a configurable interface to share the transmission lines between the various reflectometric instruments. A confocal quasi optical system made of modular blocks was designed and built for operation in the 60-160GHz range, allowing full configuration and polarization flexibility. This paper deals with the design and test of the instrument. EFDA (European Fusion Development Agreement)-JET's new Microwave Access for reflectometry [2] requires that

ISSN: 2321-8169
163 – 167

several reflectometers share a common transmission line. A configurable system is required for power- or frequency-splitting among the existing instruments and possible new additions. A reasonable but arbitrary number of instruments can be added. Since transmission lines are made of oversized corrugated circular waveguides, the system must also provide an interface between them and the fundamental waveguide input of the transmitters/receivers. The required bandwidth (in sub-bands) is 60 to 160GHz.[2]In this paper modular blocks (Quasi Optical Boxes, QOB) forming a quasi-optical system of mirrors in confocal arrangement, with a magnification factor (focal ratio) chosen for best coupling with fundamental waveguide, to be achieved with a suitable horn. The system resulting from these design choices, and the ones described below, is shown in fig 2 Horns end with a standard circular waveguide port suited for the lowest frequency required, and

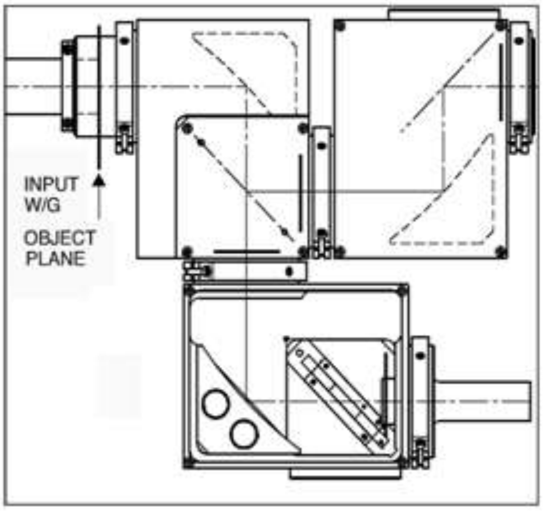


Figure 2: Arrangement of the splitting modules [2]

commercial (although not always standard) transitions to the proper rectangular waveguide band are fitted to them. Since horns can be replaced easily, should an instrument require lower coupling losses over a narrower band, a suitable corrugated feed horn can be fitted to a block. The position of the horn aperture with respect to the output focal plane was numerically optimized using physical optics. The former configuration allows the directmeasurement of the reflection coefficient of a single QOB. The measurements were made in sub-bands between 72 and 75GHz, the curve is double valued, because the transition used for W-band circular has a significant reflectivity below the band limit of 75GHz. This effect is not present, of course, in the data taken with the V-band transition. The strong ripple present in the 140-160GHz band is due to an imperfect matching of the WR6 to WR10 transition. [2]

***C.*** *Hairui Liu et.al*

Here Free stand wire-grids (FSWG) as polarizers, beam splitters, attenuators, and interferometers is used in millimeter wave and THz ranges. FSWG behaves as low-loss element as the wire grid is unsupported with a substrate, and provides good performance in the range of 0.1-3.0 THz. This paper analyses the characteristic of the wire-grid polarizers in sub millimeter wave range. These analysis include the spectral transmittance with different wire spacing and incident angle. Since wire-grids are usually used as polarizers, beam splitters and polarization rotators together with optics, measuring wire-grids by inserting into an optic is meaningful. At millimeter and sub-

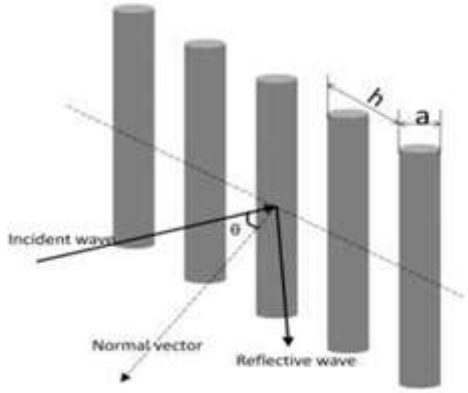


Figure 3: Model of wire-grid polarizer. Incident angle:θ, diameter of the wire:a, arranging period:h

millimeter wavelengths, quasi-optics are well coupled with the radiation from corrugated feed-horns using single mode Gaussian beams. Advantages over waveguide include low loss, negligible dispersion effects, power handing and broad band performance. [4]For an actual use, the transmission and reflective coefficient are changed with different parameters. For a model shown in Fig 3, these parameters mainly include the incident angle: θ, diameter of the wire: a and arranging period: h. In order to value the effect of the parameters, we simulate the spectral performance of the wire grid polarizer with different incident angle and different ratio between a and h. Simulation is performed using Ansys HFSS, as shown in Fig.5. To simulate the transmittance and reflectance of an unlimited grid, periodic boundary conditions have to be enforced. The unit cell boundary conditions are shown in Fig.4, where the faces denoted by Slave and Master are used to setup the expansion direction. Floquet port is selected for excitations, which function as a plane wave illuminating the grids. Simulation was made on the polarizer with vertically arranged wire of 25µm diameter.

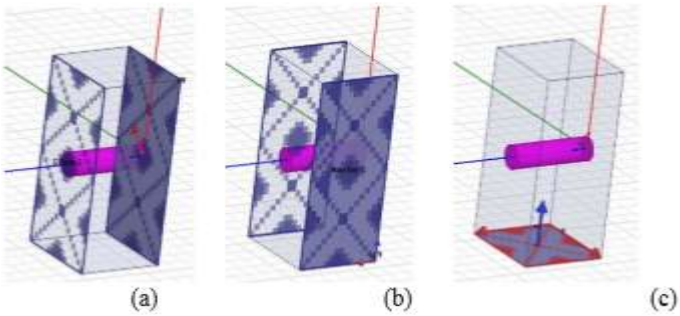


Figure 4: Grids simulation by HFSS (a) and (b) is the setup for periodic boundary, (c) is the setup for excitations. [4]

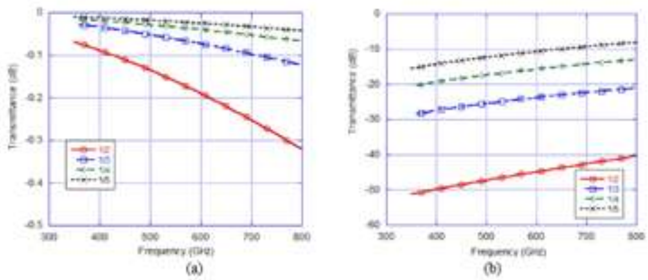


Figure 5: The transmission coefficient based on the incident angle of 0 degree: (a) $T_{\parallel}$ and (b) $T_{\perp}$. The ratio of the a and h is changed from 1/2 to 1/5. [4]

ISSN: 2321-8169
163 – 167

***D.**S. Islam et.al*

Here *grounded* Frequency Selective Surface (FSS) array as millimeter wave beam splitter is shown. The phase dependence on slot length of grounded FSS demonstrates that the reflection phase of coherent mm-wave can be altered by using FSS array with different slot lengths. A beam splitter was designed with slot FSS array where the slot length is the main design parameter used to optimize the phase properties of the array. A system to get incoherent reflection from a coherent source is designed. The slot length parameter of FSS array to be used to optimize the phase properties. It shown how phase delay can be controlled by using different values of slot lengths. [3] The measured rectangular radiation patterns of the beam splitter are shown in Figure 3 where the calibration of the measurement system is shown. The measurement radiation pattern at 90GHz, 94GHz and 100GHz frequencies are presented. As shown in rectangular, at each frequency two main lobes on both side of the antenna broad side axis is obtained. The position of lobes changes with frequency as the phase values of the FSS cells (slot length X slot width) changes withfrequency. Maximum reflection power of side lobes obtained at 94GHz. [3]

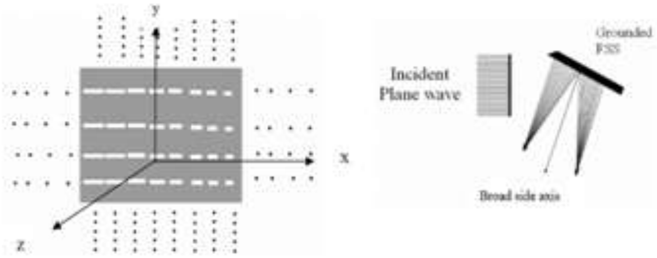


Figure 6: Slot lengths variation along x- axis & Schematic diagram of reflected beam [3]

The radiation patterns of the array were measured with Backward-Wave Oscillator (BWO). The radiation pattern of the antenna was measured with α=45˚ angular position of the antenna axis to the BWO mm-wave source axis. At 94GHz measurement, two main lobes were obtained at 130˚ and 118˚ due to the phase splitting effect of beam splitter. The measured rectangular radiation patterns of the beam splitter are shown in Fig.7. The different slot lengths FSS cells (slot length X slot width) were distributed column wise in such a way that from the centre of the array the phase delay at 94 GHz will increase in both left and right side of the array.

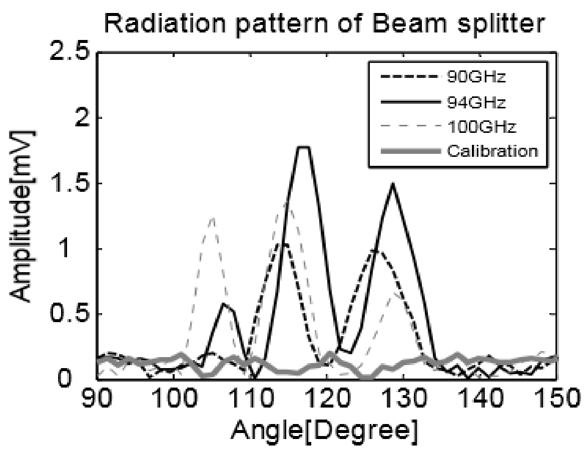


Figure 7: Measured field radiation pattern of beam splitter at different incident frequencies rectangular plot [3]

***E.** C. L. Mok et.al*

Shows free-standing grids wound from 5 µm diameter tungsten wire with 100, 50 and 25 µm wire spacing for the frequency range 40-3OOcm$^{-1}$. The special case of normal incidence with the electric vector either parallel or perpendicular to the wires is examined. Good overall agreement is obtained, both qualitatively and quantitatively, between experiment and theory. The measured reflection and transmission coefficients of grids with 12.5 µm spacing showed that their range as efficient polarizers extends to approximately 400 cm$^{-1}$ as expected. (5) However when one of these grids was employed as beam divider in a polarizing interferometer equipped with a commercial substrate mounted polarizer and a similar analyzer, the useful background spectrum of the instrument was unexpectedly found to extend to about 700 cm$^{-1}$. It appears that below about 300 cm$^{-1}$, where the grid behaves as an efficient polarizer and the radiation beams in the two arms of the interferometer are orthogonally polarized, the instrument functions as a Martin- Puplett interferometer, but as the polarizing efficiency of the beam splitter falls off at higher frequencies, components of both polarizations are present in both arms, and the instrument behaves more like a conventional Michelson interferometer. In this paper we present a detailed comparison of experimentally and theoretically determined amplitude and phase transmission coefficients for grids wound from 5 µm diameter tungsten wire with 100, 50 and 25 µm spacing, and describe the performance of a polarizing interferometer in several different modes of operation.

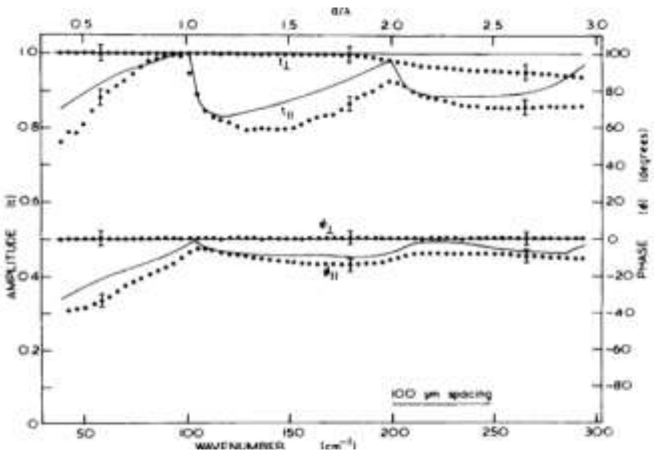


Figure 8: The calculated (----) and measured (…..) amplitude ($T_{\|}$ and $T_{\perp}$) and phase ($\varphi_{\|}$ and $\varphi_{\perp}$) transmission coefficients of a grid wound from 5µm diameter tungsten wire with 100µm spacing for normal incidence with the electric vector either parallel ($\|$) or perpendicular ($\perp$) to the wires. [5]

The amplitude and phase transmission coefficients of grids of 25 µm diameter and with d = 100, 50 and 25 µm were measured by single pass dispersive Fourier Transform spectrometry using an interferometer and techniques which have been described else- where, the optical arrangement of the interferometer is very similar to that of a Martin-Puplett interferometer. A perfect grid at normal incidence the transmission amplitudes are close to unity for both polarizations close to the frequencies where d/λ. = 1 or 2, where λ = 1/ύ is the wavelength, so that the grid is then almost totally ineffective as a polarizer or, indeed, as a mirror. This is clearly seen in Figs 8, where, for d = 100µm both the first and second order diffraction peaks lie in the measured range.[5]

***F.**D. A. Naylor et.al*

HereMylar beam splitters for far i.r. Michelson interferometers is shown. Furthermore, the improvement in the over-all response across this lobe pattern as incident angle increases toward 75º has been shown to be very significant, as demonstrated by earlier work. This has provided convincing reinforcement for the decision to design Michelson interferometers with higher incident angles than the mechanically convenient 45º angle. Experimental verification of these results would be useful, but careful consideration of the extent of the polarization of the incident radiation and the direction of the optic axis of the birefringent Mylar film would be required in order to compare results with prediction. The extreme polarization sensitivity of the Michelson interferometer under these conditions must be recognized in any measurement in which variation of the input polarization or alignment of instrument and source might occur, such as measurement of scattered radiation,coherent sources or even the solar radiation in the sub millimeter range which has been shown to be polarized. To avoid error in monitoring of variation of these parameters when such fluctuationsoccur, narrow wavenumber ranges exist for any Michelson geometry and beam splitter thickness for which polarization sensitivity can be minimized. Account must be taken in this case of a shift in these calculated wavenumber values because of absorption in the beam splitter, and this can be done with the derivation presented in this paper.Absorption and complete multipath interference have been included in the calculation of the modulation efficiency of a far i.r. Michelson interferometer with 25-um and 100-gm Mylar beam splitters over the range of wavenumbers between 20 $cm^{-1}$ and 125 $cm^{-1}$ for angles of incidence between 45º and 80°. These results show that optimum performance of an interferometer in terms of highest and most uniform modulation efficiency for unpolarized radiation will be obtained by selecting the beam-splitter thickness to cover the wavenumber range of interest within the first interference lobe and by utilizing higher angles of incidence than themechanically convenient 45°. Practical constraints will usually limit this angle to a value somewhat less than the optimum of about 75º for Mylar beam splitters. [6]

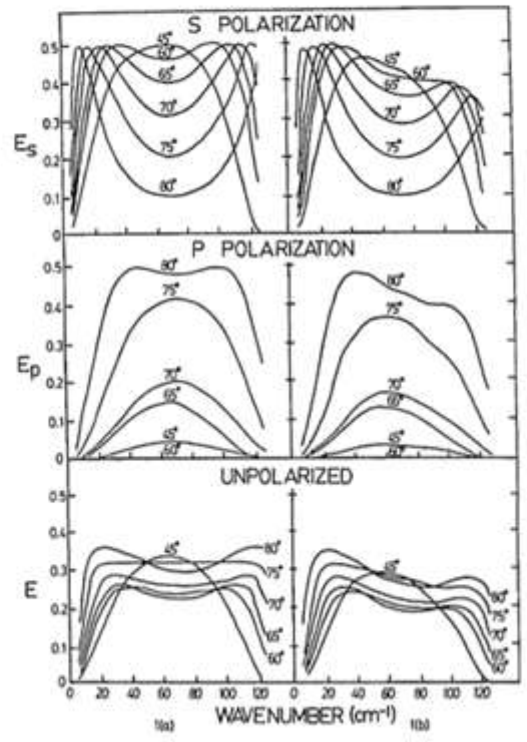


Figure 9: Theoretical modulation efficiencies of a 25-µm Mylar beam splitter as a function of wavenumber and angle of incidence for radiation polarized in the plane of incidence (Eρ) and perpendicular to the plane of incidence (Es) and for unpolarized radiation (a) without absorption and (b) with absorption included. [6]

***G.**G. Taylor et.al*

This papershows latest status of ITER ECE diagnostics polarization splitter boxes and broadband transmission system that transports the ECE from the front-end and distributes it to the ECE instrumentation room in the diagnostics hall. Each polarization splitter box consists of two Gaussian beam telescopes constructed from three parabolic mirrors and one flat mirror (Fig. 10). A wire grid separates the O and X mode polarized emission. An axial tilt of 0.1o increases the power lost to conversion by ≤ 1%. The calculated transmission efficiency of the splitter box is > 93% from 100 to 1000 GHz. [7]

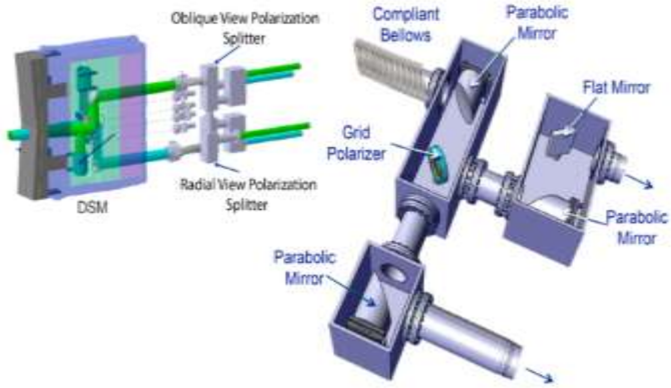


Figure 10: Polarization splitter box design. [7]

## III. Table 1

**Comparison of different techniques used in beam and polarization splitting for mm waves**

| Sr. No. | Technique | Advantages | Disadvantages |
|---|---|---|---|
| **1** | **Directional Coupler** | Low Loss | -Narrow Bandwidth[14] |
| **2** | **Rectangular waveguide based beam splitter** | -High power-handling capability<br>-Low loss | -Bulky<br>-Expensive[14] |
| **3** | **Quasi Optics unit with Wire Grid Polarizer** | -Used for wideband operation<br>-Low loss. | -Depend upon the polarisation state of the input radiation[16]<br>-Optical alignment is critical. |
| **4** | **Frequency Selective Surface** | -low-loss | - low angular sensitivity<br>- high insertion loss<br>-narrow bandwidth for large incidence angle[3] |
| **5** | **Mylar beam splitter** | -Broad bandwidth | -Multiple beam interference due to reflections [6] |

ISSN: 2321-8169
163 – 167

## IV. Conclusion

Based on literature study we concluded that various techniques can be used for beam and polarization splitting in mm waves. For wideband frequency range with low transmission loss applications, above discussed techniques has some limitations to be used, like in rectangular waveguide power splitting device,predicted loss was of about 5.5 dB and extra losses due to mode scrambling are likely to be introduced. [1] For quasi optic system transverse mirror or horn offsets have a lower impact. A horn or corrugated waveguide tilt up to 0.4 deg causes a 2% variation in coupling.[2]FreeStanding Wire Grids is preferred for the demand of low loss and independent incidence. For a wire with a fixed diameter, smaller period will provide a high isolation between two cross polarizations, but is challenging for fabrication. [4] In Mylar beam splitter, by selecting the thickness to cover the wavelength range of interest within the first interference lobe and by utilizing higher angles of incidence than the mechanically convenient 45° for good performance.[6]

## Acknowledgement

I am very thankful to Dr. H. B. Pandya and Mr. Ravinder Kumar for their valuable support and guidance to carry out the analysis. I am also thankful to Mr. Nimesh M. Prabhakar and Mr. Jignesh Pathak for their motivation and help.

## References

[1] P. Buratti, 0. Tursco and M. Zerbini "A broadband light collection system for ECE diagnostics on the FTU tokamak" *Elsevier, Infrared Physics*. Vol. 34, No. 5, pp. 533-541, 1993.

[2] A. Simonetto, Ist. di Fisica del Plasma, CNR, Milan, Italy, C. Sozzi , S. Cirant , A. Bruschi, "Design of the quasi optical interface system for JET's new microwave access" *IEEE Infrared and Millimeter Waves, 2004 and 12th International Conference on Terahertz Electronics*, Vol.10, issue 3, 0-7803-8490-3, Oct 2004.

[3] S. Islam, J. Stiens, I. Jaeger and Roger Vounckx, "Grounded Frequency Selective Surface Array as Millimeter Wave Beam Splitter", *Society of Photo Optical Instrumentation Engineers (SPIE) Digital Library*, Vol. 6994 69940A-1, 2008.

[4] Hairui Liu, Junsheng Yu and Xiaoming Liu, "Characteristic of Free Stand Wire-Grid Polarizers in Sub-millimeter Wave Range" Applied *Mechanics and Materials* Vol 290 pp 127-132, 2013.

[5] C. L. Mok, W. G. Chambers, T. J. Parker and A. E. Costley, "The Far-Infrared Performance and Application Of Free-Standing Grids Wound From 5µm Diameter Tungsten Wire", *Infrared Physics* Vol. 19. pp. 437 to 442, 1979.

[6] D. A. Naylor, R. T. Boreiko, and T. A. Clark, "Mylar beam-splitter efficiency in far infrared interferometers: angle of incidence and absorption effects", *Applied Optics*, Vol. 17, No. 7, 1 April 1978.

[7] G. Taylor, et al "Status of the design of the ITER ECE diagnostic"*European Physics Journal Web of Conferences*, 2015.

[8] Tax, David S., "Mode conversation losses in overmoded millimeter wave transmission lines", *Massachusetts Institute of Technology*, 2008

[9] Lee, C. S.; Lee, S. W.; Chuang, S. L., "Plot of Modal Field Distribution in Rectangular and Circular Waveguides," *IEEE Transactions onMicrowave Theory and Techniques*, vol.33, no.3, pp.271,274, Mar 1985.

[10] R. Nagelberg and J. Shefer, "Mode Conversion in Circular Waveguides", *The bell system technical journal*, 1321-1338september 1965.

[11] Maxim Ignatenko,A. Mase et al.,Conference on "Development of quasi optic technology for microwave diagnostic", *IEEE transaction on Fusion*, 2015.

[12] ThoreMagath, "Diffraction Synthesis and Experimental Verification of a Quasi-Optical Power Splitter at 150 GHz", *IEEE Transactions on microwave theory and techniques*, vol. 52, no. 10, October 2004.

[13] Manfred Thumm and Helga Kumric "High-power TE and TM, circular polarizers in oversized waveguides at 70 GHz", *International Journal of Infrared and Millimeter Waves*, VoL 10, No. 9, 1989.

[14] "Microwave Engineering" by David. M. Pozar, 4th edition, Wiley Publications.

[15] https://www.researchgate.net/publication/235214966_HIGH_POWER_MICROWAVE_COMPONENTS_IN_OVERSIZED_WAVEGUIDE

[16] https://www.google.co.in/=U0AS5QSpBqyqtQmtTCkbow