MEASUREMENT OF THE DIFFRACTION CHARACTERISTIC FOR THE 2 mm WAVE RADIATORS OF ASDEX

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Abstract

Regarding the problem of probing beam refraction, the experience gained with the Tokamak Pulsator and the measurements of the simulated refraction pattern for the proposed ASDEX radiators show that the measurement of the density distribution of ASDEX at a wavelength of 2 mm is possible.

INTRODUCTION

The particular shape of the ASDEX vacuum tube shown in Fig.1 does not allow the use of radiators of conventional type, because, to avoid impurity due to material spattering, it is necessary to have sufficient distance between the plasma edge and the radiators. In other words, the radiators dimension should be small enough to be mounted within the shadow of the metal limiter. By using 45^{o} plan-mirror radiators it is possible, as will be seen, to meet this requirement. On the other hand, the distance between the transmitting and the receiving radiators of each of the multichannel interferometers planned for ASDEX (about 12 channels) is of the order of one metre. One has therefore to consider the problem of wave refraction.

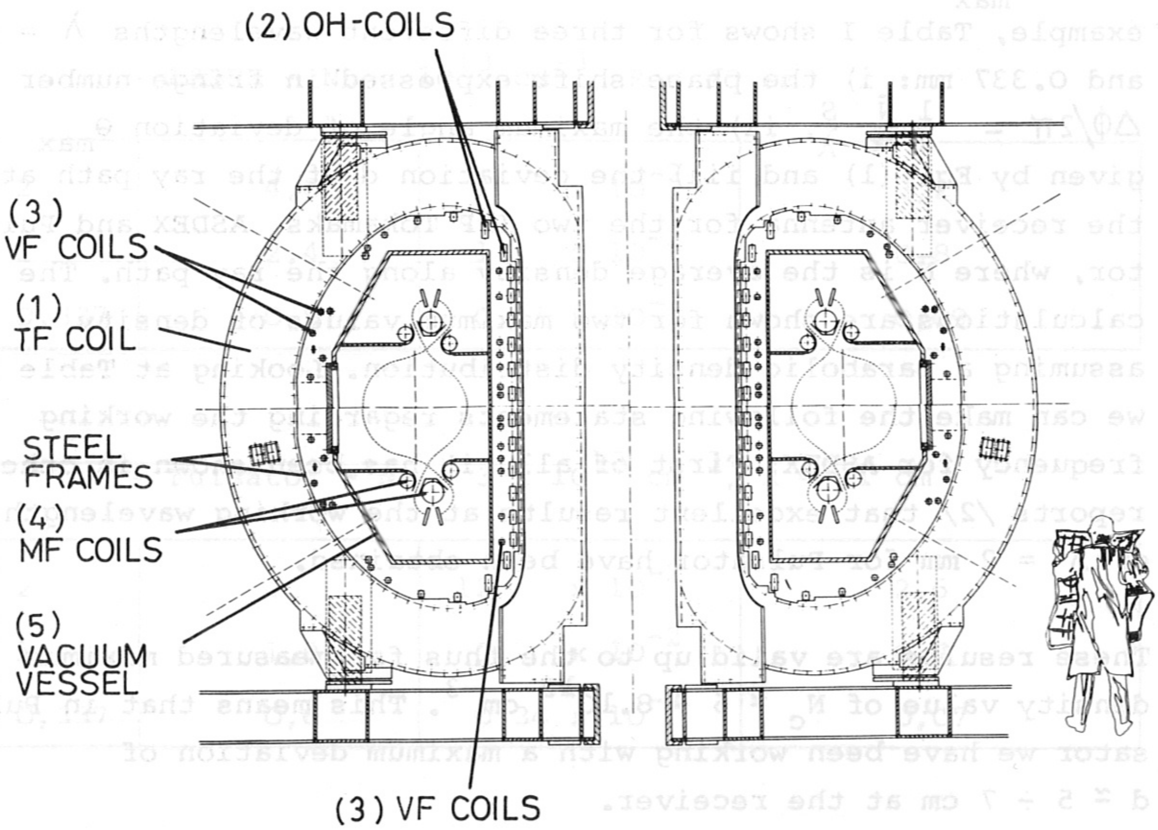

Fig. 1 Cross-section of ASDEX Tokamak

Assuming a parabolic distribution of density, the maximum angle of deviation of the wave can be expressed with good approximation in (rad) by /1/:

$$\Theta_{max} = \sin^{-1}\frac{N_o}{N_c} = \sin^{-1}\left[8.96.10^{-16} N_o \lambda^2\right] \qquad (1)$$

where the density is expressed in cm^{-3}, λ in mm. N_o is the maximum value of the parabolic density distribution and N_c is the cut-off density for the probing wave.

1) Frequency Selection

Equation (1) is very convenient for calculating the deviation $d \approx 2R\Theta_{max}$ of the ray path at the receiver antenna. As an example, Table I shows for three different wavelengths λ = 2;1 and 0.337 mm: i) the phase shift expressed in fringe number $\Delta\phi/2\pi = \frac{1}{2}\frac{\bar{N}}{Nc}\frac{S}{\lambda}$, ii) the maximum angle of deviation Θ_{max} given by Eq. (1) and iii) the deviation d of the ray path at the receiver antenna for the two IPP Tokamaks, ASDEX and Pulsator, where $\bar{N}$ is the average density along the ray path. The calculations are shown for two maximum values of density assuming a parabolic density distribution. Looking at Table I we can make the following statements regarding the working frequency for ASDEX: First of all, it has been shown in other reports /2/ that excellent results at the working wavelength of λ = 2 mm for Pulsator have been obtained.

These results are valid up to the thus far measured maximum density value of $N_c \simeq 6 \div 8.10^{13}$ cm^{-3}. This means that in Pulsator we have been working with a maximum deviation of $d \simeq 5 \div 7$ cm at the receiver.

Table I

Choice of Frequency

- ASDEX - $Ne = 3 \times 10^{13}$ cm^{-3}, R = 40 cm

λ (mm)	Number of Fringes	Maximum deflection angle(rad)	Maximum deviation at the receiver(cm)
2	14,4	12×10^{-2}	9,6
1	7,2	3×10^{-2}	2,4
0,337	2,5	$0,34 \times 10^{-2}$	0,27

- ASDEX - $Ne = 10^{13}$ cm^{-3}, R = 40 cm

2	4,8	4×10^{-2}	3,2
1	2,4	1×10^{-2}	0,8
0,337	0,8	$0,11 \times 10^{-2}$	0,09

- Pulsator - $Ne = 3 \times 10^{13}$ cm^{-3}, R = 11 cm

2	4	12×10^{-2}	2,6
1	1,9	3×10^{-2}	0,7
0,337	0,6	$0,34 \times 10^{-2}$	0,07

Hence for ASDEX one could expect a fairly good density distribution measurement at a $\lambda = 2$ mm, up to a maximum density value of $2 \div 3 \cdot 10^{13}$ cm^{-3}. It is noteworthy that the maximum angle of deviation of the ray path occurs somewhere between the centre of the discharge and the plasma edge. Thus only two, or in extreme cases for even larger density, only four of twelve channels will be affected by refraction problems. On the other hand, ASDEX being a machine primarily designed to test the feasibility of a magnetic limiter, security considerations may limit the maximum value of the density at $Ne < 3 \cdot 10^{13}$ cm^{-3} for the largest part of the experiments. In this case, the aforementioned considerations predict that the use of probing beams at $\lambda = 2$ mm is appropriate. The wavelength at $\lambda = 1$ mm, although seeming ideally suited for the ASDEX density distribution measurements, will not be considered because of the low power and high cost of the available sources.

In general, despite its complexity, the multichannel interferometer in millimetre wavelength can be assembled in a very compact form, in a small volume and has a high degree of reliability.

The construction of the submillimetre Laser interferometer has been on the other hand up to now limited to a single channel at the Tokamak TFR of Paris /3/.

For the extension of this interferometer to a system of several channels there are some difficulties due to the large volume and low power output of the sources, large beam diameter, low detection sensitivity and complexity of the channel selection.

Each channel should be provided with a rotating grating and the frequency selection of the various channels is obtained by using different rotational speeds. Furthermore it should be noted that a single-pass interferometer at submillimetre-Laser-wavelength (as is currently done for $\lambda = 2$ mm) is impossible to build in ASDEX because of the obvious limitations of the internal wall for the horizontal channels and because of the multipoloidal conductors obstructing the vertical channels. By using double-pass (Michelson) interferometer on the other hand one cannot modulate the path $k_o x$ (t) of the plasma probing beam with the rotating grating, as has been in the interferometer circuitry used in TFR. Therefore, a high level of noise due to plasma scattering and multiple reflection of the Laser-beam is to be expected with the double-pass interferometer.

Of couse the development of the infrared multichannel interferometer should be sustained in order to achieve the reliability and installation requirements for ASDEX.

2) Measurement of Simulated Refraction of the Radiating Pattern

The previously mentioned considerations leading to the use of a wavelength λ = 2 mm for the multichannel interferometer of ASDEX have been fully confirmed by the measurements of the simulated refraction pattern of the millimetre wave radiators.

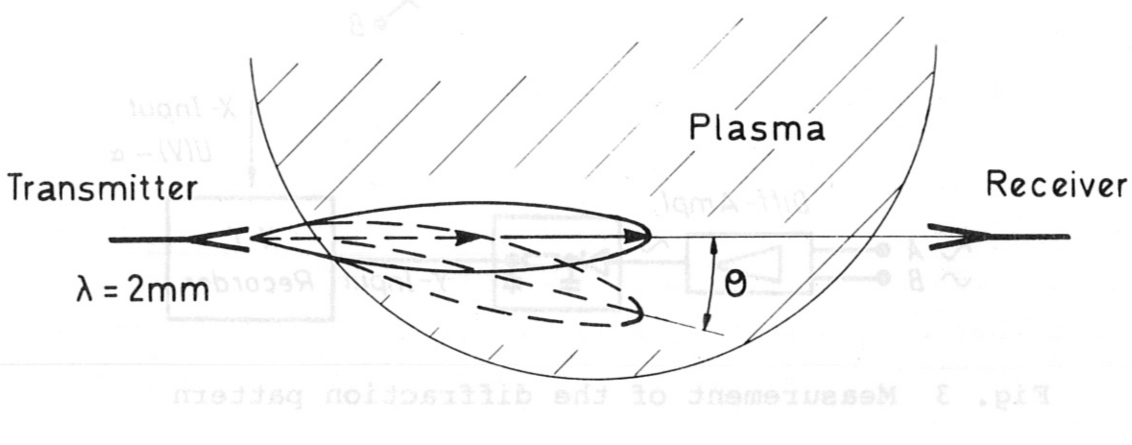

Fig. 2 Refracted pattern

Figure 2 shows a transmitting and a receiving antenna with the radiating pattern (full line) in absence of plasma and with the refracted pattern (dotted line) in presence of plasma.

From the qualitative indication of the refracted pattern of Fig. 2 it is clear that the deflection of the radiating beam, due to the plasma refractivity, lowers the received signal intensity, as indicated in Fig. 2 by the arrow.

To measure the sensitivity of the interferometer for all the beam deflection angles expected in ASDEX the refraction of the pattern has been simulated by the measuring circuitry schematically shown in Fig. 3. This permits the measurements of the intensity of the radiating beam as a function of the angular position of the transmitting antenna (diffraction pattern).

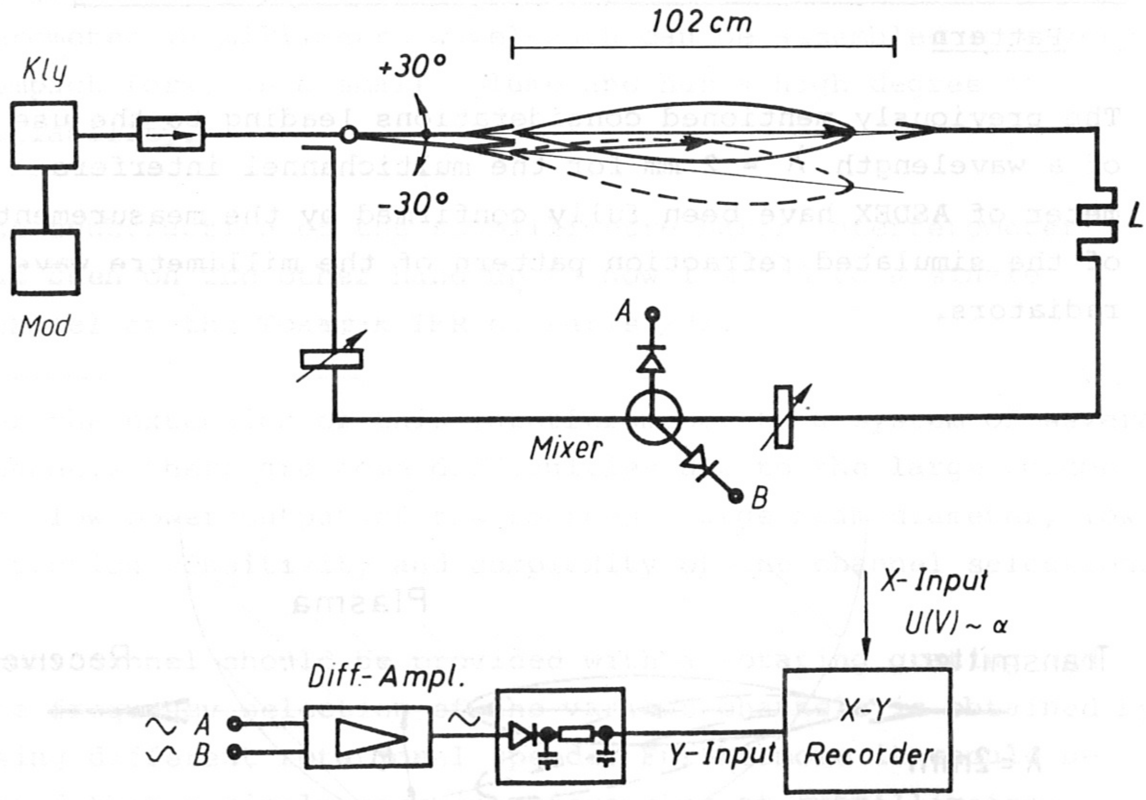

Fig. 3 Measurement of the diffraction pattern

The circuitry is similar to that of a single channel of the multichannel interferometer proposed for ASDEX /2/. The low frequency output of the interferometer after being rectified and filtered is fed to the y input of an xy recorder which x input is fed with a signal proportional to the angular position of the transmitting antenna as shown in Fig. 3.

Figure 4 gives the diffraction pattern of 4 different antennas whose dimensions are shown in Fig. 5. We note the higher directivity of the larger radiator 5 c) in comparison to the smaller radiator 5 a). This higher directivity is also measured between the 45^{o} mirror radiator shown in Fig. 5 d) and the 45^{o} mirror radiator of 5 b). As previously stated, the mirror radiators are necessary in order to minimise as much as possible the transversal dimensions of the radiator towards the discharge.

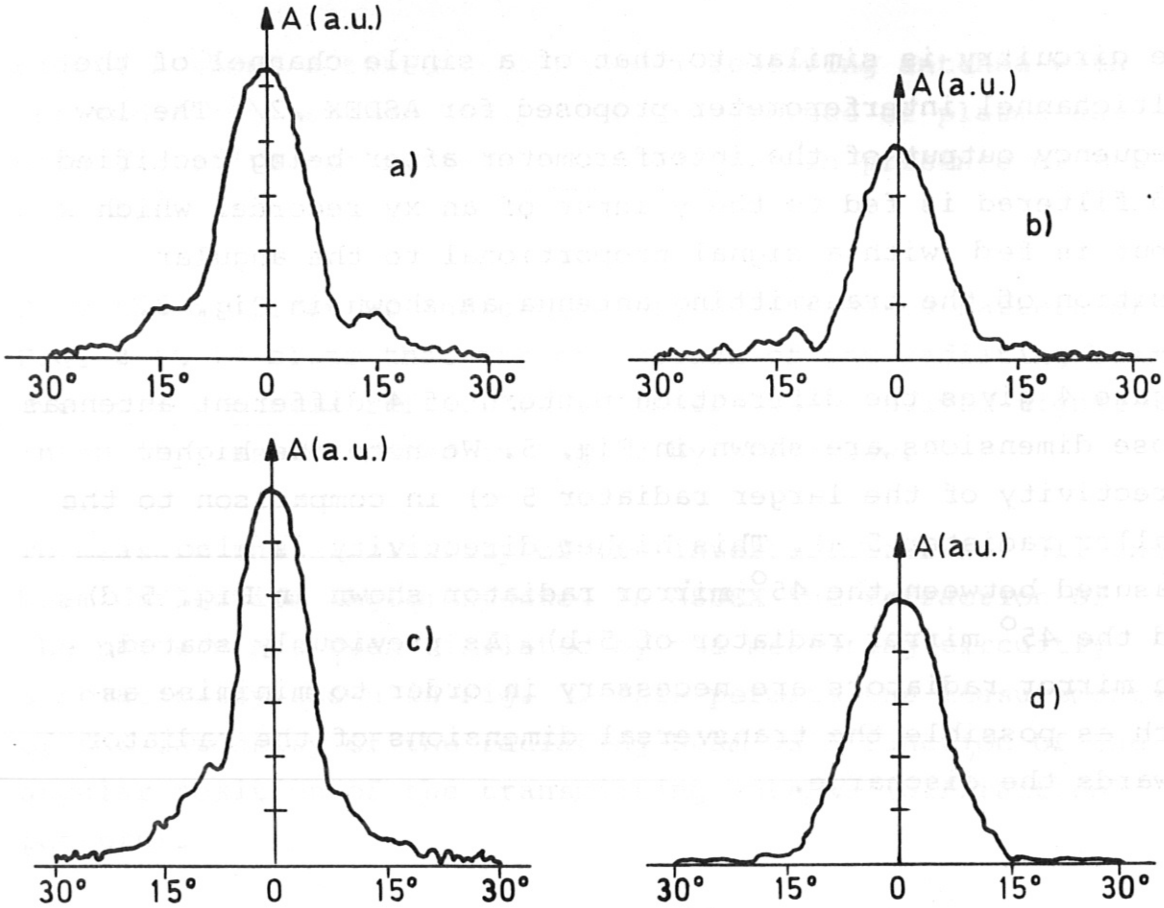

Fig. 4 Diffraction pattern

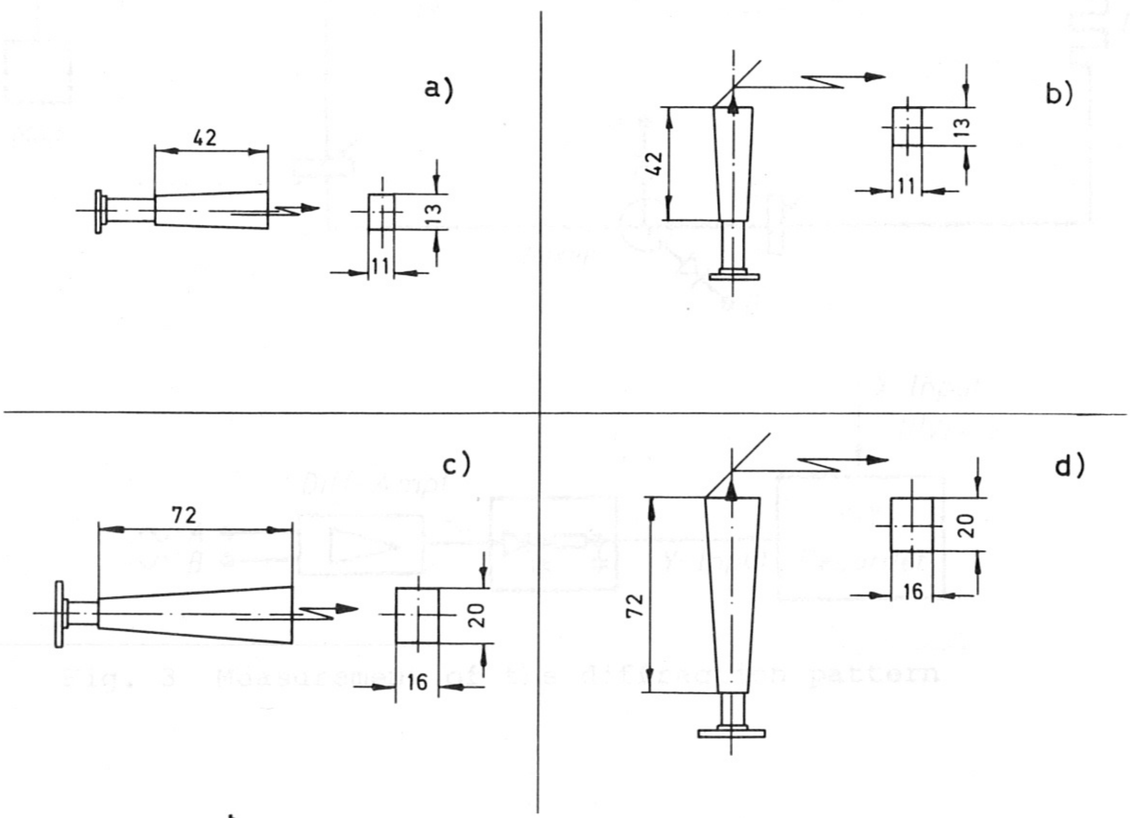

Fig. 5 Millimetre wave radiators

3) Interferometer Sensitivity

Figure 6 shows an outline of both transmitting and receiving antennae and of the radiating beam pattern.

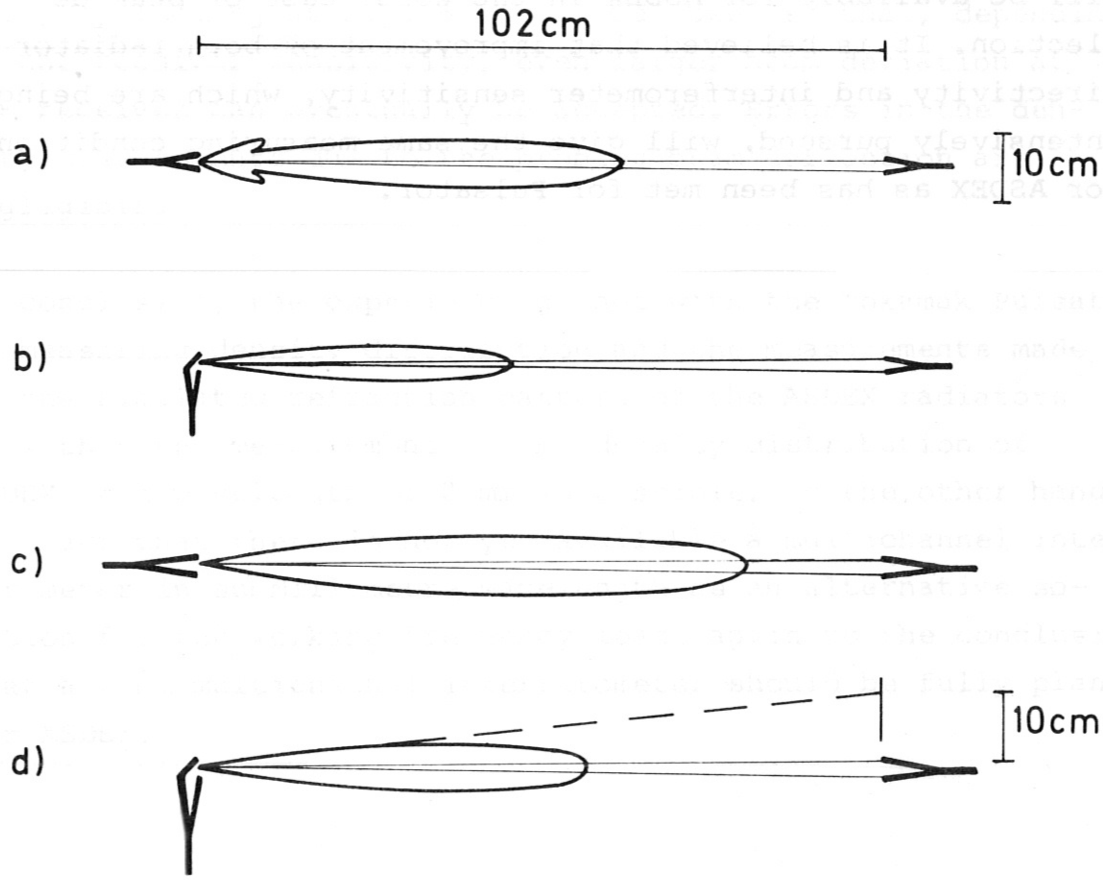

Fig. 6 Radiation pattern

We note the higher sensitivity, about 30 %, of the larger radiators c and d in comparison to the smaller ones a and b.

The mirror radiators will be positioned with the smaller side (16 mm in Fig. 5 d) emerging from the internal wall of the vacuum tube. As compared with the working interferometer at Pulsator, with 32 cm distanced radiators, the received signal for the ASDEX plan-mirror radiators of Fig. 5 d) (placed at a distance of 102 cm) is reduced to one half. This signal is high enough to carry out density distribution measurements at ASDEX, but, considering the lower signal level due to the refracted beam, about 20 % of the signal level used in Pulsator will be available for ASDEX in the worst case of beam deflection. It is believed that improvement of both radiator directivity and interferometer sensitivity, which are being intensively pursued, will give the same measuring condition for ASDEX as has been met for Pulsator.

CONCLUSION

From Figure 6 is seen that a deflection of the beam of even 10 cm at the receiving antenna can be easily accepted by a fair improvement in the sensitivity of the interferometer. By looking at Table I this means that even for the maximum density $\bar{N}e = 3 \times 10^{13}\ cm^{-3}$ with a maximum deviation of the beam at the receiver of 10 cm, the 2 mm wavelength can be used to measure the density distribution in ASDEX. Moreover, by looking at Fig. 6 it can be observed that, depending on the receiver sensitivity, even larger beam deviation at the receiver can eventually be accepted. Errors in the density measurements due to the probing beam deflection are negligible.

In conclusion, the experience gained with the Tokamak Pulsator in measuring density distribution and the measurements made on the simulated refraction pattern of the ASDEX radiators show that the measurement of the density distribution of ASDEX at a wavelength of 2 mm is possible. On the other hand, the fact that there is not yet available a multichannel interferometer in submillimetre wavelength as an alternative solution for the working frequency leads again to the conclusion that a 2 mm multichannel interferometer should be fully planned for ASDEX.

Acknowledgement

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