K-Band (18-26GHz) Single Channel Interferometer

P.K.Atrey, Varsha Siju

Institute for plasma Research, Bhat, Gandhinagar- 382428

E-mail : atrey@ipr.res.in

Abstract:

The microwave interferometer technique is a well-known method of measuring plasma density. Here we describe a homodyne single channel microwave interferometer measurement technique established at BETA lab. This set up in K-Band is used to measure the plasma density.

Principle:

An Interferometer is used to measure the difference in path length between a reference beam, which is kept constant in optical length, and a beam transmitted through the plasma. The optical length through plasma varies due to change in refractive index, connected with increase and decrease of the electron density, during the experimental sequence.

Introduction:

One of the most well known methods of measuring plasma density is the microwave interferometer technique. The method gives the average electron density along the line of sight through the measurement of the phase shift in the beam due to the plasma or refractive index. A reference beam and a beam through the plasma are derived from the same source and are mixed at the detector. The detector being a schotkky diode working on square law principle.

Theory:

When a beam of radiation passes through plasma its phase is shifted by φ.Since the refractivity of plasma is density dependent; the measurement of the resultant phase shift allows the determination of electron density.

The phase difference Φ, between the two beams caused by the presence of plasma is given by,

$$\Phi= (n_e L e^2)/(2\epsilon_0 m \omega c)$$

Where ω is the microwave frequency and L is the path length. During a pulse experiment, the density and therefore the phase Φ is a function of time.

In case of plasma refractive index,

$$\eta^2 =1-\omega_{pe}^2/\omega^2$$

For a path length L , the average electron density,

$$n_e=(2\epsilon_0 m \omega c/e^2)(\omega\Phi/L)$$
$$=(118.4*f*\Phi)/L$$

f = Source frequency, L = Optical path Length

Thus Φ is known, n_e can be estimated.

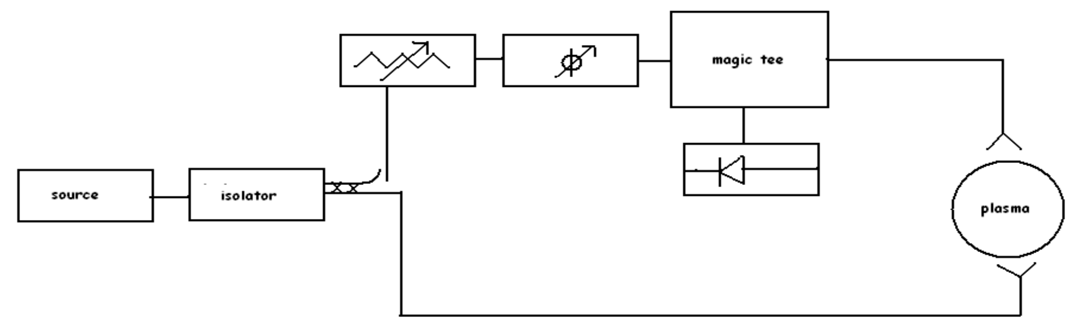

Fig.1. Block diagram

The path length through the plasma varies because of the change in refractive index connected with the increase and decrease of the electron density,

System Parameters:

Source: 22GHz Gunn Oscillator
Power: 17dBm
Phase Shifter: 0^0-180^0
Antenna Gain: 20dB
Mixer: Magic Tee
Detector Sensitivity: 1000mV/mW

Phase Detection Principle:

There are several different ways that the phase shift of a wave propagating through plasma can be detected and displayed. In general, the signal, which comes from the detector, contains a varying component, which is proportional to the sine and cosine of phase.

For a square law detector the current is proportional to square of voltage at the diode terminals and thus the microwave power. Hence, the detector signal is the sum of reference and transmitted signal.

Let $E1 = A \sin(\omega t)$ is the signal in the reference arm
$E2 = B \sin(\omega t + \phi p)$ be the signal in the transmission path.
For a square law detector,

$$I = (E1+E2)^2$$
$$= [A \sin(\omega t) + B \sin(\omega t + \phi p)]^2$$
$$= A^2 \sin^2(\omega t) + B^2 \sin^2(\omega t + \phi p) + 2AB \sin(\omega t) \sin(\omega t + \phi p)$$

Where, the first two terms are dc terms.
The cross term is proportional to

$$\sin(\omega t) \sin(\omega t + \phi p) = 1/2[\cos\{\omega t - (\omega t + \phi p)\} - \cos\{\omega t + (\omega t + \phi p)\}]$$
$$= 1/2\cos(\phi p) - 1/2\cos(2\omega t + \phi p)$$

The second term is high frequency term whose average value is 0 so that the only observable variation in the detector current is

$$I = AB \cos\phi p$$

Where phi is the phase shift caused by plasma as long as the dc levels remain constant. The final signal at the detector, which is working on square law principle, is

$$S(t)=(A^2+B^2)/2+AB\cos(\phi(t))$$

Where A and B are amplitudes of the signals in reference arm an transmitted arm, $\phi$is the phase shift due to plasma. By knowing the phase shift in plasma using the above equation the averaged electron density can be calculated.

Conclusion:

Using the K-Band interferometric setup the plasma density can be calculated with the number of fringes that are related to phase change due to plasma.

References:

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