P5-13

16th International Toki Conference
Advanced Imaging and Plasma Diagnostics
Ceratopia Toki, Gifu, JAPAN
December 5-8, 2006

Multi-channel microwave reflectometer with Fermi antenna receivers

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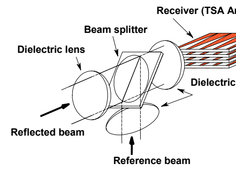
Abstract

We have evaluated a Fermi antenna newly designed in X band for use in a multichannel reflectometer.

The advantages of the Fermi antenna are that it can be adopted as an array antenna owing to its planer shape and fabricated with a low cost due to its compactness and a light-weighted structure. The radiation-beam widths in the E- and H-plane are almost equal to each other and the side-lobe levels are low.

Plasma behaviors in the HITOP device are measured by reflectometry using two Fermi antenna receivers. Time evolution of the cutoff layer and plasma rotation velocity measured by the reflectometer are in good agreement with an electrostatic probe measurement.

Schematic of Imaging System

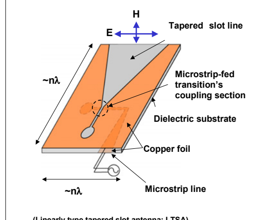


Required characteristics of the receiver

1) An axially symmetric E-plane and H-plane pattern to achieve the optimum coupling with a dielectric lens.
2) Arrangement of a large number of antennas in a limited area to obtain a high resolution of imaging.

1. *The reflected beam and the reference beam are superimposed coaxially by a beam splitter using quasi-optical system, and are focused on a TSA array.*
2. *The phase shift is detected using a heterodyne method.*

Schematic of Tapered Slot Antenna (TSA)

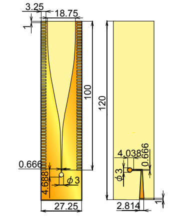


(Linearly type tapered slot antenna: LTSA)

Characteristics of TSA

- Small size
- Simple structure
- Easy to make
- Easy to be arrayed
- Low cost
- Broad bandwidth
- High Gain
- Low crosstalk

Designed Fermi antenna with corrugated structure



Substrate thickness; 1.2
Dielectric constant ; 3.3

Unit; mm

Characteristics of Fermi antenna

1.Shape of the tapered section

Fermi-Dirac function

$$f(x) = \frac{a}{1+\exp(b(x+c))}$$

Where x is a variable and a, b, and c are constants

lower side lobe

2. With corrugated structure around the edge.

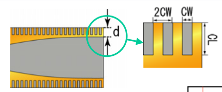
Improved beam pattern

References

[1] S.Sugawara, et al., IEEE MTT-S International Microwave Symposium Digest, pp.959-962, Denver, USA, 1997.

[2] S.Sugawara, et al., IEEE MTT-S International Microwave Symposium Digest, pp.533-536, Baltimore, USA,1998.

Designed corrugated structure



As d is shorter than λ/2, beam width and side lobe level increases.

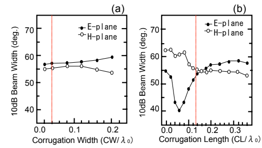
Dimensions of designed Fermi Antenna

Antenna length;

4λ = 100mm (at 12GHz)

Corrugated structure;

CW=1mm(0.04λ)
CL=3.25mm(0.13λ)



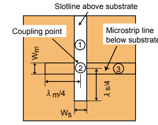
The measured 10dB beam width as a function of (a) corrugation width CW(CL=0.2λ0,d=0.5λ0)and (b)corrugation length CL(CW=0.04λ0,d=0.5λ0).
(Ref.,S.Sugawara, et al., IEEE MTT-S International Microwave Symposium Digest, pp.533-536, Baltimore, USA,1998.)

Electromagnetic Coupling Section of TSA (1)

The impedance matching condition is calculated by an equivalent circuit model.

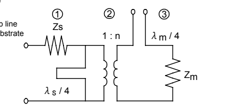
Ref. Y.H.Choung and W.C.Wong, Microwave J., 37,3,77-89(1994).

Microstrip-fed transition's coupling section



- W_s : Width of slot line
- W_m : Width of microstrip line
- λ_s : Slotline wavelength
- λ_m : Microstrip line wavelength

Equivalent circuit model



$Z_m = n^2 Z_s$ Matching conditions

where

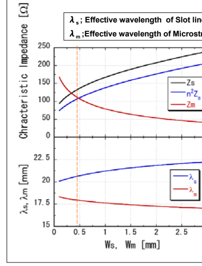
$n = \cos(2\pi ut/\lambda_0) - \cot(q)\sin(2\pi ut/\lambda_0)$

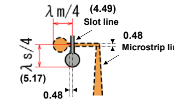
$q = 2\pi ut/\lambda_0 + \tan^{-1}(u/v)$

$u = \sqrt{\varepsilon_r - \left(\frac{\lambda_0}{\lambda_s}\right)^2}$, $v = \sqrt{\left(\frac{\lambda_0}{\lambda_s}\right)^2 - 1}$

Electromagnetic Coupling Section of TSA (2)

λ_s; Effective wavelength of Slot line
λ_m;Effective wavelength of Microstrip line



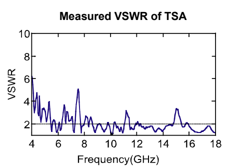


Dimension drawing of microstrip-fed transition (unit : mm)

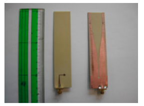
We designed microstrip-fed's coupling section from these calculation result.

- *Center frequency f_0 : 12GHz*
- *Coupling section with circular stub has a broadband frequency characteristic,experimentally.*

Measured VSWR(Voltage Standing Wave Ratio) of TSA

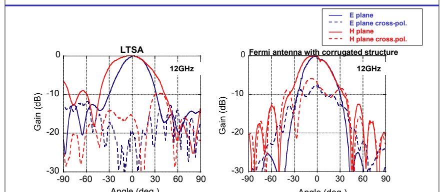


By optimizing the strip-line dimensions, the bandwidth of 8 – 18GHz with VSWR < 2 is obtained.



Fermi antenna (X-band)

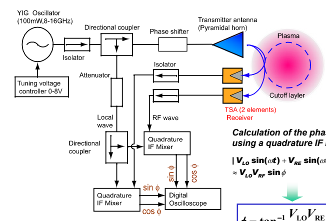
Measured Radiation Patterns of TSA



	E-plane HPBW	H-plane HPBW	Directivity (dB above isotropic)
LTSA	35°	55°	13dBi
Fermi antenna with corrugated structure	32°	37°	15dBi

This radiation pattern is an axially symmetric E-plane and H-plane. Compared with LTSA, directivity of the Fermi antenna is improved about 2dB. and side lobe level is lower.

Microwave Reflectometer System

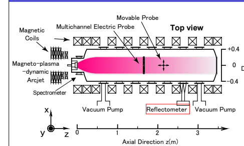


Calculation of the phase difference using a quadrature IF mixer

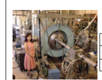
$$|V_{LO}\sin(\omega t) + V_{RE}\sin(\omega t+\phi)|^2 \approx V_{LO}V_{RF}\sin\phi$$

$$\phi = \tan^{-1}\frac{V_{LO}V_{RE}\sin\phi}{V_{LO}V_{RE}\cos\phi}$$

HITOP Plasma



HITOP(HIgh density TOhoku Plasma) device

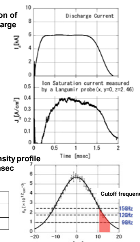


HITOP plasma parameters

Electron density	10^{12}～10^{15} (cm^{-3})
Electron temperature	1～10 (eV)
Ion temperature	10～60 (eV)

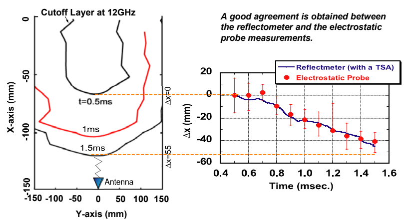
Time evolution of typical discharge

Radial density profile at t = 1.0msec



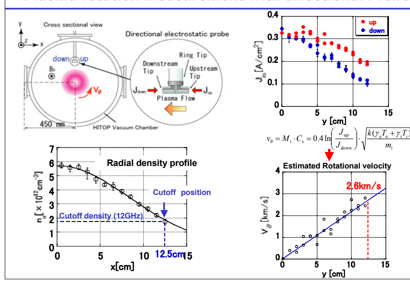
Comparison of Electrostatic Probe and Reflectometer

Time evolution of cutoff layer measured by a electrostatic probe array



A good agreement is obtained between the reflectometer and the electrostatic probe measurements.

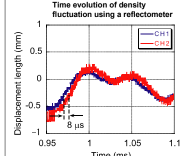
Plasma rotation measurement with directional Probe



$$v_\theta = M_i \cdot C_s = 0.4\ln\left(\frac{J_{up}}{J_{down}}\right)\cdot\sqrt{\frac{k(\gamma_e T_e + \gamma_i T_i)}{m_i}}$$

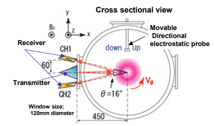
Comparison of Electrostatic Probe and Reflectometer

Time evolution of density fluctuation using a reflectometer



The two TSA receivers face to different reflecting positions in the plasma. There appears a time delay in the reflectometer signals measured by the two receivers. The time delay of 8 ms corresponds to the rotational velocity of 2.2km/s at the cutoff surface. The rotational velocity measured by reflectometer and directional probe agrees well with each other.

Cross sectional view



Rotational period $T = \frac{360}{\theta/2}\cdot\tau$

Rotational velocity $v_\theta = r\omega = r\cdot\frac{2\pi}{T}$

V_θ = 2.2km/s

2.6km/s (r = 12.5cm);
Estimated velocity with directional probe

Summary

1. We designed a Fermi antenna with corrugated structure for X-band, and measured fundamental characteristics of the TSA, VSWR and radiation pattern.
   - The impedance matching condition is calculated by an equivalent circuit model. By optimizing the strip-line dimensions, the bandwidth of 8- 18GHz with VSWR<2 is obtained.
   - The HPBW is 32 degree in the E-plane and 37 degree in the H-plane, respectively. The Directivity of Fermi antenna with corrugated structure is 2dB better than the LTSA.
2. We have measured a HITOP plasma by using the reflectometer with two Fermi antenna receicers.
   - Time evolution of cutoff layer measured by the electrostatic probe array and the reflectometer is in good agreements. Rotational velocity of the plasma is estimated from a time delay of the cutoff layer displacement measured by the two antenna receivers The obtained rotation velocity agrees well with that obtained by a Mach probe.