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Microwave Imaging Radar Reflectometer System Utilizing Digital Beam Forming

FENGQI HU, MEIJIAO LI, CALVIN W. DOMIER, XIAOGUANG LIU, NEVILLE C. LUHMANN, JR., University of California, Davis — Microwave Imaging Reflectometry is a radar-like technique developed to measure the electron density fluctuations in fusion plasmas. Phased Antenna Arrays can serve as electronically controlled “lenses” that can generate the required wavefronts by phase shifting and amplitude scaling, which is being realized in the digital domain with higher flexibility and faster processing speed. In the transmitter, the resolution of the phase control is 1.4 degrees and the amplitude control is 0.5 dB/step. A V-band double-sided, printed bow tie antenna which exhibits 49% bandwidth (46 - 76 GHz) is employed. The antenna is fed by a microstrip transmission line for easy impedance matching. The simple structure and the small antenna are suitable for low cost fabrication, easy circuit integration, and phased antenna array multi-frequency applications. In the receiver part, a sub-array of 32 channels with 200 mil spacing is used to collect the scattered reflected signal from one unit spot on the plasma cutoff surface. Pre-amplification is used to control the noise level of the system and wire bondable components are used to accommodate the small spacing between each channel. After down converting, base band signals are digitized and processed in an FPGA module.

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Microwave Imaging Radar Reflectometer Transceiver System Utilizing Digital Beam Forming

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Conceptual Schematic of MIR system

Microwave Imaging Reflectometry (MIR) is a radar-like system developed to measure electron density fluctuations in fusion plasmas.

Beam Shaping through Remote Control of Optics in current system

Optical lenses in current system are used to collect scattered wave from cutoff layer and focus the reflected beam onto the receiving antenna array with the capability of shaping a curved wave-front over a certain spatial range into a flat one.

Disadvantages: Slow to adjust; Suffer from reflections from lenses; Lack flexibility

Advantage of the DBF:
- Flexibility & accuracy
- Data memory allowed
- Long term stability
- Ease of phase & amplitude adjustment
- Easy circuit integration

Antenna Design and Testing

Photograph of the antenna with Zoom in (scale bar 0.5 mm)

(a) Antenna geometry (b) Antenna structure with the mini-lens

Phased array synthesis integrating optical simulation

Optical simulation was used to obtain the corresponding Gaussian beam waist along with the waist moving range required for refocus. The required array size and corresponding magnitude and phase coefficients for each channel are then calculated for different focusing scenarios.

Far field pattern of an N=29 array with Gaussian taper to achieve a Gaussian beam with 22 mm beam waist

Magnitude and phase coefficients for a 10 cm axial focal shift

Initial complex weight multiply stage with Xilinx 7 hardware co-simulation

A 12 channel complex weight multiply stage is modeled in Simulink and programmed into Xilinx V707 evaluation board. The plot on the right shows the hardware co-simulation results of the 12 channel array looking at broadside.

Proof of principle lab test with W band dual dipole antenna

Multi-Frequency DBF Transmitter/Receiver System

A 12 channel complex weight multiply stage is modeled in Simulink and programmed into Xilinx V707 evaluation board. The plot on the right shows the hardware co-simulation results of the 12 channel array looking at broadside.

Power Amp Mixer

4 of 1:4 Dividers
(28-32GHz)

1:4 Divider
(14-16GHz)

Phase shift
1 GHz

DDS

1 GHz

LO

55 GHz ~ 75 GHz

65 GHz

55 GHz ~ 75 GHz

0.5 GHz ~ 9 GHz

Antenna Array

Pre-amp

Power Divider

4 of 1:4 Dividers
(28-32GHz)

1:4 Divider
(14-16GHz)