Development of ECE Imaging System on LHD

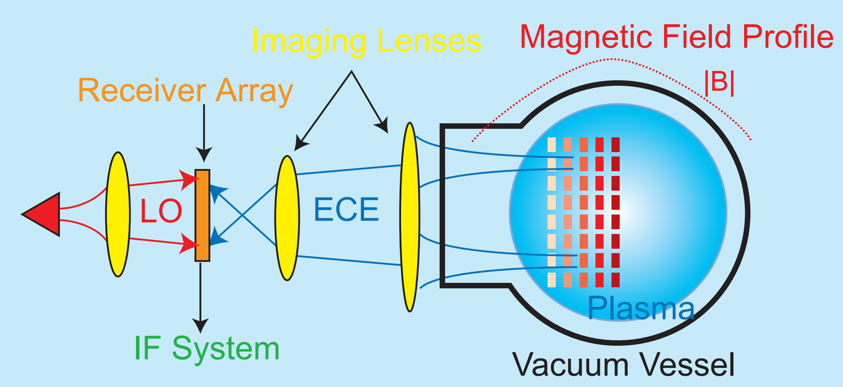
Yuichiro Kogi, Takuya Sakoda, Atsushi Mase, Naoki Ito, Soichiro Yamaguchi[1)], Yoshio Nagayama[1)], Kazuo Kawahata[1)]
ASTEC Kyushu University, [1)]NIFS

Purpose of Our Study

Introduction

It is considered to be one of the major issues to clarify the behavior of various instabilities and relations between instabilities and plasma confinement. Various methods utilizing electromagnetic wave with wave-length range of millimeter-wave have been developed to measure such instabilities. ECE imaging (ECEI) is a promising method to measure electron-temperature profile and its fluctuations precisely. We have been dedicated to develop ECEI system for visualization of the dynamic motion of electron temperature profile. In order to obtain well-resolved image, a high sensitivity (low noise) detector and a lot of detection channels like CCD in the digital camera are essential. In the previous system, we employed commercial components, such as antennas, amps, frequency-mixers and etc, to construct the imaging system. It was a very easy way, however, image resolution becomes worth due to poor integration of consisted components and moderate noise property and bandwidth of each component. We have employed millimeter (microwave) integrated circuit (MIC) technology to construct optimized system. In this presentation, we report the detail of constructed system by MIC technology and preliminary measurement results.

Brief Schematics of our ECEI System



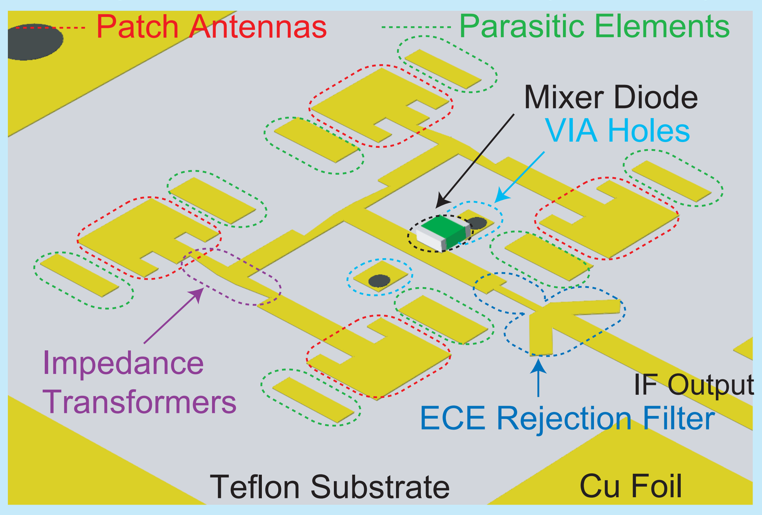
How ECEI System works

First, ECE is generated from cyclotron motion of the electrons. Since the magnetic field strength profile is a function of the radial position as shown in left figure, frequency of the ECE is also a function of radial position. ECE is an omni directional wave, however, some portion of the ECE directed to diagnostic port is focused onto the receiver array by using some focusing lenses and mirrors. In the receiver array, detecting antennas are arranged and resolve emission points in the troidal and poloidal plane. These antennas also receive LO wave, which has a fixed frequency. The LO wave and ECE are mixed in a mixer installed inside the antenna, an then an intermediate frequency (IF) signal is generated. The IF signals are further fed to the IF system, which is consisted from bandpass filter bank to resolve the ECE frequency in radial direction. The IF system also provide low noise amplifiers and video detectors for transformation of the IF signal to further low frequency (DC-MHz) level.

Development and Evaluation of Each Imaging Component

Development of the ECE Receiver Element

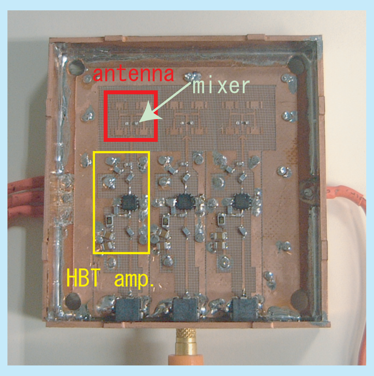
Layout of the Detector Element (70-76GHz)



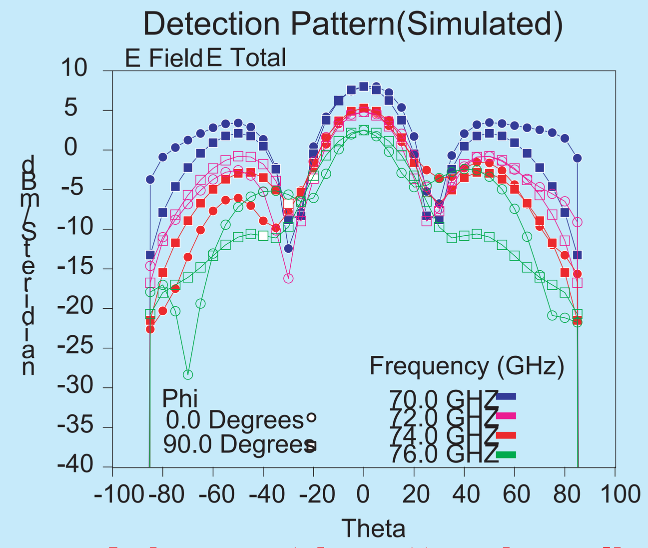
A Detector element consists of 4 patch antennas, 8 parasitic elements, 1 mixer diode, and 1 ECE rejection filter fabricated on the Teflon substrate with t=127um and ε_r=2.2. These planer-circuit components are designed by microwave EM simulator (MW Office and Sonnet). The bandwidth of each antenna is broadening by means of the parasitic elements to 10%. The ECE (70-76GHz) and the LO (70GHz) wave detected by each antenna are combined by the impedance transformers, and are mixed by the Schottoky barrier diode. The ECE and the LO wave are confined inside the mixer and the antenna region by the ECE rejection filter. Only the IF signal with frequency up to 10GHz can pass through the filter and reach the IF output port.

This prototype detector has 3 detector elements and HBT amplifiers for respective antennas. We can see IF output (below), bias line for HBT amps (right), and fixed DC current lines for the mixers (left). This detector array was able to be fabricated by PCB making machine within 5h.

Picture of 3 Detector Array



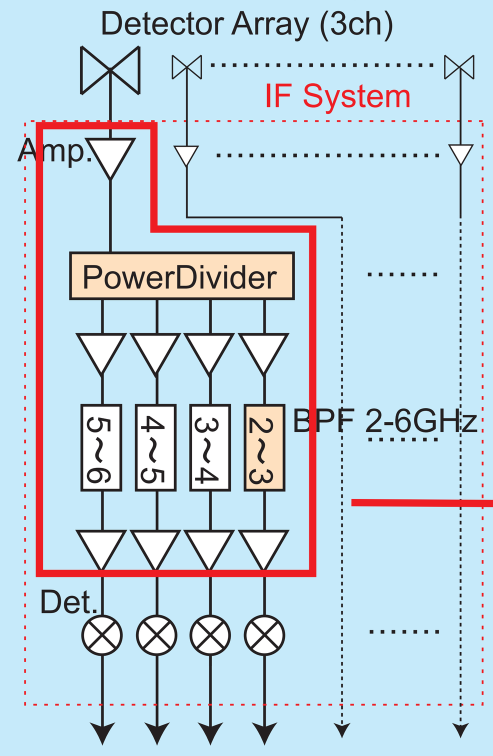
Detection Pattern(Simulated)



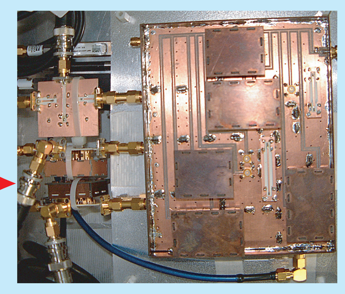
Axisymmetric pattern is realized with directivity of 5dBi.

Development of the IF System

Schematic View of IF System



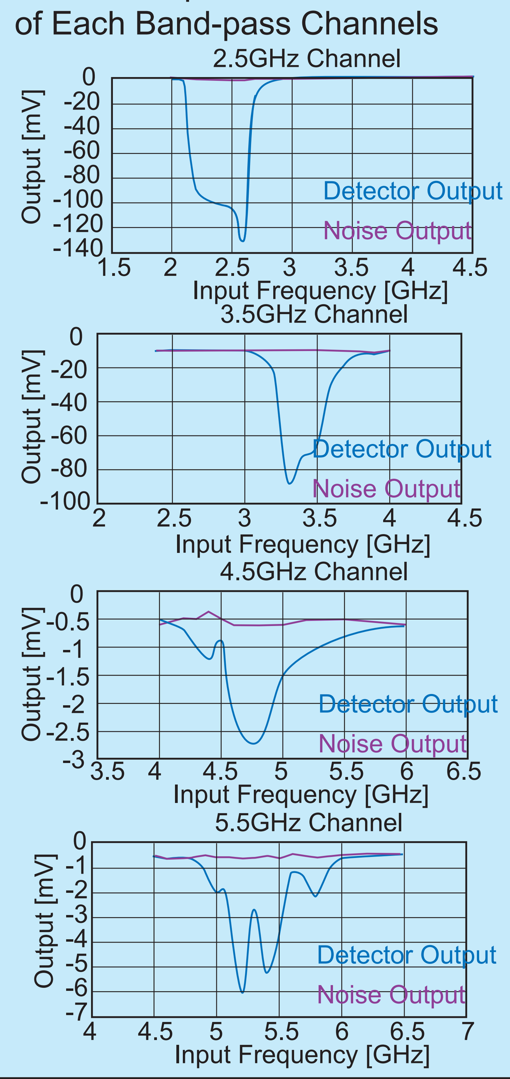
The IF signal from each detector element is first amplified by a commercial 30dB amplifier, then amplified again by multi-stage HBT amplifiers with a gain of 30dB. The amplified signal is divided into 4 signals by a Wilkinson power-divider. Each divided signal is fed to band-pass filter with center frequency from 2.5 to 5.5 GHz with 1GHz interval. Then the filtered signals are detected by video detectors. In this prototype stage, we could only integrate components inside solid red square indicated in the left figure. This integration is also performed by the microwave simulator and the PCB making system.



Picture of the IF System (1ch)

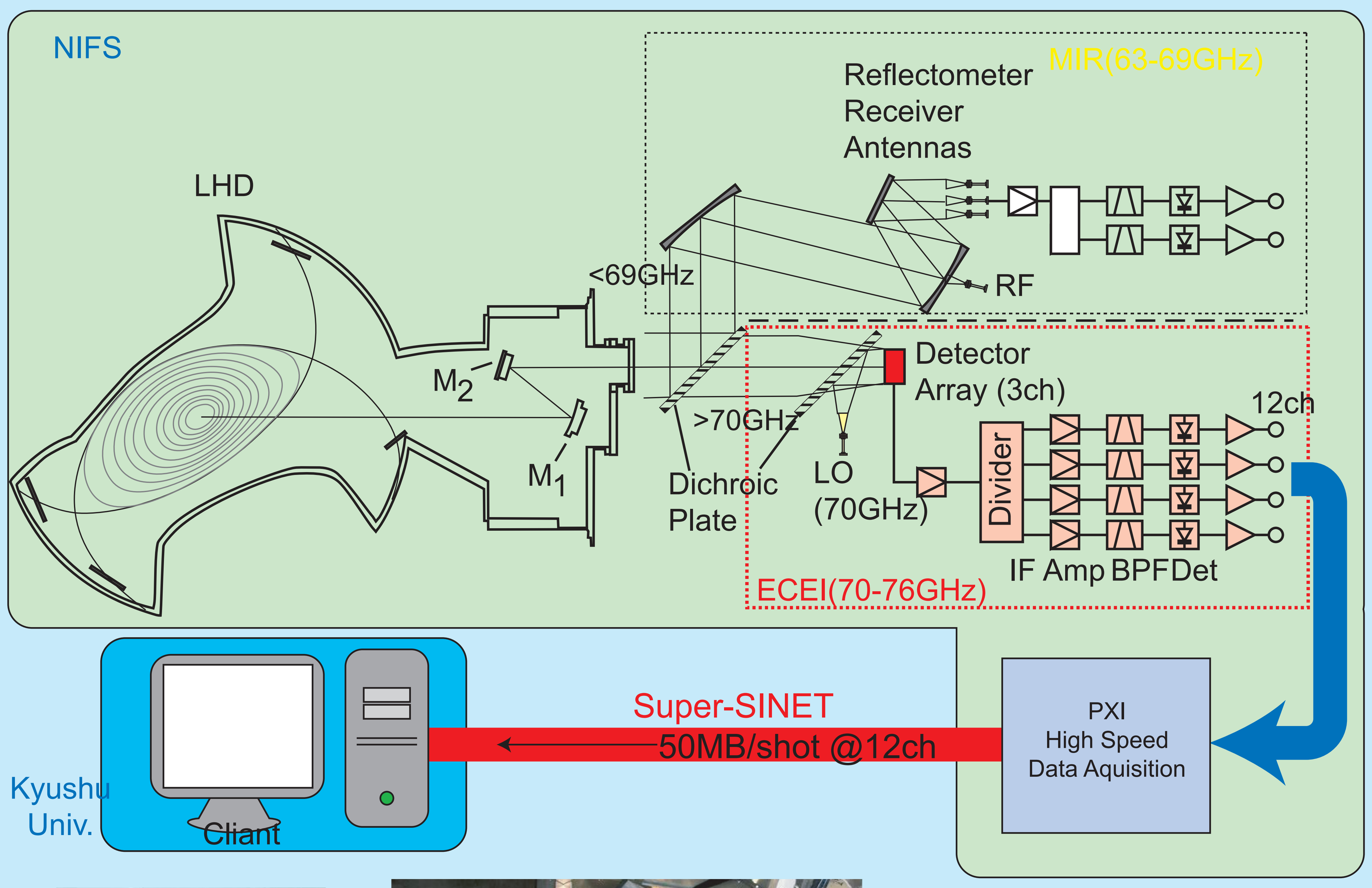
Characteristics of the detector output are shown in right figures. These pre-experiments are performed by means of the ECE detector and the IF system. Instead of the ECE, millimeter-wave source with fixed frequency and power of 0dBm is utilized. It is confirmed that the signal level can be distinguished from noise level of the system.

Detector Output Characteristics of Each Band-pass Channels

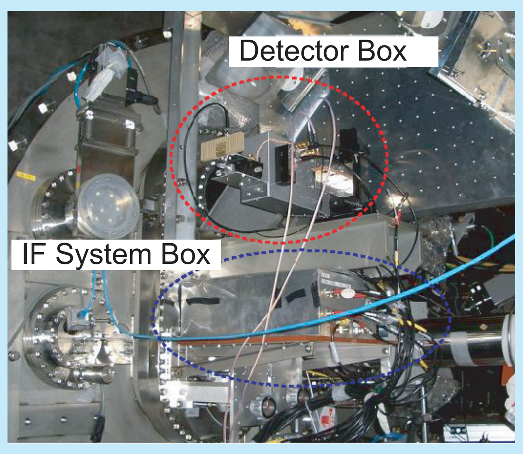


Measurement Setup and Preliminary Measurement Results

Schematic View of ECEI System



Diagnostic Port



ECEI System

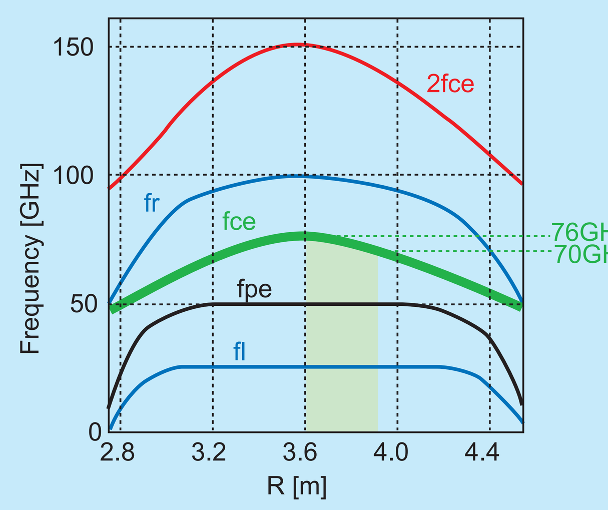
Measurement Box

Experimental Setup

The ECE transmitted from the plasma is introduced to the diagnostic port via an ellipsoidal mirror and a plane mirror. The ECE with frequency over 70GHz can propagate through a dichroic plate, and is focused onto the detector array. The frequency range from 70 to 76GHz corresponds to radial position from 3.6 to 4.0m when the fundamental frequency of the ECE is detected. The ECEI system described above is installed backside of the dichroic plate. Output signals are acquired by the PXI data acquisition system, and stored by LABCOM system. These stored data can be monitored and be analyzed from remote site (Kyushu university) by the super-SINET.

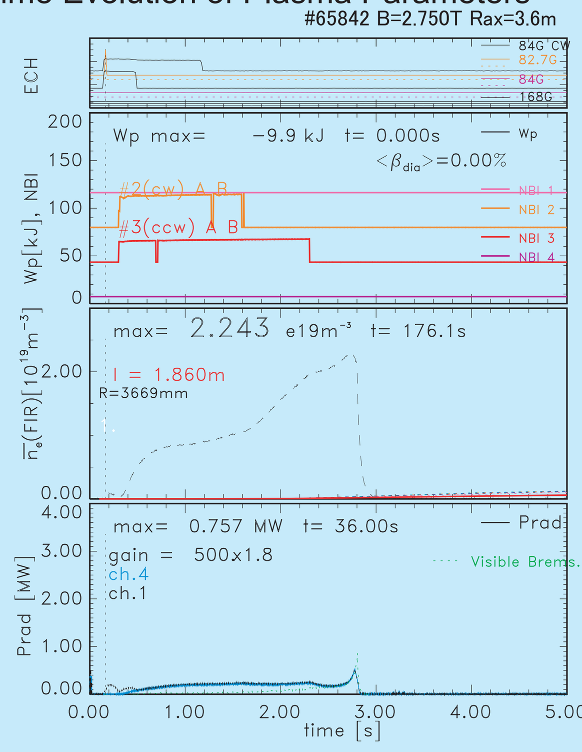
Characteristic Frequency of LHD Plasma

ax=2.75T, R_{ax}=3.6m, n_{e0}=3x10^{19} /m^3

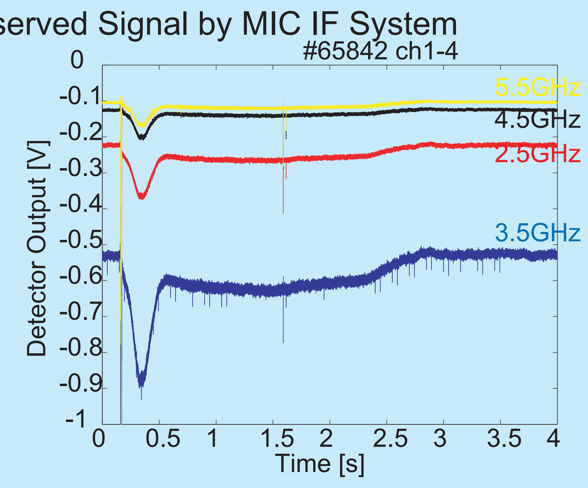


Measurement Results

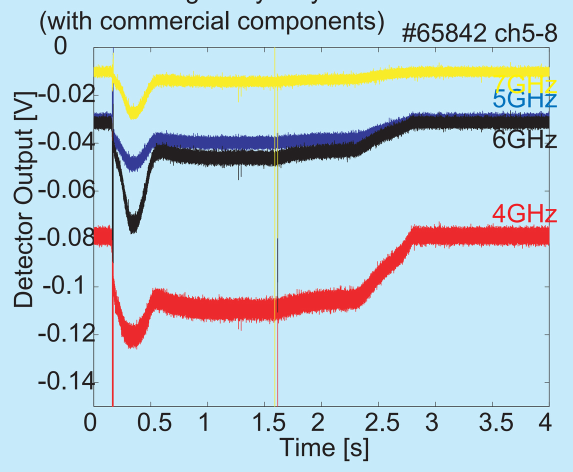
Time Sequence of Heating Systems
Time Evolution of Plasma Parameters



Observed Signal by MIC IF System



Observed Signal byIF system (with commercial components)

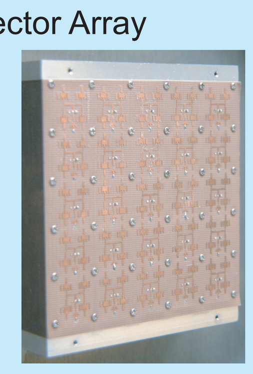


The detector output, which is proportional to electron temperature, is confirmed in each bandpass frequency channel. In order to confirm applicably of the developed IF system, an IF system composed of commercial microwave components is also applied at the same time as shown in right bottom figure. Signal to noise ratio in the case of commercial components seems to be lower than the case of newly developed MIC system. However, since the bandwidth of the bandpass filter utilized in commercial case is 1/3, and total gain of the microwave amplifier in commercial case is lower, S/N can not be directly compared with each other.

Expansion to Imaging Device in the Present Experimental Cycle

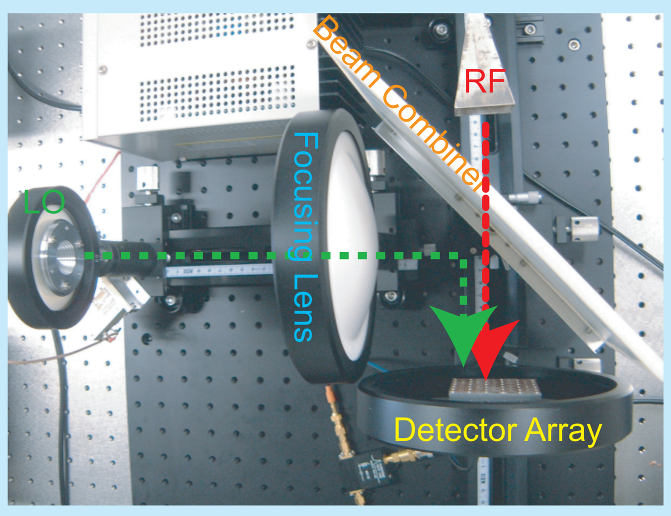
5x5 Detector Array

Detector Array

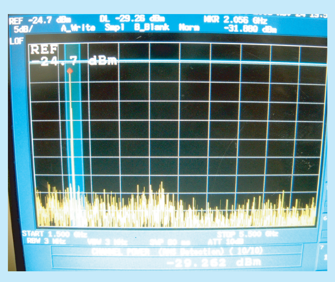


25 (5x5) detectors are arranged. IF outputs are introduced to back side of the substrate via microstrip line to coplanar line transformer.

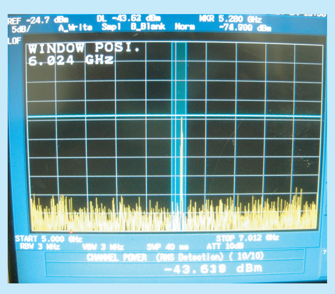
Experimental Setup



Instead of the dichroic plate utilized in preliminary experiment, the dielectric plate with a thickness of 400um and ε=10.2 is utilized as a beam combiner. Transmissivity and reflectivity of the plate are 0.5 and 0.5 around 70-80GHz, respectively

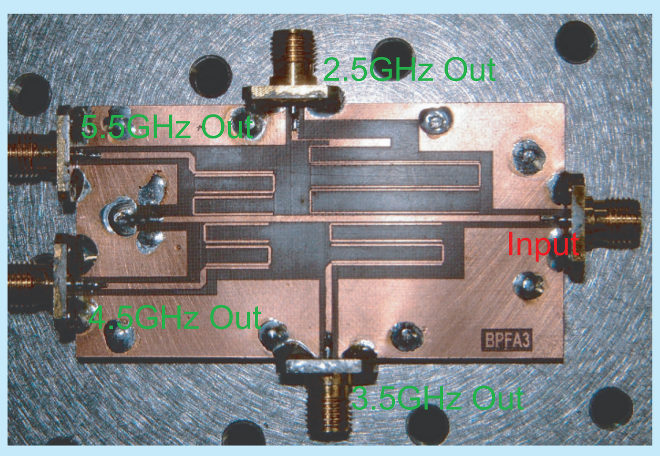


IF Output(2GHz)



IF Output(6GHz)

New IF System



In order to achieve better performance and smaller size of the IF system, the power divider and the bandpass filters are replaced by the circuit as shown in left picture. The IF signal is coupled to each bandpass filter, which contributes better performance of the return loss at the input port. The video detectors have also being developed by the MIC technology to achieve higher sensitivity and lower cost.

Please refer to B30pC14P T. Sa koda. et.al.