§42-10 Development of Advanced Microwave and Millimeter-Wave Devices for LHD Diagnostic Systems

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Microwave to millimeter-wave diagnostics have been well developed by the advancement of devices using integrated circuit and micro-fabrication technologies and of computer technologies. Microwave imaging is one of the attractive methods to visualize dynamic behavior of plasma fluctuations.[1), 2)] The purpose of this research is to develop components and systems for these diagnostics, and apply to the LHD experiment.

In microwave/millimeter-wave diagnostic systems, a band-stop filter (notch filter) is usually required to protect microwave/millimeter-wave detectors from stray power of microwave heating sources. The development of notch filters with good performance is one of the high-priority issues in the ITER microwave diagnostics. There are following requirements for notch filters: i) it must cover the whole area of beam diameter to irradiate the detectors, ii) it should be relatively insensitive to the angle of incidence, iii) it is required to exhibit low loss in the pass frequency band in addition to large rejection at the notch frequency resulting in a requirement for high Q.

During 2013-2014 large-aperture 170 GHz notch filters of various geometries have been fabricated under the Japan-Korea collaboration program[3)] and are installed in the KSTAR-ECEI (electron cyclotron emission imaging[2)] with an angle of < 10 degrees with respect to the optical axis to minimize standing waves between adjacent optical components. The test results are compared with the analytic calculations based on an equivalent circuit model, where the wave transmission through a substrate with infinite periodic gratings is modeled as a single series circuit shunted across the transmission line with the characteristic impedance of free space. The notch filters of 170 GHz become also important to the LHD experiment, since new gyrotrons with those frequency are operated.

Recently, we have started a study of synthetic imaging as well as of optics imaging. The advantage of synthetic imaging is that the image can be produced without the need for a large lens of high optical quality, and each frequency that is launched can be independently imaged. The synthetic imaging is applied to a remote-sensing, so called, synthetic aperture radar (SAR). Two types of SAR system have been operated, strip-mapping mode and spotlight-mode. In the former type, the processing of the returned signals of allows the effective synthesis of a very large antenna, which provides high resolution. The spotlight-mode SAR utilizes a tomographic reconstruction problem.

In conventional microwave SARs having the frequency of X band (10 GHz) and Ku band (16 GHz), the bandwidth is limited for various conditions. Ultra-wideband microwave modulated laser radar is designed and fabricated for the improvement of spatial resolution.[4)] The frequency modulation (0.05–18 GHz chirp) is applied to an infrared laser source in 1550 nm wavelength. Figure 1 shows a schematic diagram of the microwave-modulated laser SAR. The transmitter unit contains both optics and control electronics. The wave is amplified by a fiber amplifier and irradiated by a transmitting optics (a beam expander with a fiber collimator). The reflected wave is picked up by a receiving optics and injected to a receiving unit via a fiber amplifier. A tunable filters with bandwidth of 1 nm is inserted between amplifiers in order to improve the signal to noise ratio (SNR). In order for the spotlight-mode operation, the direction of the incident beam is controlled by a gimbal rotor unit or a fast scanning optics. A vector network analyzer is utilized for the amplitude modulation of laser and phase and amplitude measurements of reflected waves.

The measurement results have been proved that spatial resolution in the range direction of ~ 1mm is obtained by analyzing the phase information of reflected waves. We plan to fabricate a diagnostic system for application to high-density plasmas, for example, plasma imaging diagnostics such as of diverter plasmas.

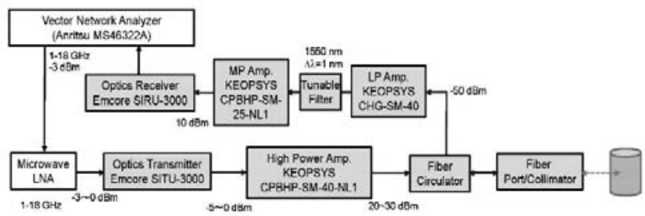

Fig. 1. Schematic of synthetic imaging system using microwave-modulated infrared laser.

In conclusion, the FSS notch filters with notch frequency of 170 GHz have been designed and fabricated for application to the KSATR ECE-imaging and LHD microwave diagnostic systems. The characterization of the notch filters was performed by using a high-frequency network analyzer. The transmission characteristics (S_{21}) was measured. The angle dependence of the filter is also verified. Ultra-wideband microwave-modulated laser radar with a beam expander is fabricated. The spatial resolution is expected to be 1-10 mm in three dimensions by phase analysis of the reflected waves.

1) D. Kuwahara N. Ito, Y. Nagayama, Y. Kogi, A. Mase et al., Rev. Sci. Instrum. 85 (2014) 11D805.
2) G. S. Yun et al., Rev. Sci. Instrum. 85 (2014) 11D820.
3) J. Leem et al., KSTAR Conf. 2014.
4) X. Wang, A. Mase, H. Ikezi, M. Inutake, Y. Kogi, K. Uchino, J. Electromag. Waves Appli. 28 (2014) 917904.