# Quasi-Optical Notch Filters for Plasma Imaging Applications

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***Abstract*—Quasi-optical notch filters are employed to protect plasma imaging arrays from stray radiation from high power electron cyclotron resonance heating (ECRH) sources. A new imaging arrangement permits stacking of multiple filters to maximize ECRH rejection. Simulations indicate that a stack of three filters can provide a notch depth of >60 dB at 140 GHz, and retain this high rejection over an incident angle range of ±8°.**

## I. Introduction And Background

ELECTRON cyclotron emission (ECE) imaging (ECEI) and microwave imaging reflectometry (MIR) are plasma visualization techniques employed to study the electron temperature $T_e$ and electron density $n_e$ fluctuations, respectively. In ECEI, broad bandwidth millimeter wave ECE radiation is collected and imaged onto a 1-D planar mixer array through large aperture optics to form 2-D $T_e$ fluctuation images [1]. MIR is a radar technique in which large aperture optics at the plasma edge illuminate an extended portion of the plasma cutoff layer with low power millimeter-waves, and then collect the scattered wavefront and optically focus an image of the cutoff surface onto a similar 1-D array [2].

Quasi-optical notch filters, consisting of an array of resonant metallic structures placed on one surface of a thin dielectric that form a frequency selective surface, are required to protect plasma imaging arrays from stray radiation from high power electron cyclotron resonance heating (ECRH) sources. ECRH power levels range from a few hundred kW to several MW depending on the plasma device, with frequencies ranging from 84 to 170 GHz. Significant ECRH power can by scattered by the plasma onto the ECEI and MIR. In the case of ECEI, the levels of scattered ECRH power can be tens of mW and thus many orders of magnitude greater than the tens of nW typically received by ECEI. This level of leakage onto the array can modulate the diode conversion loss at lower levels, or even damage the diodes at high levels.

## II. Use of Frequency Selective Surfaces

As a planar, light, and low cost structure, the frequency selective surface (FSS) is suitable for incorporation into imaging optics to protect the mixer arrays from spurious ECRH power. However, there exist several challenges for the design of the FSS notch filter. Unlike waveguide filters, FSS notch filters must provide low passband insertion loss with high notch rejection over a wide range of incident angles. This strongly affects both the filter steepness as well as the depth of the notch that can be obtained. The optical beams that require filtering are quite large, and filters of size 35 cm × 15 cm or more are required. The latter requirement makes it difficult to employ photolithographic techniques, and our focus is therefore on standard PCB board fabrication methods. However, the resolution limitations of this fabrication method bring challenges to the design process, especially at high frequencies.

The current 140 GHz quasi-optical notch filter employed on the TEXTOR plasma device [3] uses a FSS with a square loop structure as shown in Fig. 1. The measured transmission results are plotted in Fig. 2. This filter exhibits 35 dB rejection at normal incidence, with >25 dB rejection over an incident angle range of ±15° while maintaining a passband insertion loss of < 3 dB [3].

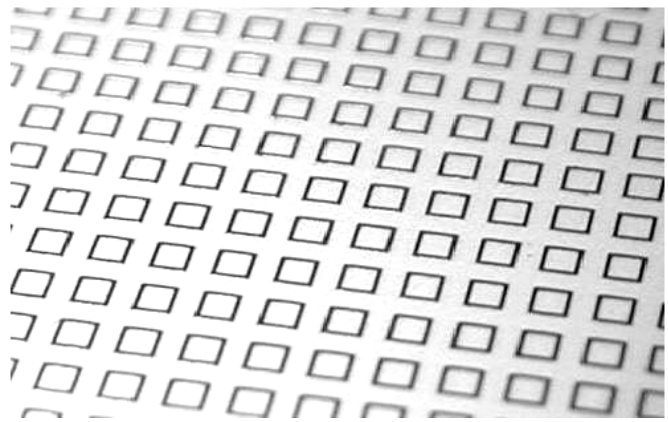

*Fig. 1*: Photograph of a section of a test FSS notch filter with square loop structure.

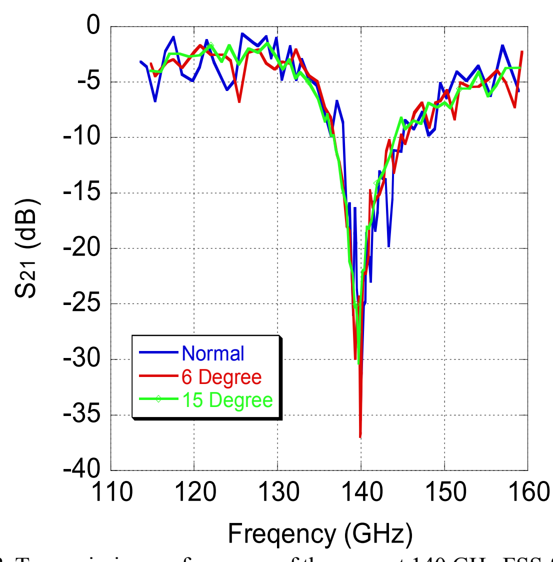


*Fig. 2*: Transmission performance of the current 140 GHz FSS filter at normal incidence, 6° and 15° oblique incidence.

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## III. 140 GHz Notch Filter Development

While it is theoretically possible to stack multiple filters to significantly improve the ECRH rejection, the current TEXTOR design has insufficient room to place more than one filter between the imaging array and the first optical element (lens). However, this limitation is addressed by a new imaging array concept which involves the use of an array of miniature elliptical lenses or mini-lenses (one per antenna, see Kong *et al*., these proceedings). The new mini-lens configuration is shown in Fig. 3. Here, the lens-antenna array is arranged in a staggered two column format producing a tall narrow beam close to the array. ECRH shielding of the array can then be considerably enhanced by employing multiple notch filters. Each filter is tilted at a small angle (5°) so that the standing waves can be eliminated. In contrast to the previous notch filter design, the goal here is not to maximize the passband to notch depth ratio but rather to minimize the passband loss (< 2 dB) while maintaining a >20 dB notch depth. The new imaging arrangement also employs more tightly focused beams; hence, less angular acceptance of the filter is required than the previous design. With three cascaded FSS filters in the new optical arrangement, it is possible to achieve significantly better filtering performance as compared to that of a single filter.

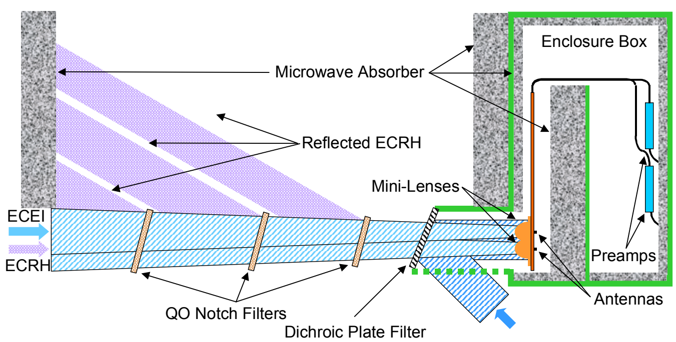


*Fig. 3:* Top view illustration of the mini-lens concept, with a staggered two column antenna arrangement with front-side LO coupling and a three element QO notch filter.

A new 140 GHz FSS notch filter has been designed and modeled with Ansoft Designer, which employs the periodic moment method (PMM). The square loop structure (see Fig. 1) has again been chosen as the metallic pattern due to its very good angle insensitivity and ease of fabrication compared to other kind of patterns [4]. The filter consists of periodic metallic square loop structures on a low loss Rogers RO3003 substrate with a dielectric constant of 3.00. The substrate thickness and metal patch thickness and dimensions are chosen to obtain the desired resonant frequency, notch depth and angle insensitivity.

## IV. Results

The goal of the new QO filter design is to have a maximum passband loss of about 1 dB, while maintaining a notch depth of >20 dB over a range of incident angles of ±8° superimposed on a horizontal tilt angle of 5°. This means that the absolute incident angle will have a range extending up to 13° from normal incidence in the horizontal plane and up to 8° from normal incidence in the vertical plane.

Plotted in Fig. 4 are simulation results for one such filter, with a <1 dB insertion loss passband extending from 90 to 120 GHz (<2 dB passband extending to 130 GHz) and a notch attenuation of 34 dB. Like most FSS filters, it is expected to have a down shifted notch frequency and decreased notch depth as the incidence angle increases. The frequency shift phenomena have been simulated and only a 0.8 GHz frequency down shift and 1 dB rejection decrease have been observed for a 13° incidence angle. This angle insensitivity will ensure high rejection at 140 GHz over the entire incident angle range. The notch frequency at normal incidence is designed to be slightly higher than 140 GHz to give an optimal overall performance. It can be observed that the rejection at 140 GHz is higher than 20 dB over the incident angle range from normal to 13°. The combination of three such filters is expected to provide >60 dB rejection at 140 GHz.

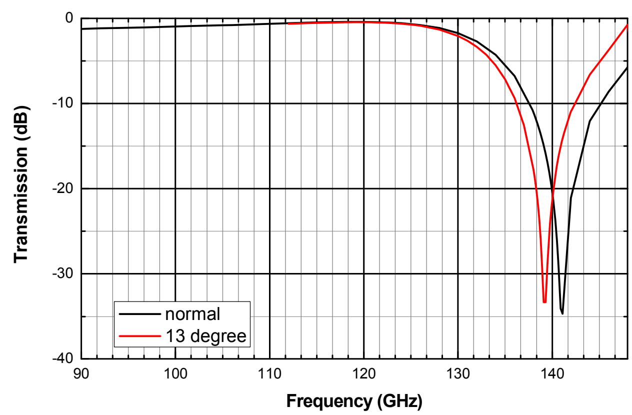


*Fig. 4:* Simulation results of a test 140 GHz QO notch filter at horizontal tilt angle of 0° and 13°.

Small test samples of 140 GHz FSS filters have recently been fabricated by a commercial PCB company. These samples are presently under test and full size filters are expected to be fabricated and installed on the TEXTOR imaging system in September, 2008.

## V. Acknowledgement

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