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Design of a quasioptical test bench for VNA extenders

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Abstract—**The CAD design, simulated optical performance, and test measurements of a quasioptical test bench for VNA extenders are presented. The system allows straightforward integration of off axis parabolic mirrors and VNA extenders. The mirror orientation reduces aberrations and results suggest optical properties are close to what is expected with geometric ray tracing.**

I. INTRODUCTION

THz imaging and spectroscopy applications often require close integration with collimating and focusing of THz radiation [1]. This optical instrumentation is commonplace for typical THz time-domain systems (TDS) but less reported on for vector-network analyzer (VNA) extender-based systems. This abstract reports on the design, simulation, fabrication, and testing of a quasioptical test bench for VNA extenders of various ranges.

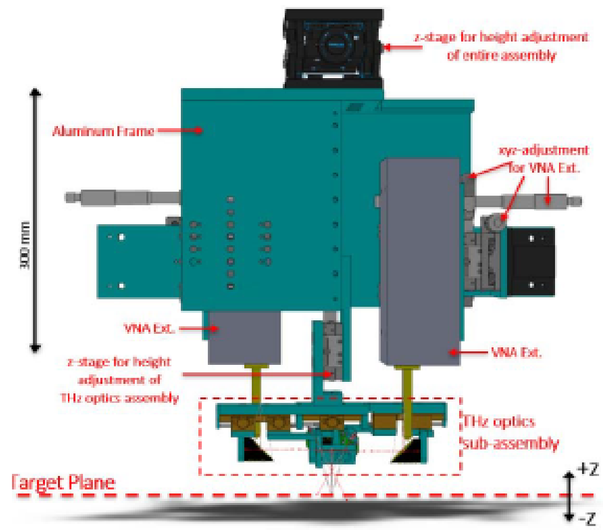

Fig. 1. CAD design of quasioptical system

A CAD drawing of the design is shown in Fig. 1. The main assembly consists of two VNA extenders labeled "VNA Ext.". The THz optical system, labeled "THz optics sub-assembly" consists of four off-axis parabolic (OAP) mirrors to collimate, focus, and collect radiation to and from the target plane [2]. The assembly is indicated by the dashed rectangle in Fig. 1 The foci of the assembly are aligned with the extender feeds through a precision *z*-axis stage. The extenders are mounted in a downward facing orientation allowing the OAP mirror aperture edges to set the working distance between system and device under test (DUT).

Varying view angles of the THz optical system CAD design are shown in Fig. 2. The assembly is rotationally symmetric and consists of four 90° OAP mirrors and two kinematic mount coupled diode lasers for alignment assistance. Mirrors 1 and 4 (Fig. 2 Top) are coupled to the extenders, while mirrors 2 and 3 (Fig. 2: Bottom) focus/collect radiation to/from the target. All components are mounted on shared dovetail rails enabling rough adjustment and repeatable re-mounting.

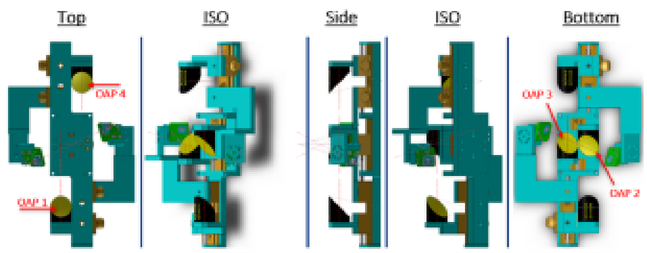

Fig. 2. CAD design of THz optics sub-assembly

OAP Mirrors 2 and 3 can be swapped for matching pairs with varying focal lengths while keeping mirrors 1 and 4 and the overall optical assembly fixed. This enables on-target optical parameter exploration without re-alignment.

Fig. 3 shows the manufactured and constructed setup. The THz optics assembly was mounted on a rigid aluminum rail suspended above the optical table by 4 75 mm x 75 mm thick aluminum extrusions. Observation of metallic reflectors suggest minimum mirror and extender vibration.

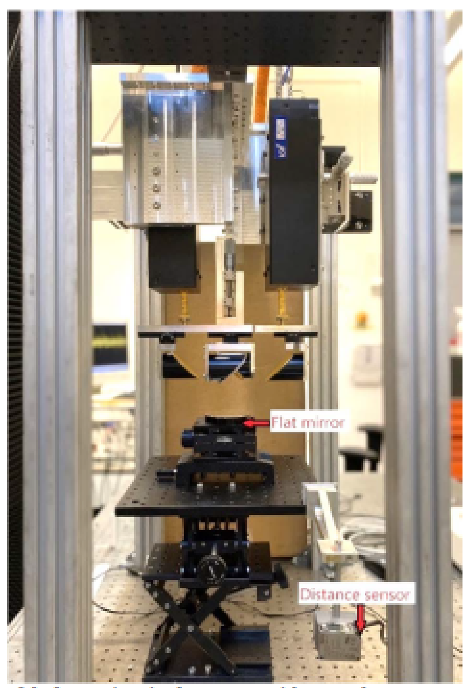

Fig. 3. Assembled quasioptical system with sample stage mounted below the OAP mirror train.

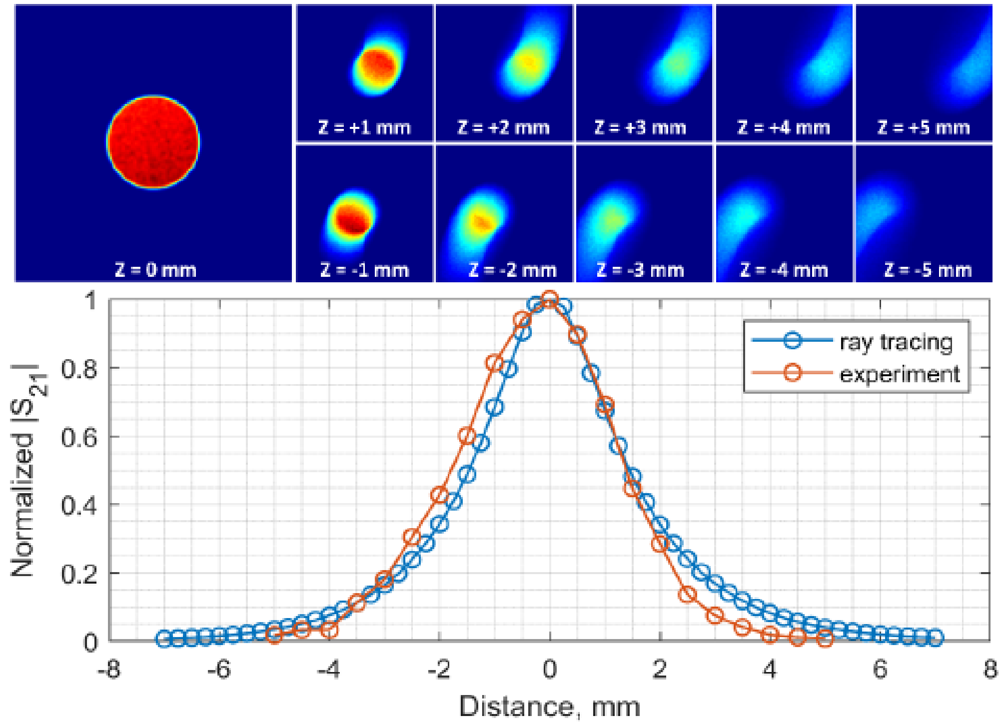

Fig. 4. Top: Ray-tracing results of target misalignment due to placement. Bottom: measured change in absolute value of S_{21} due to -5- and +5-mm displacement in z-plane.

II. Results

Measurements of the system depth of focus were realized with a VNA (N522B PNA by Keysight Technologies) coupled to millimeter-wave extension modules (WR 2.2-VNAX by Virginia Diodes Ltd). The main limitation of the proposed design is inability to perform the traditional full two-port calibration. Standard SOLT (Short-Open-Load-Thru) or TRL (Thru-Reflect-Line) routines are not realizable, for example, due to impossibility to connect two ports together for the Thru step. One may go for calibration a transmitting port only, although the accuracy will be questionable. A flat mirror was placed at the target plane and its elevation relative to the focal point shared by mirrors 2 and 3 was varied with a vertical translation stage. Height perturbation was verified with a laser range finder (OD1-B100H50U25 by SICK Sensor Intelligence)

The target height was varied from 5 millimeter below the focal point (- 5mm) to 5 mm above (+5mm) in increments of 0.5 mm. Complex S_{21} was acquired at every step and depth of focus was estimated via band integrated, total power.

The optical performance of the system was estimated with non-sequential ray tracing package ASAP (Breault Research Organization). An emitting disk of 1-mm semi-radius and 15° half-power angle was used as a Gaussian beam source representation and placed in the focal plane of OAP 1. The target was moved in and out of the image plane ($\pm z$ in Fig. 1) and the received rays monitored at the OAP 4 focal plane. A mask was applied to the ray tracing derived irradiance to mimic the effective aperture of the extender diagonal feedhorn

The aligned case ($z = 0$ mm) disk image is in the left side of Fig. 4 (Top) and shows a small gradient in field density from bottom to top, due to the inherent asymmetry introduced by OAP mirrors. The misaligned cases demonstrate increasing coma as the DUT distance from $z = 0$ is increased. However, the coma is asymmetric, suggesting the mirror radial asymmetry has a significant effect on the optical performance.

The normalized integrated radiance limited by the mask aperture, as a function of target height, is superimposed on the experimental data in Fig. 4. The good agreement indicate that the submillimeter wave/THz frequency properties OAP mirror optical train can be estimated by ray tracing alone and suggest aberrations have been limited by OAP orientation.

III. Summary

A quasioptical test bench for VNA extenders was presented. The design enables extender use in imaging and spectroscopy situations commonly explored with TDS instrumentation. Practical trial of presented setup has been demonstrated high measurement accuracy: the overall losses of the system, obtained by placing flat mirror on the target plane and measuring reflectivity through S_{21}, was -2dB.

References

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