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Optical Designing of Spatial Heterodyne Spectrometer using TracePro

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ABSTRACT: This paper describes the designing of an interference spectroscopy system, the Spatial Heterodyne Spectrometer (SHS), for faint airglow measurements, in optical design software called TracePro. SHS stands on two blazed diffraction gratings in littrow configurations and plays an important role in ground based aeronomy. Fizeau fringes of wavenumber dependent spatial frequency are produced, which is a form of Michelson interferometer revised with diffraction gratings over mirrors. Position detector records the fringes and Fourier transformed to recover the spectrum over a limited spectral range. By designing in TracePro, which is used for designing and analyzing illumination and imaging systems, easiness in its practical implementation can be improved.

KEYWORDS: Aeronomy, Fizeau fringes, Spectrometer, Spatial Heterodyne Spectroscopy, TracePro.

I. INTRODUCTION

Spectroscopic techniques have been applied in all technical fields of science and technology. It helps to study the upper atmosphere through the interactions between particles and with other particles. Interference spectrometers, like Fabry-Perots and Michelson instruments yields large etendue, compact size and high resolution, makes it suitable for the study of faint spatially extended sources [1]. Recently, Spatial heterodyne Spectrometer (SHS) has emerged which offers similar advantages but with no moving elements is required, which become very crucial in rocket and satellite based programs [1]. Since SHS is a significant instrument to study the planetary atmosphere, it is designed in optical design software, TracePro [2] which reduces the difficulties in its practical implementation.TracePro is optical engineering software for designing and analyzing different optical systems. It gives the information about the light distributions, through put, flux or power absorbed or scattered by the surfaces. With the help of preexisting models in TracePro, optical components in SHS are designed. Finally, using that design parameters and specifications, SHS can be practically implemented.

II.LITERATURE SURVEY

In the basic spatial heterodyne spectrometer, Fizeau fringes of wavenumber-dependent spatial frequency are produced by a modified form of Michelson interferometer in which the mirrors are replaced by blazed diffraction gratings at litrrow configurations [3] as shown in Figure 1.

SHS concept can be evoked by the fact that the gratings can be tuned to place zero spatial frequency at a selected wavenumber σ_0, the Littrow wavenumber of the gratings. For the monochromatic light of wavenumber σ_0 entering into the system, two coherent plane wavefronts are produced at the output governed by the equation $2\sigma_0 \sin(\theta_L)=m/d$ with a crossing angle 2γ between them according to the equation $\sigma\{\sin(\theta_L)+\sin(\theta_L-\gamma)\}=m/d$, where 'm' is order of diffraction, 'θ_L' is Littrow angle, '1/d' is groove density, and 'γ' is diffraction angle with respect to Littrow for wavenumber σ and their superposition leads to generation of Fizeau fringes of spatial frequency $f_x = 2\sigma\sin\gamma \sim (\sigma-\sigma_0) \tan\theta_L$. These fringes are recorded by a Charge Coupled Device (CCD) [4].

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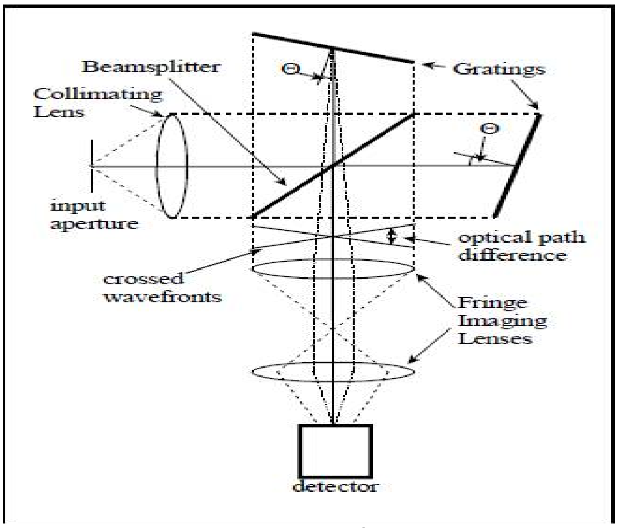

Figure 1. SHS Configuration

For an arbitrary input spectral density B(σ), the intensity distribution recorded is given by:

$$I(x)=\int_{0}^{\infty} B(\sigma)[1+\cos\{2\pi[4(\sigma-\sigma_0)x\tan\theta]\}]d\sigma \text{ ....(1)}$$

where,'x' is measured in direction of dispersion plane. Obviously, SHS records cosineFouriertransform of input spectra without any scanning and heterodynes the interferogram with a frequency corresponding to Littrow wavenumber of grating. Fourier transform of I(x) yields input spectra about the heterodyne wavelength.

III.DESIGN AND SIMULATION

A. TracePro

TracePro is commercial optical design software, for designing and analyzing illumination and imaging systems. It creates a virtual prototyping environment to perform software simulation before manufacture. We can create geometry either by using the TracePro CAD interface or by importing models directly from other design softwares also. TracePro additionally has an add-in to Solidworks, the TracePro Bridge. The TracePro Bridge allows users to apply and save optical properties directly to the SolidWorks model via the TracePro System Tree within SolidWorks. Ray tracing, optical designing, mechanical designing and modifying optical parameters can also done in TracePro.We can also import models from other optical design programs such as OSLO, Zemax or Code Vto create a complete optomechanical design. After creating the optical-mechanical model, create sources using built-in source wizards. Then rays are traced through the systems to find energy distributions on any surface or track volume flux through any space. It also simulate the appearance of illumination or lighting systems and trace bitmap images through optical systems to check for uniformity, veiling glare, flare, and distortion issues. Thermal effects and stray light issues can also be simulated. It gives the information about the light distributions, through put, flux or power absorbed or scattered by the surfaces.

B. Designing of SHS

SHS is designed in TracePro based on the block diagram shown in figure 2. To direct the light from the sky to the system, a combination of a mirror and two lenses are used. Light then passes through the aperture after filtering at center wavelength of 6304 A°. Then they are collimated by the collimating lens and fed into beam splitter. The splitted lights after diffracted from the grating gets interfered and detected after passing through two imaging lenses.

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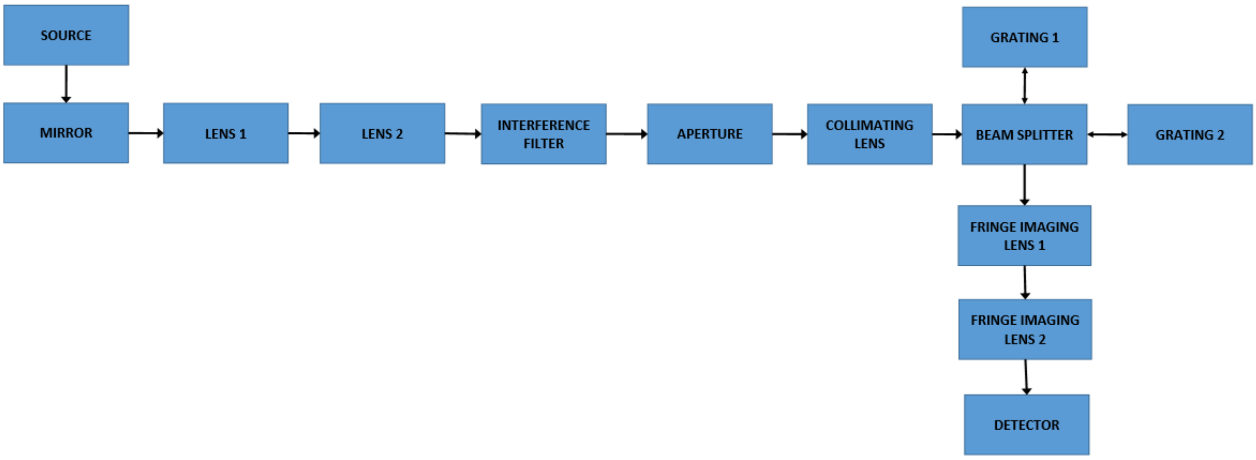

Figure 2 Block diagram of SHS

To design SHS in TracePro, every optical component are built in the shape of blocks, cylinders etc and apply the required properties to the selected surface. Different optical components, their shapes, and dimensions are specified in table 1.

COMPONENT	DIMENSIONS(mm)
Tube (Cylinder)	Thickness : 2, Length : 110 Major Radius : 32 Rotation (X, Y,Z) : (90, 0, 0)
Mirror (Block)	Width (x, y, z) : (110, 10, 110) Rotation (x, y, z) : (45, 0, 0)
Lens 1 (Lens)	Material : Schott BK7 Thickness : 15 Surface 1 Radius : 175 Surface 2 Radius : -175 Semi diameter : 40
Interference Filter (Cylinder)	Major Radius : 25 Length : 2
Aperture (Block)	Thickness : 2 Aperture Shape : Rectangle Aperture Semi diameter : 20 Obstruction Shape : Circle Obstruction Semi diameter : 5.5
Collimating Lens (Lens)	Material : Schott BK7 Thickness : 15 Surface 1 Radius : 175 Surface 2 Radius :-175 Aperture : Circle Semi Diameter : 40

COMPONENT	DIMENSIONS(mm)
Beam Splitter (Block)	Width (X, Y, Z) : (90, 5, 90) Rotation (X, Y,Z) : (-45, 0, 0)
Grating 1 (Block)	Width (X, Y, Z) : (60, 5, 60) Rotation (X, Y, Z) : (-20.7, 0, 0)
Grating 2 (Block)	Width (X, Y, Z) : (60, 5, 60) Rotation (X, Y, Z) : (-69.3, 0, 0)
Image Forming lens 1(Lens)	Material : Schott BK7 Thickness : 15 Surface 1 Radius : 80 Surface 2 Radius : -80 Aperture : Circle Semi diameter : 35
Image Forming lens 2 (Lens)	Material : Schott BK7 Thickness : 10 Surface 1 Radius : 25 Surface 2 Radius : -25 Aperture : Circle Semi diameter : 35
Detector (Block)	Width (X, Y, Z) : (20, 5, 20)

Table 1 Dimensions and specifications of optical components used in SHS

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A source is generated with wavelengths 5461 A°, 5577 A°, 5890 A°, 5896 A°, 6300 A°, 7316 A° and 7402 A° and a field of view (FOV) of 3°. The designed SHS in TracePro is shown in figure 3.

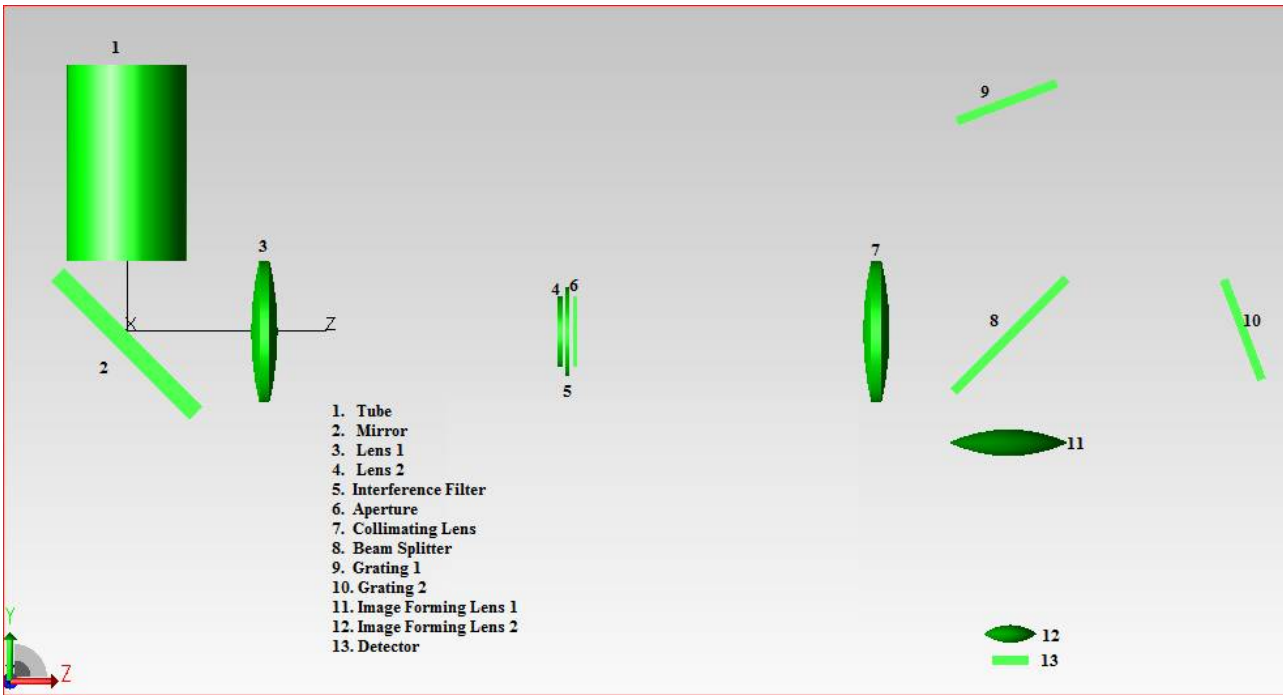

Figure 3 SHS designed in TracePro

Interference filter is designed by applying a specular transmission for 6300 A° to 0.9 out of 1and other wavelengths as 0.1 and this surface property is applied to required surface. Thus it will block other wavelengths except 6300 A°. Here, grating is designed for two orders (-1, 0, 1) and is placed at littrow angle of 20°7'. This property is also applied to the required surface. Mirror, beam splitter and detector will perform its function only after applying the 'perfect mirror', 'beam splitter' and 'perfect absorber' properties respectively to the required surface.

IV. RESULTS AND DISCUSSIONS

SHS is designed in TracePro with the specified dimensions and specifications. Ray tracing is performed and is shown in figure 4.Since this instrument is configured at littrow angle, light after split from the beam splitter is following the same path with diffracted light from the grating. Also, the incoming light with a field of view of 3° is uniformly distributed and detected at the detector.

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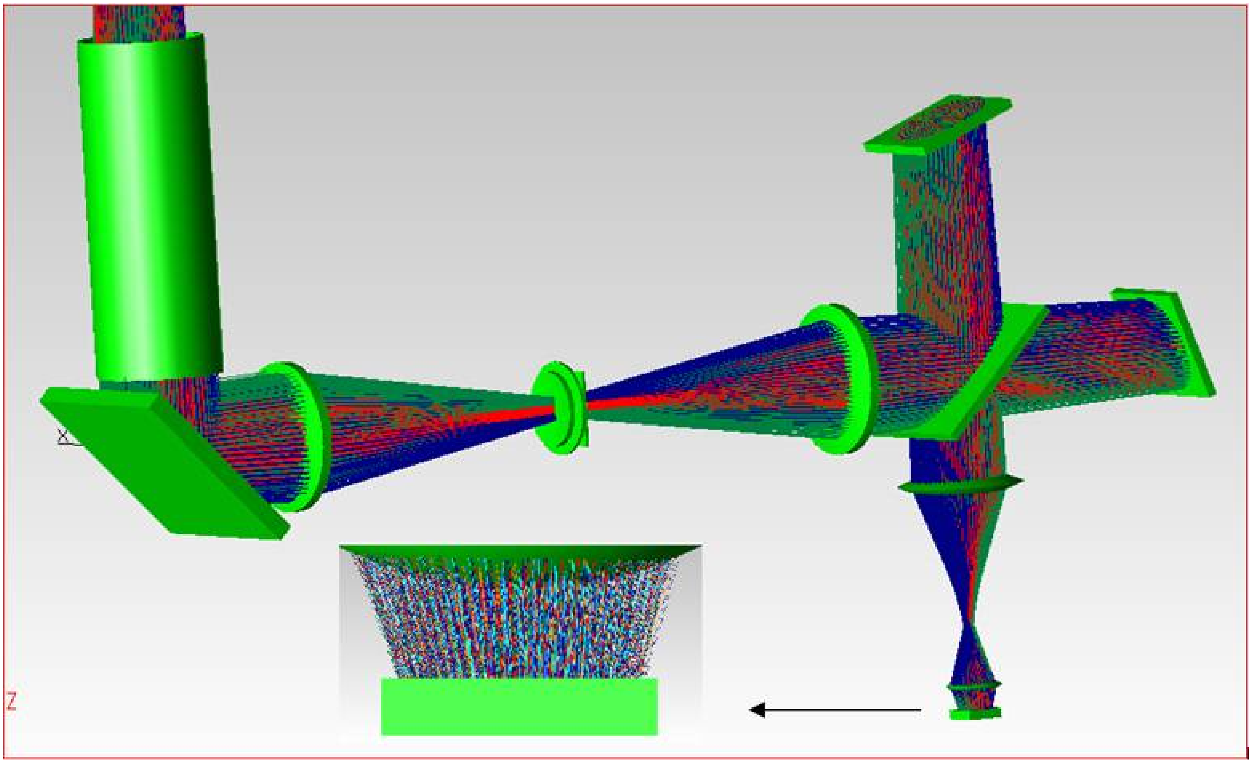
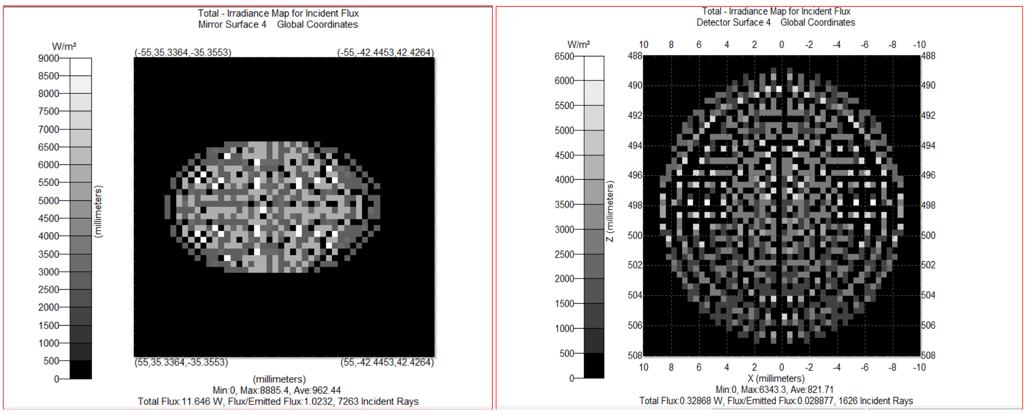


Figure 4 Ray traced diagram

Irradiance map obtained at the surface of mirror and detector is shown in figure 5.



(a) (b)

Figure 5 Irradiance maps of (a) Mirror and (b) detector

From this figure, it is clear that the system transmittance is 1.0232 W.

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IV. CONCLUSION

SHS is an important tool for satellite based aeronomy. Here, SHS is optically designed in TracePro, which gives light distribution, throughput and system transmittance. Ray tracing also helps to visualize how the rays follow through each componentin real time before manufacturing. This improves the easiness of its practical implementation. SHS can then be practically implemented using the designed parameters and specifications done in TracePro.

V. ACKNOWLEDGEMENT

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