# TIMED Doppler Interferometer (TIDI)

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## ABSTRACT

The TIMED Doppler Interferometer (TIDI) is a Fabry-Perot interferometer designed to measure winds, temperatures, and constituents in the mesosphere and thermosphere (60-300 km) region of the atmosphere as part of the TIMED mission. TIDI is a limb viewer and observes emissions from OI 557.7 nm, OI 630.0 nm, OII 732.0 nm, $O_2$(0-0), $O_2$(0-1), Na D, OI 844.6 nm, and OH in the spectral region 550-900 nm. Wind measurement accuracies will approach 3 $ms^{-1}$ in the mesosphere and 15 $ms^{-1}$ in the thermosphere. The TIDI instrument has several novel features that allow high measurement accuracies in a modest-sized instrument. These include: an optical system that simultaneously feeds the views from four scanning telescopes which are pointed at ±45° and ±135° to the spacecraft velocity vector into a high-resolution interferometer, the first spaceflight application of the circle-to-line imaging optic (CLIO), and a high quantum efficiency, low noise CCD.

**Keywords:** Fabry-Perot interferometers, remote sensing, wind measurements

## 1. INTRODUCTION

The TIMED Doppler Interferometer (TIDI) will investigate the dynamics and energetics of the Earth's mesosphere and lower thermosphere-ionosphere (MLTI) from an altitude of 60 to 300 km as part of the TIMED mission.[1] TIDI measurements will obtain a global description of the vector wind and temperature fields, as well as important information on gravity waves, species densities, airglow and auroral emission rates, noctilucent clouds, and ion drifts. TIDI will provide basic information about global winds and temperatures. TIDI will also contribute to the study of MLTI energetics. Some of the key TIDI parameters are shown in Table 1.

Table 1. TIDI parameters

| | |
|---|---|
| Spacecraft altitude | 625 km |
| Orbital inclination | 74.1$^{o}$ |
| Time to precess through 24 hours of local time | 120 days |
| Instrument mass | 41.8 kg |
| Electrical Power | 19.32 watts (orbit ave.) |
| Heater Power | 11.0 watts |
| Data Rate | 2494 bits/s |
| Altitude Resolution | 2 km |
| Spectral Range | 550 - 900 nm |
| Lifetime | >2 years |
| Operational temperature | 20±5°C for profiler<br>-80°C for detector<br>-20°C to 40°C for telescopes |
| Retrieved quantities | vector wind field, temperature, and some constituent densities from 60 to 120 km |

The TIDI interferometer (or Profiler) primarily measures horizontal vector winds and neutral temperatures from 60 to 300 km, with a vertical resolution of ~2 km at the lower altitudes and with accuracies that approach ~3 m/s and ~2 K, respectively, under optimum viewing conditions. The TIDI design allows for 100% duty cycle instrument operation during daytime, nighttime, and in auroral conditions. TIDI is a limb viewer and observes emissions from OI at 557.7 nm, OI at 630.0 nm, OII at 732.0 nm, $O_2$(0-0) at 762 nm, $O_2$(0-1) at 861 nm, Na D at 589 nm, OI at 844.6 nm, and OH to determine Doppler wind and temperature throughout the TIMED altitude range. TIDI also makes spectral ratio observations to determine $O_2$ densities and rotational temperatures.

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TIDI is a direct descendent of other spaceflight Fabry-Perot interferometers built at the Space Physics Research Laboratory of the University of Michigan. The first instrument was the Dynamics Explorer Fabry-Perot Interferometer (DE-FPI) which was a single-etalon instrument designed for observations of emissions from the thermosphere.[2] It was launched in 1981 and operated for 18 months until the satellite re-entered the Earth's atmosphere. The High Resolution Doppler Imager flying on the Upper Atmosphere Research Satellite (HRDI/UARS) is a triple-etalon Fabry-Perot system designed for observations of the stratosphere, mesosphere, and lower thermosphere (10-120 km).[3,4] It was launched in 1991 and is still operating at the time of this writing. The TIDI instrument uses designs and concepts developed in these programs while incorporating new ideas and technologies. This paper will discuss the optical design of the TIDI instrument and summarize the performance of many of the optical components. Other important aspects of the instrument such as the mechanical and thermal design, and instrument operations are beyond the scope of this paper. At this writing, the complete TIDI calibration is not complete, so it is not possible to provide a complete description of the end-to-end performance. However, some metrics will be provided to indicate the type of performance expected from this instrument.

## 2. INSTRUMENT OVERVIEW

TIDI comprises three major subsystems: four identical telescopes, a Fabry-Perot interferometer with a CCD detector, and an electronics box (Figure 1). Light from the selected regions of the atmosphere is collected by the telescopes which are fiber-optically coupled to the detection optics. The four fields of view are spatially scrambled by the random distribution of the fibers in the bundle. A fifth field from a calibration deck is combined with the others so the input to the profiler consists of an array of five concentric circular 90 degree wedges. This input is collimated for transmission through a selected filter, followed by a Fabry-Perot etalon, and is finally imaged onto a CCD via a Cassegrain telescope and a circle-to-line imaging optic (CLIO) device. Two telescopes are required to form a wind vector since the telescopes have no azimuth adjustment. The same volume of the atmosphere is viewed from orthogonal viewpoints about 9 minutes apart. The four telescopes permit vector winds to be measured along two tracks on either side of the spacecraft. This has the advantage of allowing two local times to be sampled at the same latitude for low and mid latitudes while also providing complete pole to pole coverage.

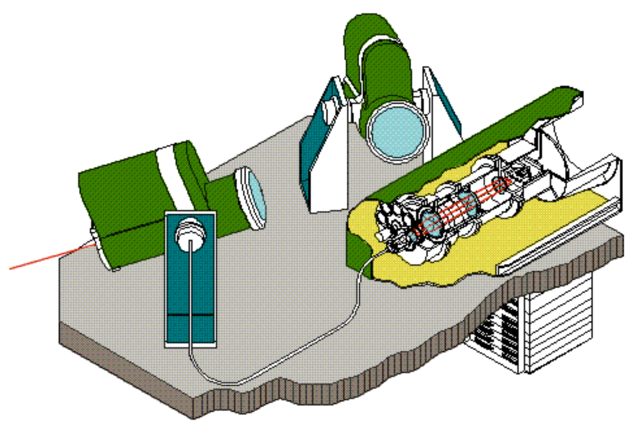

Figure 1. TIDI layout showing two of the four telescopes, the fiber optic connecting the telescopes and profiler and the electronics box.

The optical concept of the profiler is shown in Figures 2 and 3. Figure 2a shows a basic imaging system. One lens (in reality a set of lenses) collimates light from the object while a second lens (in reality a Cassegrain telescope) images the object. The magnification of the system is simply the ratio of the focal lengths of the imaging and collimating lenses. In Figure 2b the effect of adding a Fabry-Perot etalon between the two lenses is illustrated. If the image consists of light from a nearly monochromatic light source, then the image field will be modulated by the Fabry-Perot fringe pattern. Light will be passed through the etalon when the resonance condition is met ($2t\cos\theta/\lambda$=integer; t=gap thickness, $\theta$ the angle of incidence, and $\lambda$ the wavelength of light) and reflected for other conditions. If the input field is large enough a series of rings, corresponding to different orders of the etalon will be observed. By designing the input fiber optics correctly it is possible to stack fibers from the 5 fields (4 telescopes, 1 calibration) so that each field projects to slightly more than one order through the etalon. If, instead of a full circle, a 90 degree segment of the circle is used as the input, then Figure 2c will result. This 90 degree segment is suitable for use with the circle-to-line imaging optic (CLIO),[5] which images the circle segment into a wedge on the CCD as shown in Figure 3. This optical design has several advantages:

- The simultaneous imaging of all telescopes on the detector allows for a significant multiplexing advantage.

- The use of a CCD provides a much larger collection efficiency that the image plane detectors used by both DE-FPI and HRDI/UARS.

- The CLIO allows efficient use of the CCD, allowing for on-chip integration of the signal which improves the duty cycle by reducing the time required to read the chip and reduces the read noise by reducing the number of reads necessary.

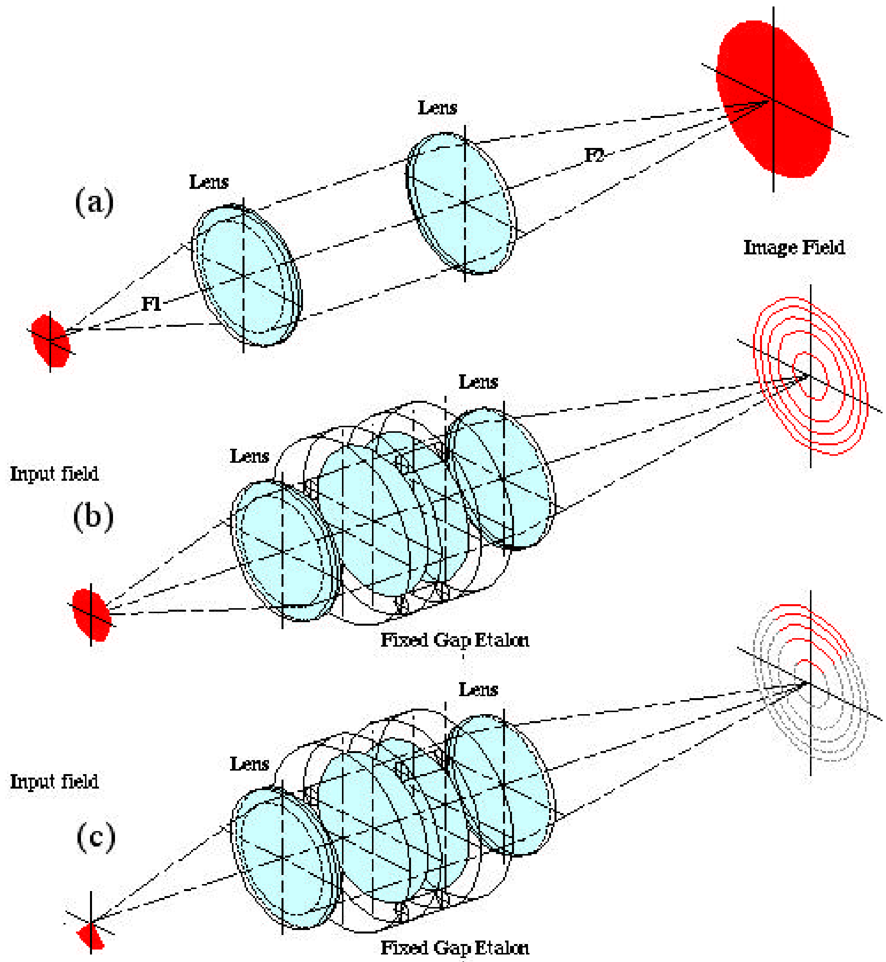


Figure 2. TIDI profiler optical concept.

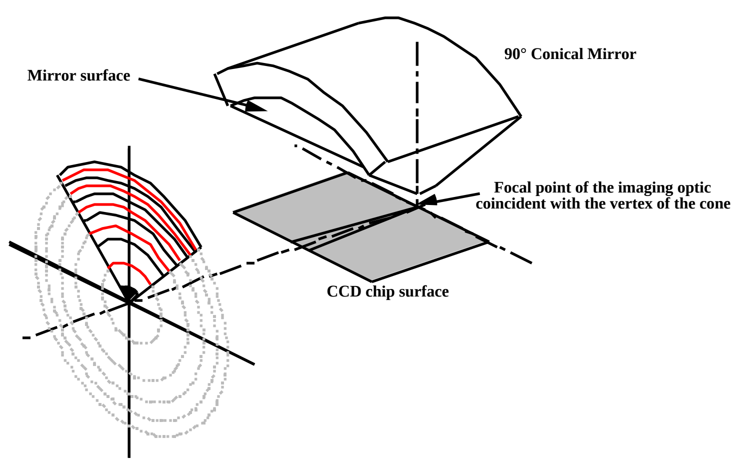


Figure 3. Conversion of the Fabry-Perot fringe pattern by the CLIO.

## 3. DESCRIPTION OF OPTICAL COMPONENTS

### 3.1 Telescope

The four TIDI telescopes were constructed by the Applied Physics Laboratory (APL) of Johns Hopkins University. Table 2 summarizes the major characteristics of the telescopes. Optically, two of the most important telescope characteristics are the transmission and field of view. Figure 4 shows the measured and calculated transmission of the telescope as a function of wavelength. The calculated values were determined by using the optical properties of the gold coating. The two curves are in excellent agreement. Figure 5 shows the field of view map of the TIDI telescopes. The map is very close to the predicted field of view based on ray tracing the optics. Figure 6 shows the field of view once it is integrated in the horizontal direction, thus giving the vertical distribution of the light intensity. The full width at half height is ~0.056 degrees, very close to the desired value.

Table 2. Summary of the TIDI telescope parameters

| Parameter | Value |
|---|---|
| Type | Off-axis Gregorian |
| Clear aperture | 7.5 cm |
| Focal length | 17.0 cm |
| f number | 2.27 |
| Nominal horizontal field of view | 2.5 degrees |
| Nominal vertical field of view | 0.05 degrees |
| Scan range | ±5° from nominal 20.35° below horizon |
| Maximum off-axis angle to view primary | 11.5 degrees |
| Primary coating | gold |
| Surface roughness | 2.6 nm |
| Cleanliness level | less than 450 |
| Mass | ~3.8 kg (each) |

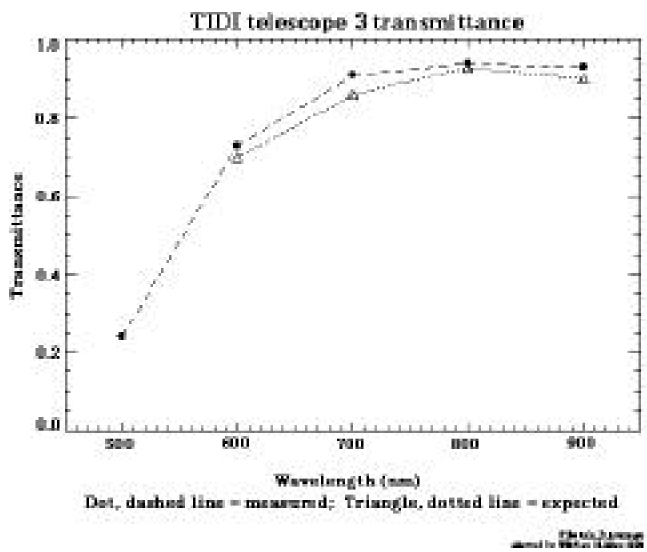


Figure 4. Actual and expected telescope transmission.

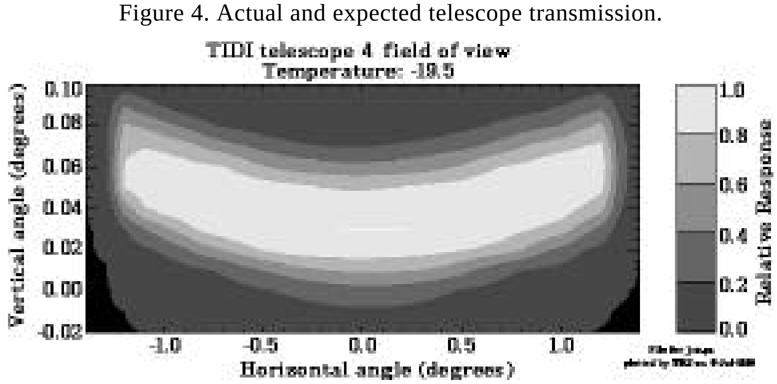


Figure 5. Approximate field of view map of TIDI telescope 4.

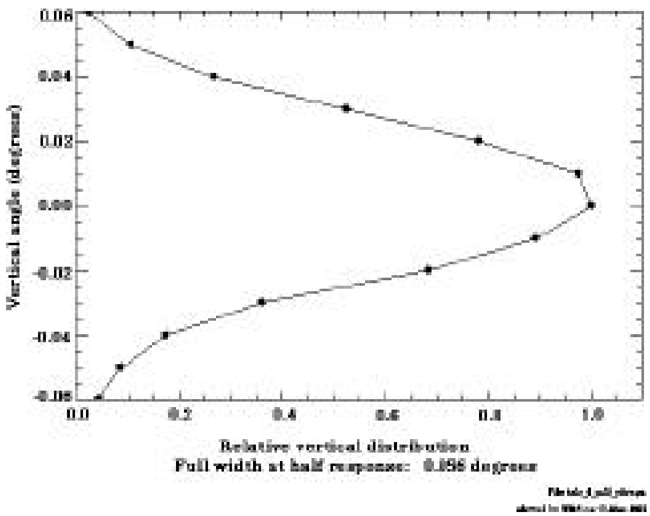


Figure 6. Vertical distribution of the TIDI telescope field of view.

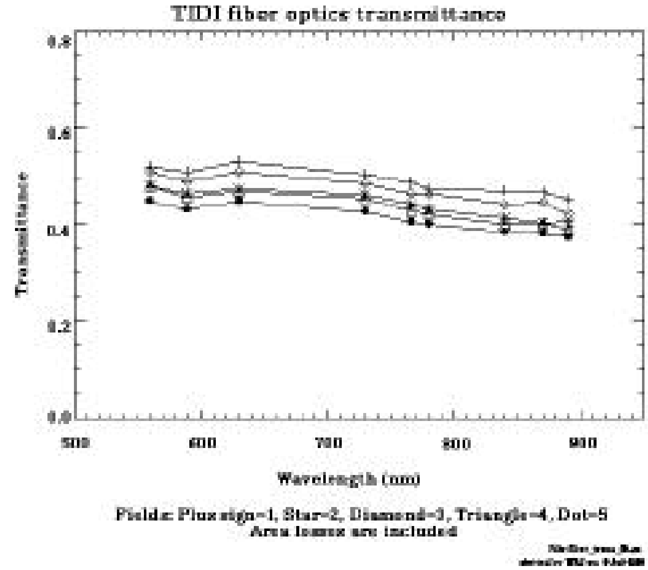


Figure 7. Approximate transmission of the fiber bundle. The transmittance value includes the area loss due to the cladding and the packing of the fibers.

### 3.2. Fiber Optic

The fiber optic bundle connects the telescopes and calibration deck with the profiler. The main optical concerns are the number of broken fibers, the transmission of the bundle, and how well the fibers are randomized from the telescope end to the profiler end. It is important that this randomization be well done since the design of TIDI requires that the end of the fiber bundle be focused on the detector. The randomization was performed by Dolan Jenner during the construction of the fiber bundle using a proprietary process. TIDI is different from the DE-FPI and HRDI instruments which only imaged a single field on the detector for which the input need not be well focused. Figure 7 shows the approximate transmission of the fiber bundle for each of the telescope fields. The transmittance is difficult to measure and there is some uncertainty in the absolute value, but the wavelength dependence is reliable. For an individual fiber, the ratio of core area to total area is 0.51 and with a packing density of ~0.88, the expected transmittance of a fiber bundle should be about 0.45. This prediction is in good agreement with the measurements and indicates the transmission of an individual fiber is quite high. Figure 8 shows images of both ends of the fiber optic bundle. There are very few broken fibers visible (10% broken fibers would have been acceptable) indicating a high quality manufacturing process. The fiber optics parameters are summarized in Table 3.

Table 3. Fiber optics summary

| Parameter | Value |
|---|---|
| Material (core and cladding) | fused silica |
| Fiber manufacturer | Poly Micro Inc. |
| Bundle packaging | Dolan Jenner |
| Core diameter | 40 microns |
| Cladding diameter | 56 microns |
| Numerical aperture | 0.22 |
| Number of fibers per field | ~390 |
| Spacing between fields on profiler end (same for all fields) | 50 microns |

### 3.3. Optical Transfer Elements

The optical transfer elements consist of optics to collimate the light for passage through the filters and etalon and to image the fringe pattern onto the detector. Table 4 summarizes some of the characteristics of the optics. The collimator section is composed of refractive elements while the imaging system is reflective. It would have been desirable to make both collimating and imaging systems reflective since it is difficult to make a system totally achromatic over the range of 550-900 nm. Because it is necessary to have the light collimated twice in the inputs, once for the filters with a diameter of 3.0 cm and again for the etalon, with a diameter of 7.5 cm, it was impractical to use reflective optics on both ends. The imaging optic is a Cassegrain telescope manufactured by Speedring, Inc.