An absolute dual beam emission spectrometer

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Introduction: Astronomical spectroscopy at submillimetre wavelengths holds much promise for fields as diverse as the study of planetary atmospheres, molecular clouds and extragalactic sources. While strong absorption bands of water vapour preclude ground-based observations over much of this spectral range, it is possible to observe in the atmospheric *windows*, regions where the earth's atmosphere has partial, though often variable, transmission. Fourier transform spectrometers (FTS) are well suited to those applications which require broad spectral coverage through these windows. For example, the study of pressure broadened absorption lines of constituents in planetary atmospheres, or unbiased searches for, and identification of, spectral features in molecular clouds.

Historically, the Martin-Puplett[1] polarizing interferometer has been the spectrometer of choice at submillimetre wavelengths[2] since it offers several advantages over a classical Michelson interferometer which are of particular importance in astronomical spectroscopy. First, the modulation efficiency of a polarizing beamsplitter is both high and uniform over a wide spectral range. Second, in contrast to a Michelson interferometer, a polarizing interferometer provides access to two input and two output ports. In the simplest case, one port may be used with blackbodies of known temperatures to provide absolute intensity calibration. The separation of ports also allows for differential measurements, which can be important when one is trying to detect a weak astronomical signal in the presence of a large atmospheric emission component. The interferometric signals at the two output ports are complementary, and can be subtracted to double the modulated component of the interferogram while in principle cancelling any common mode noise. Alternatively, if desired, the two output ports can be configured to observe simultaneously two different wavelength ranges. One disadvantage of the polarizing FTS is that, in its simplest form, it accepts only one polarization of the incoming beam, thus rendering it sensitive to source polarization. Polarization in the continuum emission could arise from the alignment of dust grains in molecular clouds, or in the line emission from the presence of magnetic fields (Zeeman splitting of spectral components).

Interferometer design: In this paper we present the design of a novel non-polarizing FTS, which uses a new type of intensity beamsplitter to give high and uniform efficiency over a broad frequency range. The design is based on the Mach-Zehnder interferometer, which allows access to the two input and two output ports, and is shown in Fig. 1. For operation in this configuration, it is essential that the beamsplitters are identical and efficient. The spatial separation of the two input ports allows a reference blackbody to be viewed at all times in one port, while continually viewing the astronomical source in the other. Sequential source interferograms recorded with the blackbody set at two different temperatures allow the resulting spectra to be calibrated on an absolute intensity scale. As is the case for the polarizing FTS, the two input ports can be configured in a differential mode and the two output ports could observe, simultaneously, two different wavelength ranges.

Beamsplitter design: Many types of beamsplitters have been used in far infrared Fourier spectrometers ranging from the standard dielectric film (usually Mylar), inductive metal mesh and polarizers (free standing wires or metal strips deposited on a thin substrate). However, the dielectric and metal mesh beamsplitters have a limited spectral range and typical efficiencies (4*RT*) of 60 and 75%, respectively. By comparison, the polarizer affords a high efficiency over a broad spectral range. However, as discussed above, in its basic form the polarizing FTS detects only one source polarization.

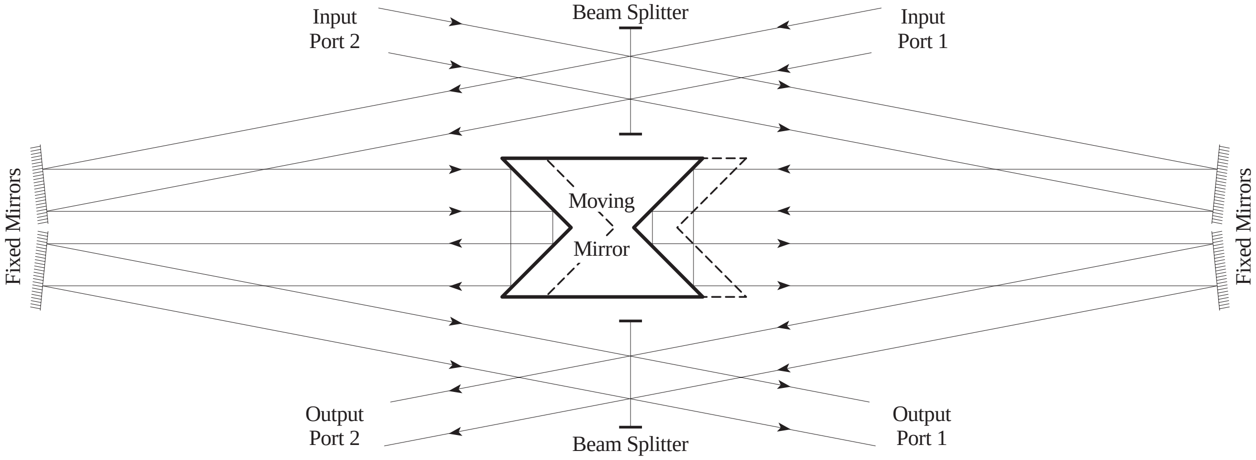

Figure 1: A schematic of the interferometer.

Extending on previous work in the development of far infrared metal mesh filter technology[3], we have developed an intensity beamsplitter with a high and uniform efficiency over a broad spectral range which is insensitive to source polarization. The beamsplitter uses two metal meshes in a Fabry-Perot configuration designed to meet the 50% transmission and 50% reflection criteria of an ideal intensity beamsplitter. By using complementary structures (capacitive and inductive grids) on a thin Mylar support substrate we have been able to achieve beamsplitter efficiencies (4*RT*) above 90% over a range in frequency of a factor of 4. Furthermore, the precise spectral range can be accurately determined by the geometry of the grids and their spacing. Two serendipitous features of these beamsplitters are noted: The first is that since they consist of two thin films separated by an air gap (50 µm), they have been found to be much less sensitive to vibration than single film beamsplitters; the nearly sealed air gap acting to damp any vibrations. This feature is particularly important in the often hostile telescope environment. The second is that the beamsplitters also have 50% transmission and reflection at the HeNe laser wavelength (632.8 nm), which greatly simplifies the alignment of the interferometer. The measured efficiency of the new beamsplitters is shown in Fig. 2 and the complementary nature of the FTS outputs in Fig. 3.

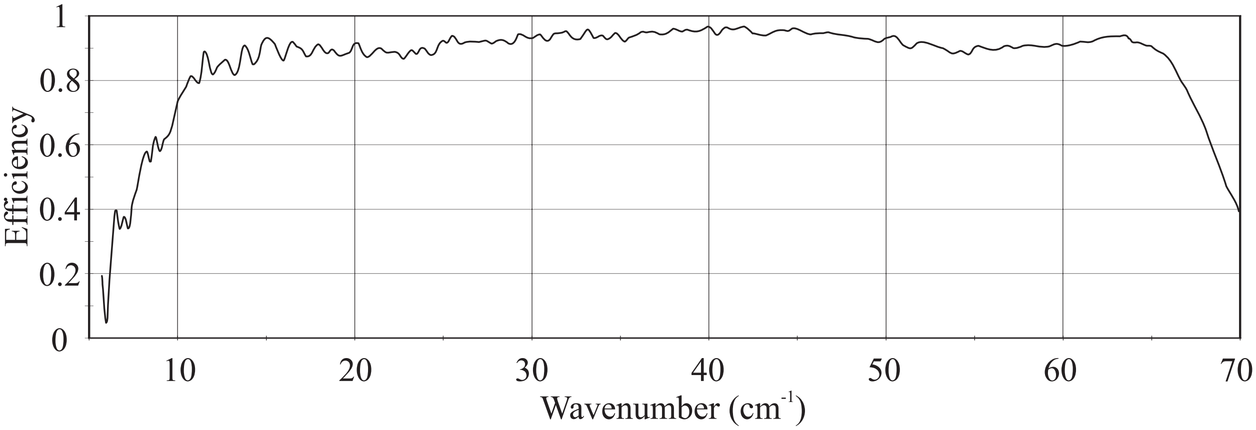

Figure 2: Measured beamsplitter efficiency.

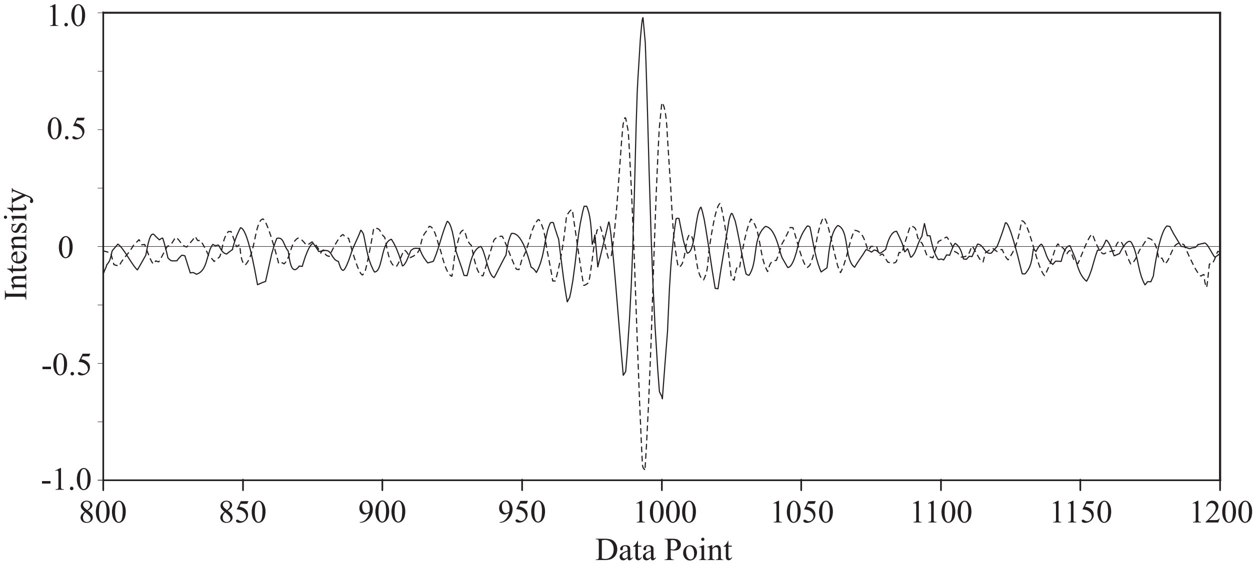

Figure 3: Complementary output interferograms.

It is worth noting that this same filter technology can also be used to make the reflecting plates for a broadband Fabry-Perot interferometer. By carefully adjusting the grid parameters a nearly constant reflection of 97 % can be achieved over a broad spectral range. This will have the advantage that, unlike other Fabry-Perot interferometers, the resolving power and efficiency will be nearly constant over this extended range. Resistive losses in the plates will limit the attainable finesse and ultimate efficiency but these are known to be small for the simple metallic grid structures used here.

Conclusion: An absolute dual beam emission spectrometer has been presented which exploits a new type of intensity beamsplitter that has been developed as part of an ongoing program of far infrared filter design. The spectrometer is ideally suited to astronomical and aeronomical studies at far infrared and submillimetre wavelengths. We are currently working on the development of a larger scale version of this design for use with the recently commissioned, and already highly successful, SCUBA detector at the JCMT and for the SPIRE spectrophotometer proposed for FIRST. This will allow, for the first time, imaging Fourier spectroscopy at submillimetre wavelengths.

[1] Martin, D.H. & Puplett, E.F., “Polarised interferometric spectroscopy for the millimetre and submillimetre spectrum”, *Infrared Physics*, **10**, pp. 105—109, 1970.

[2] Naylor, D.A., Clark, T.A., Davis, G.R., Duncan, W.D. & Tompkins, G.J., “Broad-band spectroscopy with the James Clerk Maxwell telescope using a polarizing Fourier transform spectrometer”, *MNRAS*, **260**, pp. 875—882, 1993

[3] Lee, C., Ade, P.A.R. & Haynes, C.V., “Self Supporting Filters for Compact Focal Plane Designs”, *Proceedings of the 30th ESLAB Symposium*, ESTEC, Noordwijk, The Netherlands, Sept. 1996,