V-INTERFEROMETER FOR PUSHBROOM SPECTRAL IMAGING:

CI SYSTEMS
Setting New Standards In Electro-Optical Testing

HOW TO CHARACTERIZE IT AND DESIGN THE SYSTEM?

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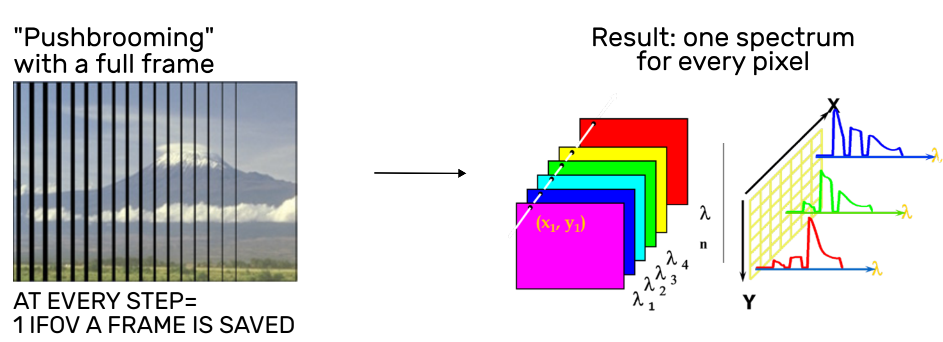
Abstract

After building two prototypes of infrared pushbroom spectral imagers using two-prism block interferometers based on the Sagnac configuration, we realized that a similar two-prism interferometer based on the Michelson configuration (taking the name from its shape) has some advantages over the previous ones, e.g. a better visibility of fringes and a lower potential source of ghosts. In order to design an interferometric spectral imager with a given spatial resolution, field of view, spectral range and spectral resolution, it is necessary to link these requirements with the physical parameters of the interferometer itself, its shape, prism material index of refraction (related to the internal unvignetted field and maximum achieved optical path difference), and with the detector array size, number of pixels and pixel pitch (related to the Nyquist requirement of fringe sampling), and optical pupil size and f-number.

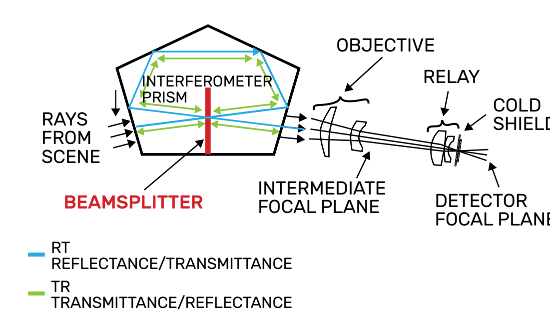
In this paper I present the relationship between the interferometer shape and the optical path difference function versus field in analytical form for the case of two-sided interferogram.

SPECTRAL IMAGERS

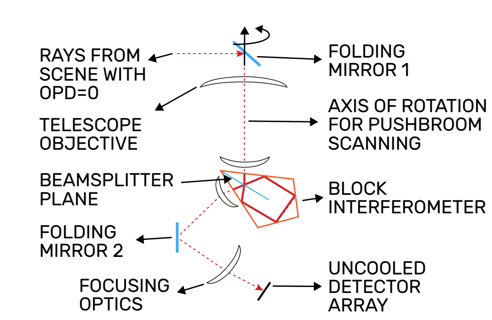
Instrumentation that provides calibrated spectra at each pixel of a scene



PRIOR SYSTEMS BASED ON SAGNAC BLOCK INTERFEROMETER



EXAMPLE 1 of interferometric pushbroom spectral imager: Proc. of SPIE Vol. 6737 673704-1, 2007

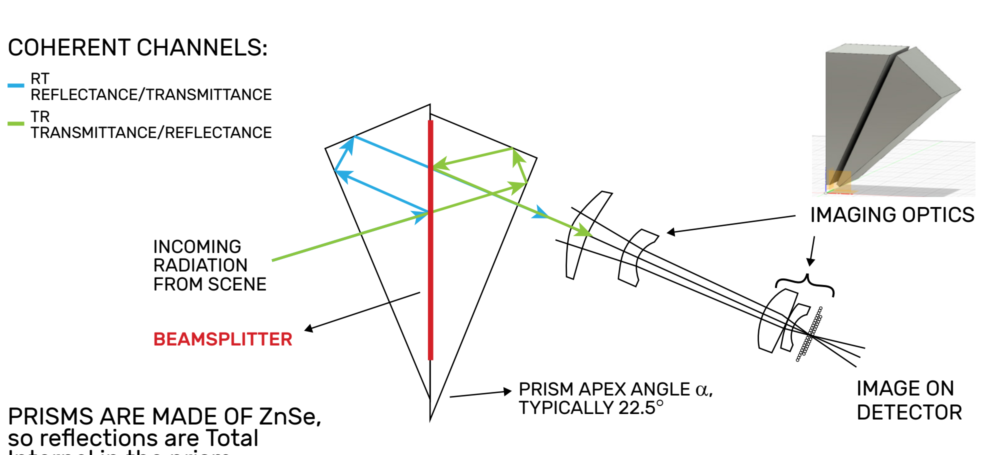


EXAMPLE 2 of interferometric pushbroom spectral imager: Proc. of SPIE Vol. 8012 80123H-1, 2011

IN THE SAGNAC CONFIGURATION THE TWO COHERENT BEAMS GO AROUND IN OPPOSITE DIRECTIONS (COMMON PATH)

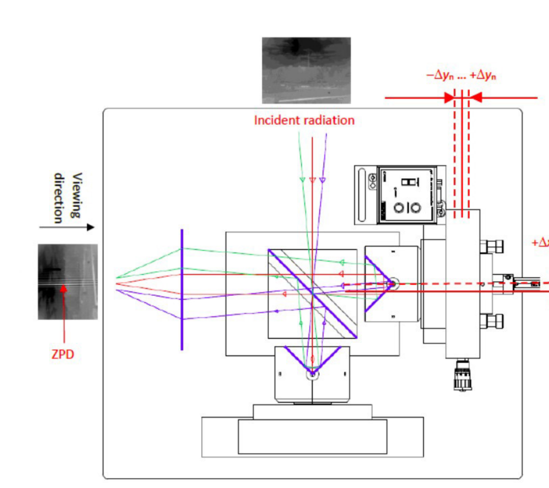
PUSHBROOM SPECTRAL IMAGER BASED ON MICHELSON BLOCK INTERFEROMETER: HIGHER FRINGE CONTRAST THAN SAGNAC

COHERENT CHANNELS:



PRISMS ARE MADE OF ZnSe, so reflections are Total Internal in the prism

PRIOR SYSTEM BASED ON MICHELSON INTERFEROMETER WITH CORNER MIRRORS



Thomas Svensson et al.: https://www.researchgate.net/publication/33193616 ,2019

SYSTEM AND INTERFEROMETER PARAMETERS RELATIONS ARE NEEDED FOR SYSTEM DESIGN

SYSTEM:
FIELD OF VIEW (FOV) = (detector size/back focal length of focusing)
SPECTRAL RESOLUTION = (wavelength/number of fringes on image)
NUMBER OF DETECTOR PIXELS

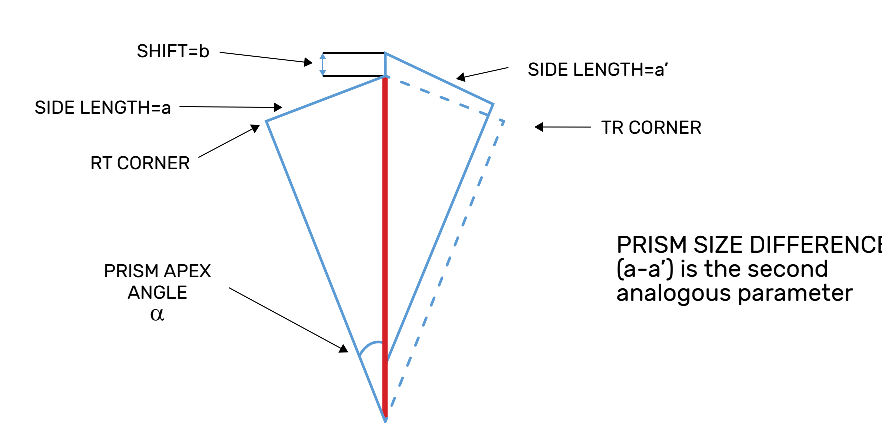
INTERFEROMETER:
OPTICAL PATH DIFFERENCE (OPD) VERSUS ENTRANCE ANGLE
MAXIMUM UNVIGNETTED ENTRANCE ANGLE RANGE

SYSTEM DESIGNER'S TASK:

1. ADJUST OPD VERSUS ENTRANCE ANGLE SLOPE TO YIELD MAXIMUM OPD WITHIN UNVIGNETTED FIELD = WAVELENGTHˆ2/$\delta\lambda$, where $\delta\lambda/\lambda$= required spectral resolution
2. INSURE LINEARITY OF OPD VERSUS ENTRANCE ANGLE (OPD=0 FOR RADIATION ON OPTICAL AXIS)
3. OPD STEP FROM PIXEL TO PIXEL SATISFIES NYQUIST REQUIREMENTS, ACCORDING TO THE SAMPLING THEOREM

HOW IS THIS DONE?

1. SHIFT ONE HALF-PRISM OVER THE OTHER, AND
2. MAKE THEM A DIFFERENT SIZE, STILL MAINTAINING SIMILARITY OF SHAPE.



PRISM SIZE DIFFERENCE (a-a') is the second analogous parameter

CONDITION FOR SYMMETRIC OPD VS. ANGLE: OPD AT OPTICAL AXIS = 0

THIS CONDITION MEANS WE NEED TO SET OPD_{AXIAL} =0,

OR:

$OPD_{AXIAL} = 2(a-a') \cos(2\alpha) - 2b \sin(\alpha) = 0$:

THIS ESTABLISHES THE RATIO $(a-a')/b = \sin(\alpha)/\cos(2\alpha)$

AT THE ABOVE CONDITION THE OPD CREATED FOR A BEAM INCOMING AT ANGLE γ is:
$OPD(\gamma) = d \sin(\gamma) = [2(a-a')*\cot(\alpha)] . \sin(\gamma)$, WHICH IS APPROXIMATELY LINEAR IN γ, BECAUSE $[2(a-a')*\cot(\alpha)]$ IS A CONSTANT

NOW WE CAN PROCEED TO DESIGN THE SYSTEM

- THE SYSTEM FOV AND THE SPECTRAL RESOLUTION ARE THE STARTING POINT TO ESTABLISH THE NEEDED SHEAR SIZE (d) $2d \sin(FOV/2) = OPD_{MAX} = \lambda^2 / |\delta\lambda|$
- THE F# AND THE DIFFRACTION LIMIT ESTABLISH THE PRISM SIZE a TO AVOID VIGNETTING, AND (a-a') IS THEN SET TO SATISFY THE ABOVE RELATION BETWEEN $OPD(\gamma)$ AND d FOR THE GIVEN PRISM APEX ANGLE α
- ONCE (a-a') IS FOUND, THE SHIFT b IS CALCULATED FROM THE ABOVE RELATION $(a-a')/b = \sin(\alpha)/\cos(2\alpha)$

METHOD TO LINK SYSTEM'S PARAMETERS WITH INTERFEROMETER PARAMETERS

1. CALCULATE CONTRIBUTION OF SHIFT b TO LATERAL AND AXIAL DISPLACEMENT OF THE TR CORNER
2. CALCULATE CONTRIBUTION OF SIZE DIFFERENCE (a-a') TO LATERAL AND AXIAL DISPLACEMENT OF THE TR CORNER
3. THESE CONTRIBUTIONS, IN THE PRESENT EXAMPLE, ARE ONLY TO THE TR PATH (RT PATH IS UNAFFECTED BY EITHER CHANGE)
4. FROM THESE CONTRIBUTIONS, CALCULATE THE SHEAR AND THE OPD

   1. THE AXIAL DISPLACEMENT OF THE TR PATH DUE TO BOTH b AND $(a-a') \neq 0$, GIVES RISE TO A TOTAL OPD: $OPD_{AXIAL} = -2b \sin(\alpha) + 2(a-a') \cos(2\alpha)$
   2. THE LATERAL DISPLACEMENT OF THE TR PATH INTRODUCES A TOTAL SHEAR d: $d = 2[(a-a')\sin(2\alpha) + b \cos(\alpha)]$
   3. THE TOTAL OPD FOR A BEAM ENTERING THE INTERFEROMETER AT ANGLE γ IS: $OPD = OPD_{AXIAL} + d \sin(\gamma)$