Optical Aperture Synthesis

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Outline

- Introduction
  - Objectives and Benefits
  - Background
  - Principles
- Programme
  - Risk Analysis
  - Risk Mitigation

Objectives and Benefits

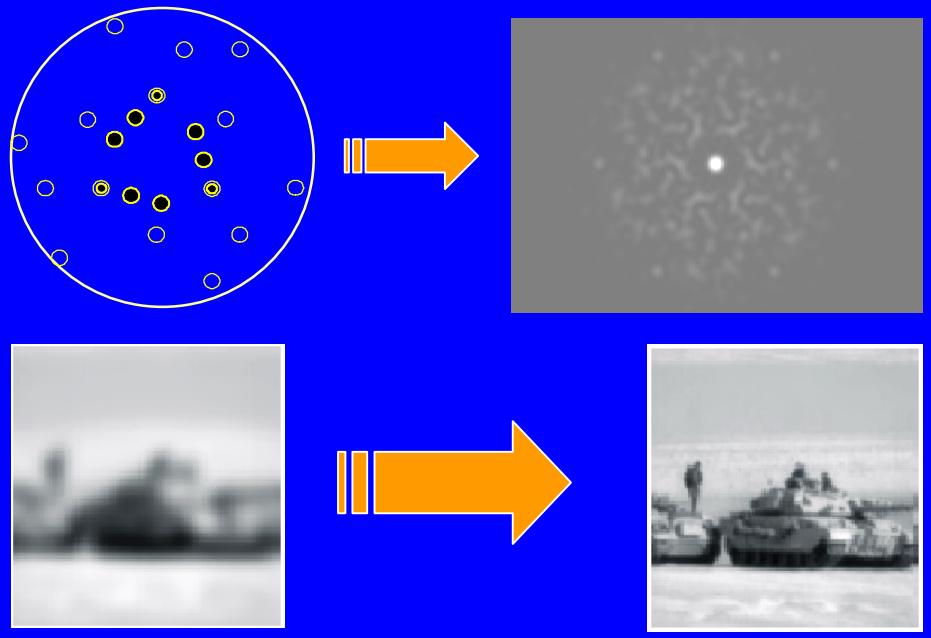
- Array of small apertures
  - ➢ Lightweight
  - ➢ Deployable (terrestrial)
  - ➢ High-resolution
    - ➢ Long range recognition and ID
    - ➢ >10x range or 10x resolution
- Distributed, self-calibrating system
  - ➢ Good-quality images

Objectives and Benefits

- Synthetic imaging can give high-resolution images through small apertures

Angular Resolution

$$\alpha = 1.22\frac{\lambda}{D}$$



For OAS D is max baseline - not aperture diameter

Background

- Solicitation for Research Proposal from EMRS DTC dated 21 May 2003
  - Risk analysis
  - Literature survey
  - Mitigation strategy

Principles

- Principles well known
  - ➢ Used in astronomy at optical-, radio-, mm-λ
- Unused in military
  - ➢ High reward, high-risk
- Why high risk?
  - – Why different from astronomy?
    - ➢ Lower data volume
    - ➢ Snapshot images needed
    - ➢ Extended, cluttered scenes
    - ➢ Less benign environment

New features in Surveillance

- Crowded space on platform
  - ➢ Bulk optics beam transport not feasible → use waveguides
- Vibrating, manoeuvring platform
  - ➢ Path-length compensation
- Active illumination
  - ➢ Increase flux level
- Thermo/mechanical load
  - ➢ Use AO correction

Risk Analysis

- 3 Critical Risks
  - ➢ Must be resolved to achieve anything useful. Fundamental.
- 6 Severe Risks
  - ➢ Must be resolved to achieve useful results but incremental nature.
- 5 Important Risks
  - ➢ Must be resolved to obtain good performance.

Risks

Critical

- Pointing and beam-feeding
- OPD equalisation
- Instrument calibration

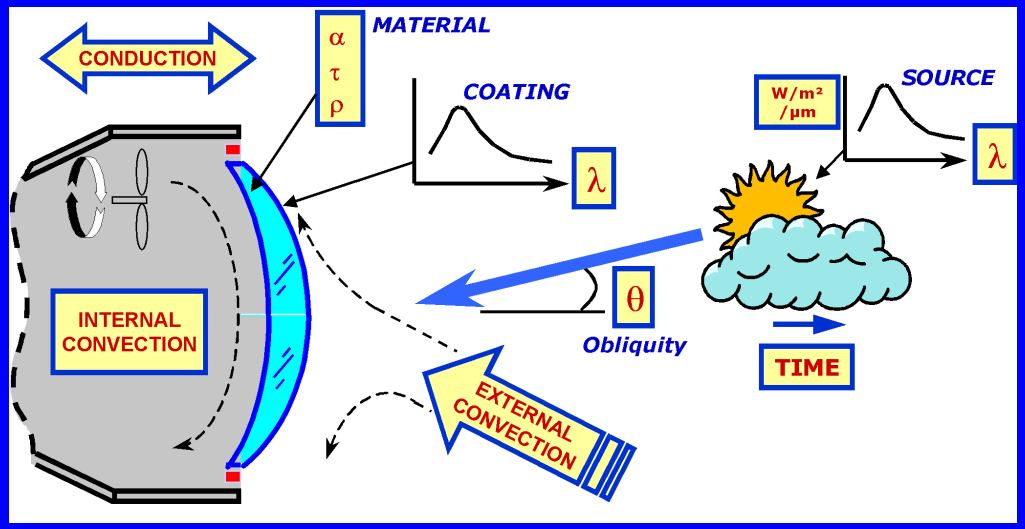
To get interference:

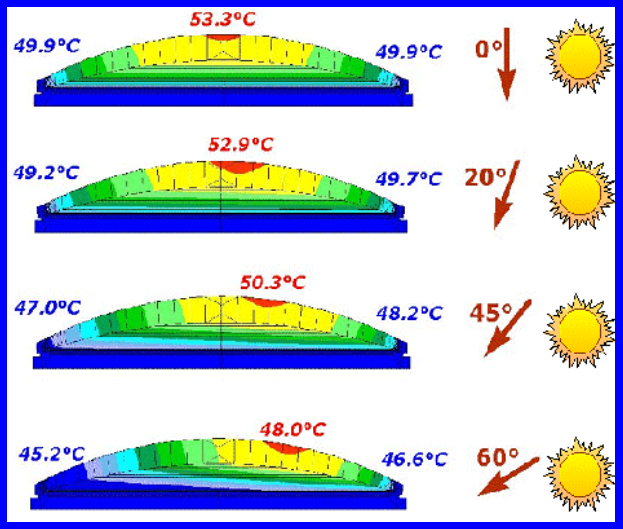
- ➢ Must overlap images from each collector accurately
- ➢ Must operate within coherence length
- ➢ Must achieve real-time calibration

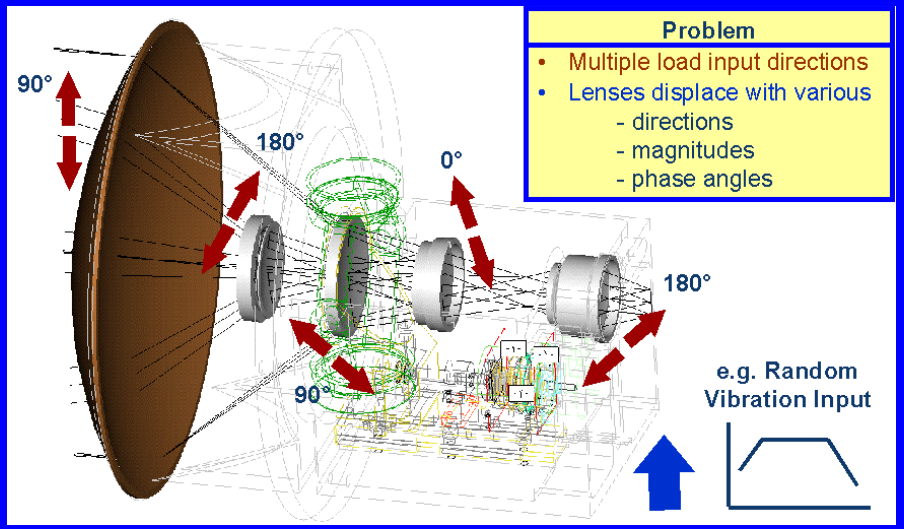
Critical Risk Treatment

- Pointing & feeding
  - ➢ SNR implications
  - ➢ Platform constraints
- OPD control
  - ➢ Internal control OK
  - ➢ External calibration
- Instrument calibration
  - ➢ RSC, Fourier telescopy

Thermo/mechanical load



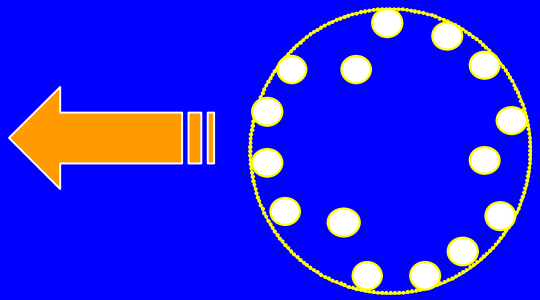


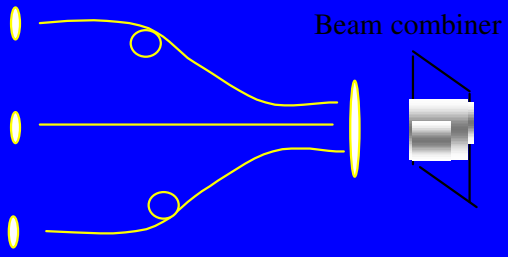


Illustrations courtesy Thales Optics UK

Attention to design

Wish	1975	2004
Greater Boresight Stability	0.25 to 0.50mradians	20 to 50μradians
Higher Tolerance of Vibration	Low tolerance	10g rms random
Capable of handling Higher Loads	25 to 100g	50 to 150g
Smaller space envelope	Possible within reason	Small & complex
Lower Mass	Possible	Reduce by 3-5% per annum
Result	Make & see if it works	Modeling before manufacture





Pointing & Feeding

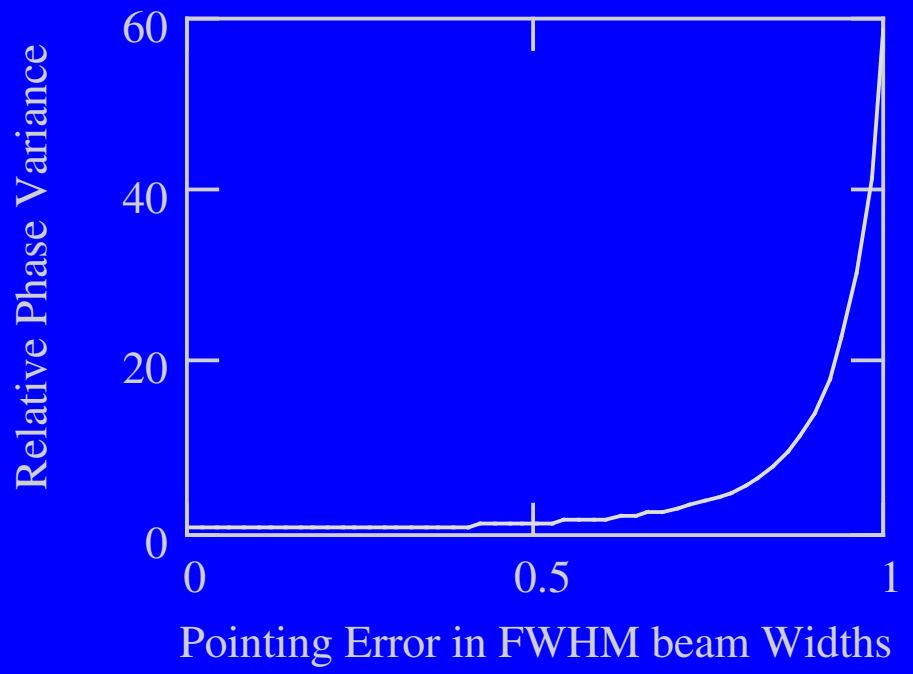
- Vibration within optical subsystem
- Flexing airframe
- 'Static' boresight errors

- ➢ μ–radian errors
- ➢ milli-rad errors
  - ➢ inertial gimbals - 50Hz
  - ➢ adaptive control
- ➢ Offset to flexure errors with long time constant

Pointing & Feeding

- Images must overlap to get interference
- Fibre feed must be very accurate
- Phase accuracy

$$\sigma_{\varphi}^{2} = \frac{1}{2n\left|J(\xi)\right|^{2}}$$



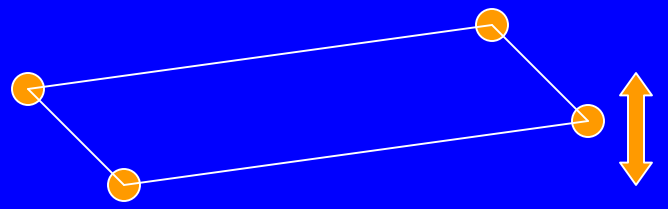
OPD correction

- Within coherence length
- Active illumination
- Within $\lambda/4$ (active or passive)

- ➢ Required for passive operation
- ➢ Needed for interference
- ➢ Narrow band
- ➢ Relaxed OPD control
- ➢ Speckle effects
- ➢ Needed for high image quality

Redundant Spacings Calibration

- Repeated measurement of a Fourier component should give same result
  - ➢ Differences relate to instrument/atmosphere and not to target
- Gives model-independent calibration of OAS array
  - ➢ Direct matrix inversion or use as adaptive instrument



Fourier Telescopy

- Fourier integral underlies imaging

$$\int dr\ o(r)\ e^{-ikr.\xi} \equiv>$$

$$\int dr\ o(r)\left(\cos(kr.\xi) - i\sin(kr.\xi)\right)$$

- Coherent projection of fringes
- Modulation to get Sin & Cos
- Integration

➢Mathematical image reconstruction

➢Large area detector for sensitivity

➢RSC for calibration and anisoplanatism

Active imaging

- Speckled images
- Betrays observation
- Speckle statistics?
- ‘Holographic opportunity’

- ➢ Unfamiliar appearance
- ➢ Speckle mitigation
- ➢ Increased range
- ➢ Increased opportunity
- ➢ Geometric data?
- ➢ Phase-sensitive detection?

Other Possibilities

- Parametric imaging
  - ➢ May not require full imaging facility
- Speckle statistics
  - ➢ Shape of target
  - ➢ Surface finish
- Target statistics
  - ➢ Number and relationship of facets
  - ➢ Number and relationship of retro-reflections

Optical Aperture Synthesis

- High risk but big payoff
  - ➢ Greatly-increased range/resolution
- Parametric imaging
  - ➢ Recognition and ID based on key features?
- Technically challenging
  - ➢ Challenges not intractable
- Requires staged approach
  - ➢ Manage risk and cost/benefit