Terahertz Technology for Space and Earth Applications
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Outline
• Introduction
• Space Applications (some examples):
  – Large Reflectors for Space Astronomy
  – Other Traditional Drivers
• Terrestrial Applications (some examples):
  – Concealed objects detection
  – Medical
  – Pharmaceutical/NDT
• Future Trends in Antenna Technology
  – “Classical” and “Non-Classical” Feed Technology

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The THz Frequency Range
CLAIM: the most scientifically rich, yet most underutilized region of the electromagnetic spectrum

The THz gap
THz is at the transition from microwaves to optics

Optical photons are emitted when electrons change energy states during relaxation (e.g. from a conduction band to a valence band)

THz photons are emitted when a molecule changes its thermal, rotational or bending state – energies involved are much smaller

Optical spectroscopy provides information regarding the molecular structure as well as its physical condition (heat, pressure, speed, etc.)

THz radiation emitted or absorbed by a gaseous region allows to investigate chemical and physical processes in places where instrumentation cannot (easily) be sent
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Herschel/Planck

COMPLETING THE SPECTRUM COVERAGE
Herschel is the only space facility covering the far infrared to submillimetre range (no atmospheric absorption, no atmospheric emission)
“Discovery potential” is large

Sub-mm Wave Observation

- Things look “different” at “different” frequencies.
  Millimetre and submillimetre wavelengths can penetrate dark clouds.

M16 – the ‘Eagle Nebula’

Orion nebula

Using 3 different parts of the electromagnetic spectrum allows us to peer through the obscuring matter to see objects hidden within:
1) visible light: Nebula is opaque
2) Near IR: will remove the reflected light, the stars are revealed inside it.
3) THz: dust is revealed from which new stars and planets are born.
HERSCHEL (previously named FIRST)  
- Frequency coverage 450 GHz to above 4 THz  
- Cassegrain Antenna (3.5 m)  
- System focal length 28.5 m  
- Wave Front Error < 10 µm (goal is 6 µm)  
- High accuracy and in-orbit thermal stability required  
- Passively cooled to below 80 K  
- Total mass (reflectors, support, interfaces, Thermal hardware) 320 kg.

Herschel Reflectors  
- Assembly of petals  
- M1 after grinding  
- M1 on completion of polishing

M1 cleaned and prepared for coating  
- M2 after polishing. Note scatter cone in the centre

Herschel First Light  
- 160 microns: Herschel vs Spitzer. At 100 and 70 microns Spitzer is blind  
- M51 shown as a composite of 160, 100, and 70 microns.

HIFI spectral scan of Orion. A HIFI spectrum displaying a plethora of lines from a number of molecules obtained in just a couple of hours, displaying the spectral richness so characteristic of Orion.

Planck: Features a modified Gregorian Reflector design with  
- An aplanatic main antenna (dimension 1.5 m)  
- Extremely low side lobes  
- System focal length 1.8 m  
- Main reflector surface accuracy is about 10 µm  
- Very important to have strict control of stray light (micro-cracking, dust, etc.)  
- Total mass (reflectors 30/14 kg) + support 175 kg.

Distinctive features  
- Imaging the sky emission at many frequencies

Therefore, as a “by-product”, Planck’s observations will provide a wealth of information about our own Milky Way and other galaxies.
Planck Mapping of Sky

Cosmic Microwave Background

Planck reflectors

Planck Instrument

Planck Instruments

Planck First Light

A map of the sky at optical wavelengths shows a prominent horizontal band which is the light shining from our own Milky Way. The superimposed strip shows the area of the sky mapped by Planck during the First Light Survey. Filamentary structures are apparent on large scales (Planck, right) and small scales (Herschel, left) in the Milky Way. The Planck image, was obtained by the HFI at 857 GHz. The dark horizontal band is our Galaxy. The colours represent the intensity of heat radiation by dust.
Other Traditional Drivers

- Planetary/Cometary Science
- Atmospheric Sciences
- Meteorology

Outline

Space Applications
- Planetary/Cometary Science
- Astronomy Science
- Meteorology
- Atmospheric Science

Terrestrial Applications

Atmospheric Science

Key topics

a) To measure and to understand the human impact on the chemistry and composition of the lower and middle atmosphere.

b) Investigate the interactions between atmospheric chemistry, atmospheric composition and climate.

- limb-viewing observations at millimetre and submillimetre wavelengths in addressing the scientific objectives identified has a lot of potential.

Limb sounding

Freq: 100GHz to 3.5 THz

\[ \text{ClO Chemistry} \]

\[ \text{e.g.: } \text{O}_3, \text{N}_2\text{O}, \text{H}_2\text{O}, \text{O}_3, \text{BrO}, \text{HCl}, \text{HBr}, \text{OH}, \text{NO}, \text{N}_2\text{O}, \text{CO}, \text{ClO} \]

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People screening
Security and Defence Applications

- Checkpoint people screening for hidden weapons & Explosives
- Stand-off detection of explosives - suicide bomber
- Baggage screening for explosives
- Postal screening for explosives, biological & chemical agents
- ChemBio detection
- Mine detection
- Communications
- Non-destructive evaluation

Melanoma Characteristic Spectra

![Graph showing Melanoma Characteristic Spectra](image)

Image Analysis

- **THz Image**
  - Clinical photograph showing suspected basal cell carcinoma on patient's forehead
  - Histology confirms diagnosis

3-D-Imaging

- Visual and terahertz images of a patient with a basal cell carcinoma, one of the common forms of skin cancer.

Imaging of semiconductors

- **THz Image**
  - THz image and THz image of an integrated circuit before and after over voltage applied on supply terminals

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CNF/CNT CFRP material

- The incorporation of nanotechnology in the field of composites has opened new horizons towards the development of advanced materials with unique functional properties.
  - Carbon Nanofiber (CNF) and Carbon Nanotubes (CNT) are very promising filler materials due to high axial Young modulus and thermal and electrical properties. (Increased fracture resistance for 0.5% and 1% CNTs content)

CAD and Integration

- Following advances in CAD, fixed tuned diode mixers and multipliers can now be accurately designed using commercial non-linear software and EM structure simulators which describes the circuit arrangement.
- Design and fabrication methodology is validated for frequencies up to 1THz
- There are potential advantages in integrating several functional components (e.g., mixer LO, IF amplifier) within a single waveguide cavity:
  - Smaller, lower mass, potential performance improvements, simpler interfaces...

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“Non-Classical” Technology

Conventional Technology exists, but keep an eye on:

- Integrated Antenna Technology
- Micromachined antenna Technology

-Metamaterial Technology

Objective: to obtain equal or improved performance as compared to classical technologies with higher reliability.

Dipole measurements

Radiation patterns

Beamwidth E plane => 44 deg
Beamwidth H plane => 64 deg

The high directivity values are due to an increase in the effective radiating area.

Dipole measurements

E-plane => 1-1.13 λ
H-plane => 0.58-0.78 λ

Agrees well with predictions

EBG Heterodyne Mixer

Complete EBG Mixer Circuit

Noise Temperature at 250 GHz ≈ 3500K

Imaging Array

Manufactured Heterodyne Imaging Array for 500 GHz

250-300GHz Twin Array

Assembled 8x250GHz mixers
Conclusions

- Traditional heartland of THz technology (remote sensing and radio astronomy) continues to represent a strong technology push and pull.

- Key to success is top-performance combined with low-power and mass.

- Arguably this has paved the technological path towards broadly usable THz systems for everyday applications.

Questions ??