NOVEL LIDAR AND REMOTE SENSING TECHNIQUES AT FRAUNHOFER CAP

Gerald Bonner, Brynmor Jones, Haochang Chen, Matthew Warden, Ludwig Prade

Fraunhofer UK

OUTLINE

- GLAMIS
  - Laser requirements for a global lidar system
  - Pulse compression lidar
  - Tapered diode lasers

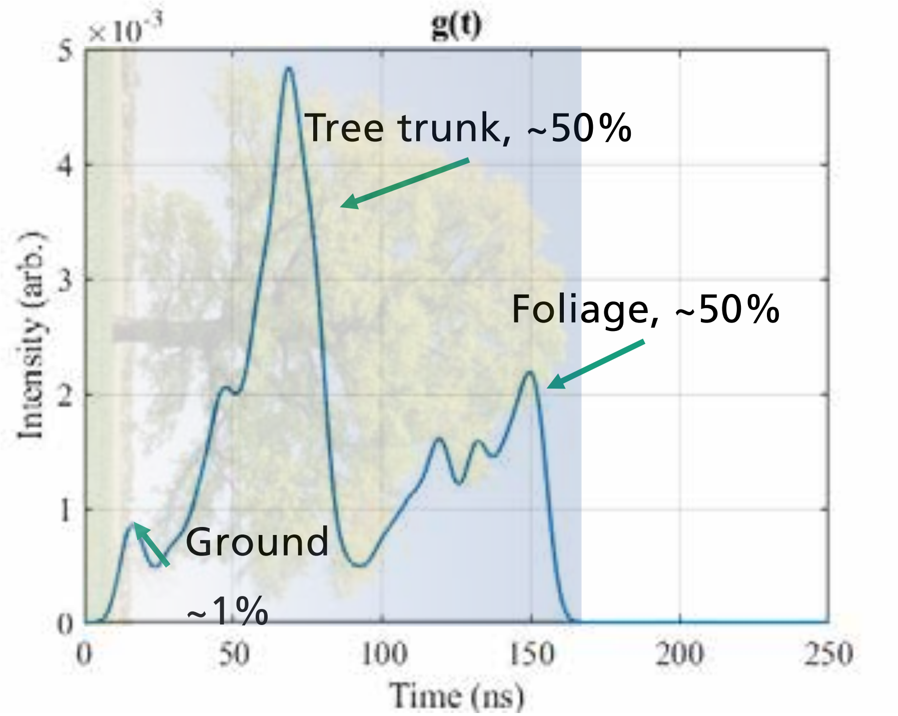
- Broader capabilities at Fraunhofer CAP

Laser requirements for a global lidar system

- Conventional pulsed lidar needs ~ 10 mJ per pulse (c.f. GEDI mission, @ 242 Hz)
- For global coverage, need much higher repetition rates – many kHz or even MHz
- Q-switched, diode-pumped solid-state lasers can be built to give high energies and high rep rates, or could launch many units
  - BUT both options difficult, especially in form factor suitable for space due to bulk, complexity, and cost
- Diode lasers offer high average powers (~ 5 W with good beam quality, kW with poor beam quality), high efficiency, potentially short pulses, and low SWaP
  - BUT pulse energies are low (=> low peak power)

- **Can we use different lidar technique to bring space-borne lidar within operating envelope of diode lasers?**

What are we trying to measure?



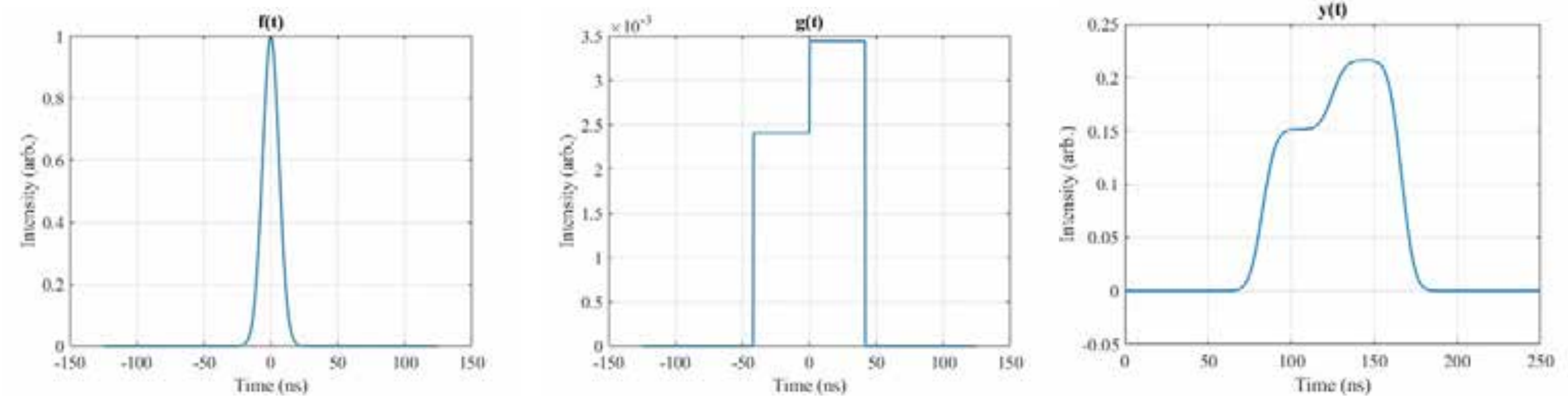
Conventional pulsed lidar

If a laser has a pulse shape $f(t)$ and illuminates a target with a profile $g(t)$ the detector sees the signal

$$y(t) = f(t) * g(t)$$

➔Convolution between f and g

Convolution: “Hiding” a pattern in another



Pulse compression – the maths

- $y(t) = f(t) * g(t)$ ➔Convolution (**HIDING** one pattern in another)
- $x(t) = y(t) \circ g(t)$ ➔Correlation (**FINDING** one pattern in another)
- So what is: $x(t) = (f(t) * g(t)) \circ f(t)$???
  - $x(t) = g(t) * \underbrace{\left(f(t) \circ f(t)\right)}_{???}$

IF $g(t)$ is a **C**onstant **A**mplitude **Z**ero **A**uto**C**orrelation (CAZAC) function

THEN $f(t) \circ f(t) = \delta(t - t_0)$

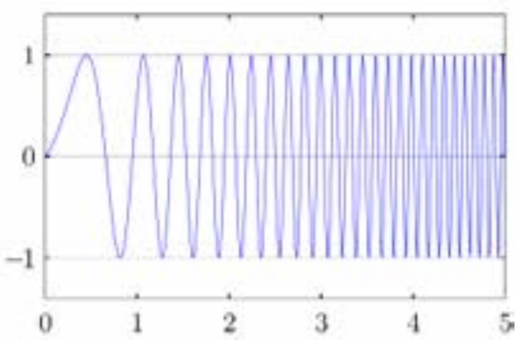
AND $x(t) = g(t) * \delta(t - t_0) = g(t)$

IF $f(t)$ is a CAZAC function,

THEN we can remove the effect of $f(t)$ on $g(t)$ **by cross correlating** $y(t)$ with $f(t)$

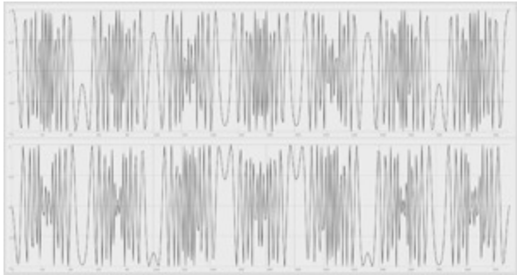
CAZAC functions

- Their autocorrelation approaches a pulse function for infinite bandwidth
- The energy content of the pulse is the energy content of the entire waveform
- We can generate the same resolution and signal strength from a CAZAC function as from a single pulse if both contain **the same energy and bandwidth**
- Unlike pulses, CAZAC functions are very easy to generate using laser diodes – **energy is spread out over much longer time**



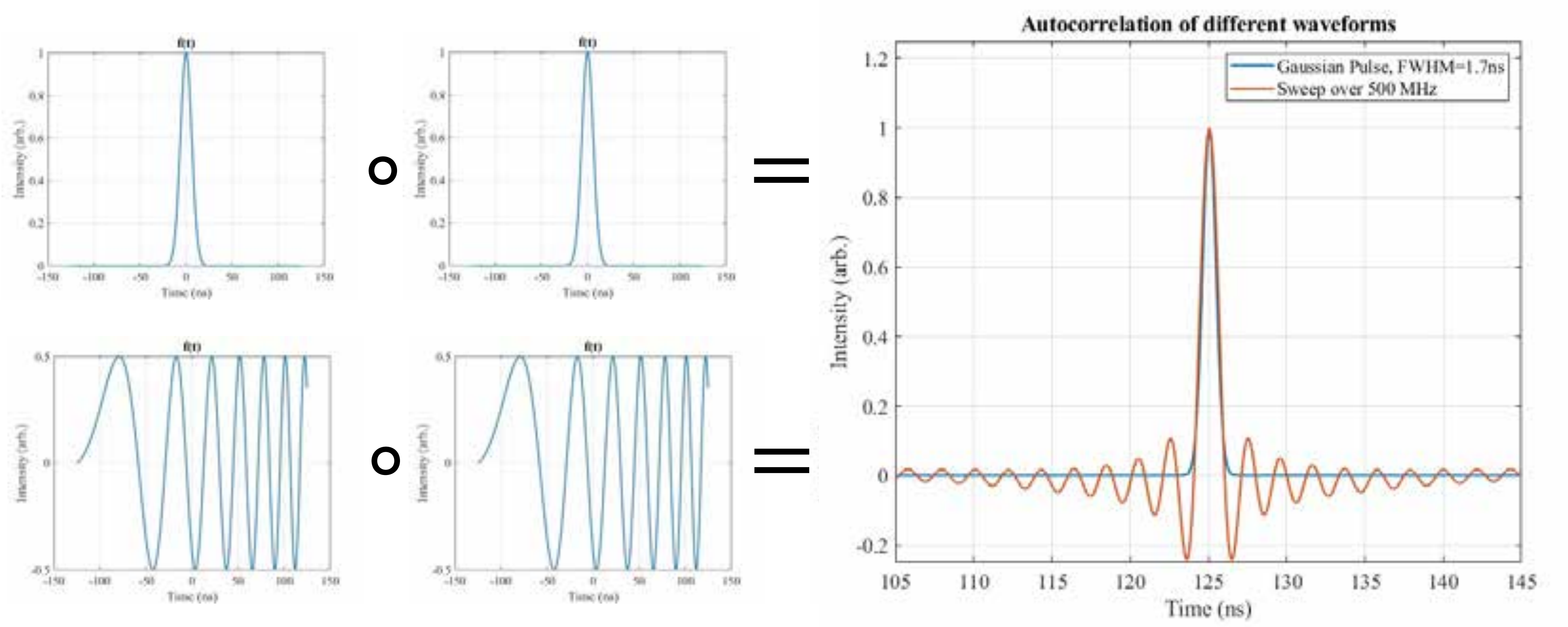
Import examples of CAZAC functions:

- A pulse (trivially)
- The chirp function i.e. frequency sweep
- Maximum length sequence (binary, easy to generate)
- Zadoff–Chu sequence (cyclical orthogonal, used in mobile data networks)

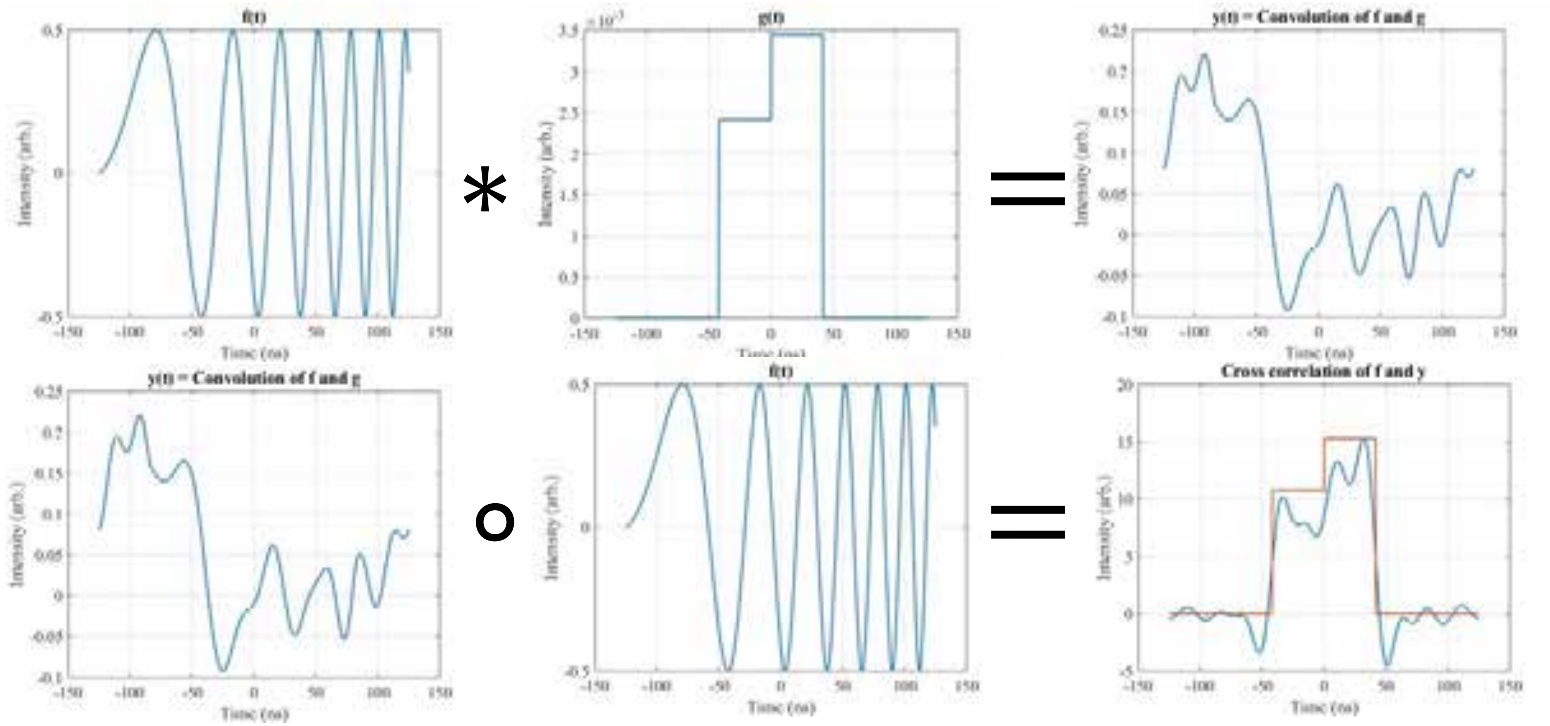


Pulse compression

- Correlating a CAZAC function with itself gives a pulse-like function



Pulse compression lidar



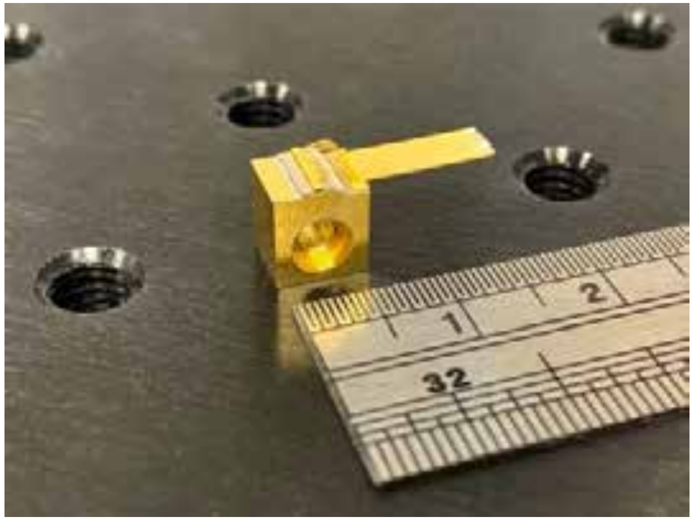
Fraunhofer UK

Requirements for space-borne PCL

- Need 2000 detected photons => need ~ 10 mJ output per footprint on ground
- At 5 W average power, with chirp up to 600 MHz, 100 m (333 ns) long => 1.67 μJ per chirp
  - => Need ~ 6000 chirps per footprint
  - => 2 ms – compatible with dwell time of LEO satellite over 30 m footprint (~ 4 ms)
- Space-borne lidar PCL viable, or close to viable, with current diode laser technology
- Further improvements to diode laser technology conceivable, opening pathway to improved performance and/or reduced mission cost

Tapered laser diodes

- Multi-watt CW output with high beam quality
- E.g. 860 nm, rated 3 W @ 4.06 A, with M2 = 1.1
  - Tested that unit up to 5.2 W @ 6 A, 1.3 V
  - => 67% electrical-to-optical efficiency
  - More like 30% once thermal management implemented
- Manufacturers continue to push performance
  - Coherent Dilas have reported ~ 8 W, but not for sale yet



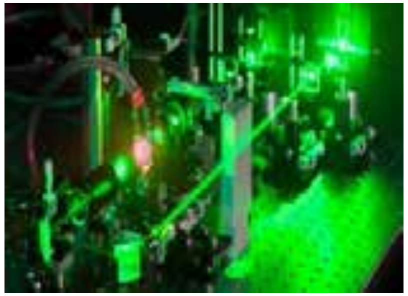
Next steps on GLAMIS

- Engage with diode laser manufacturers on realistic improvements (10 – 100% improvement in output power conceivable in my view in reasonable timeframe)
- Implement suitable drive electronics (multi-amp at up to 600 MHz)
- Optical and mechanical design for mounting multiple lasers on each satellite

Fraunhofer Centre for Applied Photonics: Introduction

- A UK research and technology organisation
- UK not-for-profit limited company
- Legally independent affiliate of Fraunhofer Society – Europe’s leading independent research organisation
- Providing professional R&D services
- Working with industry to translate technology into products
- 27 research staff, 8 support staff, 22 students

Fraunhofer Centre for Applied Photonics: Capabilities



Source Development

- Capability in a wide range of laser source development
- UV to infrared and beyond
- Pulsed and CW

System

- Combination of source plus transmit and receive optics
- Remote sensing
- Optical communications
- Quantum technology
- Biophotonics

Instrumentation

- In-house electronic engineering
- In-house mechanical engineering
- Development of proof-of-concept devices
- Hand-over to manufacture


Fraunhofer
CAP