Laser Based Communications: Reducing Reliance on Satellites

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Public Version

Executive Summary

Military operations are increasingly dependent on satellite communications particularly for strategic communications links. The ability to continue to operate in a satellite denied environment has been identified as a vulnerability that may also impact air and maritime operations.

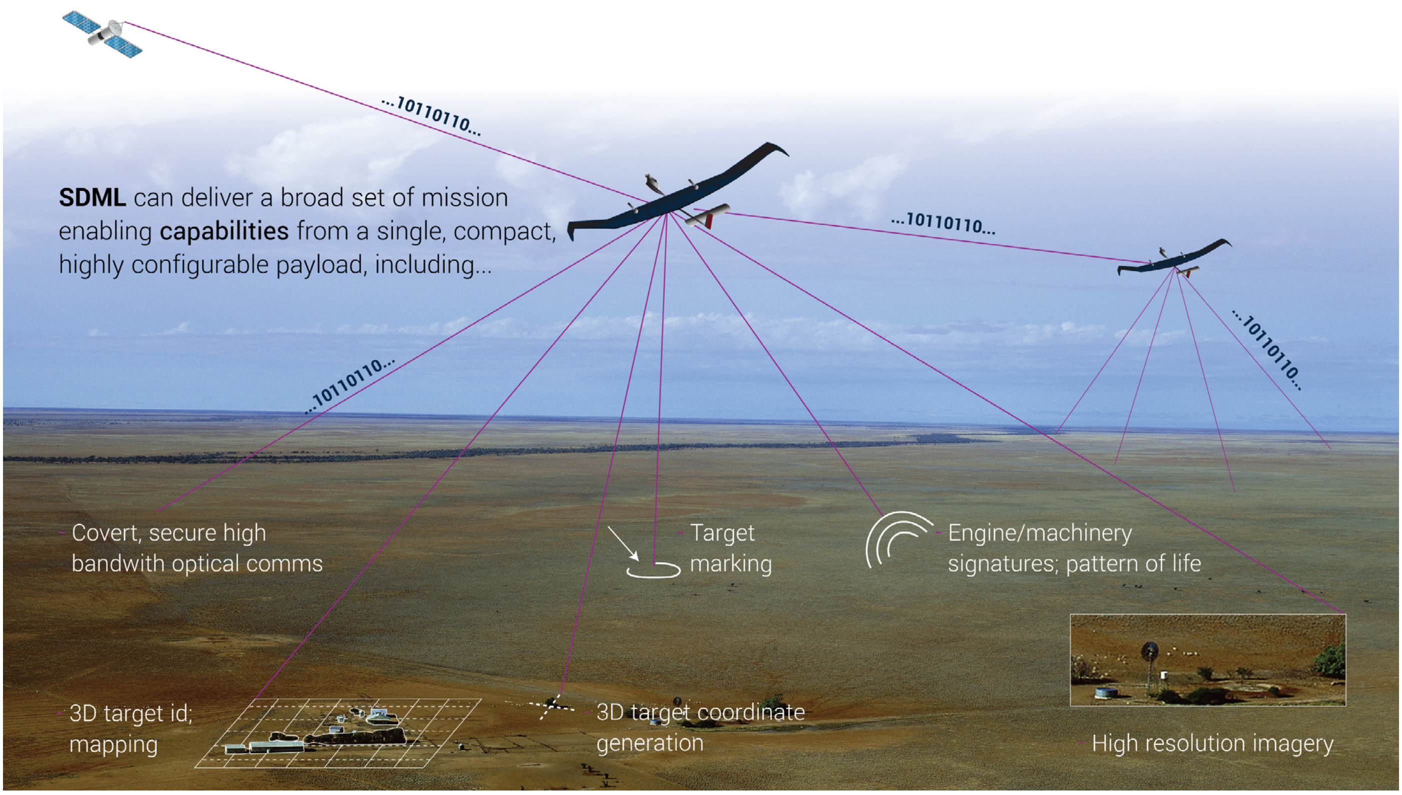
QinetiQ has developed a system combining Free Space Optical Communications (FSOC) and real-time Light Detection and Ranging (LIDAR) Intelligence, Surveillance and Reconnaissance (ISR) collection capabilities within the same sensor. The Software Defined Multifunction LIDAR (SDML) has the potential to provide multi-gigabit per second (Gbps) beyond-line-of-sight communications in a satellite denied environment. This is achieved by using line-of-sight laser based communications between a portable ground station and an airborne relay, either on aircraft of opportunity, high altitude pseudo satellites (HAPS) or aerostats.

The software defined nature of SDML means that the mode of operation can be changed mid-mission between communications and ISR modes such as:

- 3D imaging – traditional LIDAR imagery from a mobile platform;
- Target designation – using low-power SWIR laser and custom modulation scheme all but undetectable by conventional OTS systems; and
- Vibrometry – to remotely detect whether machinery is running or buildings are occupied.

QinetiQ UK has developed and tested an SDML payload for the Zephyr HAPS and are developing a ground station for space based SDML systems. SDML is a completely novel technology.

QinetiQ are seeking to develop a sovereign SDML capability that complements the work being done in the UK. We will draw on the existing IP in the UK to develop vehicle and man-portable SDML systems in Australia. The systems will become part of the suite of SDML capabilities being offered globally.



Introduction

The challenge of meeting the communications demands of a modern military in a satellite denied environment has been identified as a vulnerability that may also impact air and maritime operations.

QinetiQ has developed a novel technology called Software Defined Multifunction LIDAR (SDML) that offers a potential solution to this challenge.

This whitepaper provides an overview of the SDML technology, its current developmental state, its functions and the operational capabilities it could provide for the Defence user.

Capability Gap

Satellite communications form the backbone of over-the-horizon battlefield communications. Australian forces often operate where sovereign satellite services aren't available, making them dependant on coalition or commercial satellite services.

Similarly, military operations are underpinned by the speed with which Intelligence, Surveillance and Reconnaissance (ISR) and Command and Control (C2) data can be moved from point to point allowing timely and accurate decisions to be made and operational outcomes achieved. The ADF warfighter utilises various technologies and sensors to gain an advantage in battlespace co-operation and awareness. The next generation of battlefield ISR will involve hyperspectral and covert remote sensing systems to augment visual and IR imagery. Increasingly, the data collection capability of modern military platforms is outstripping the ability to achieve the timely transfer of data over RF communications channels that are congested, vulnerable and subject to spectrum management constraints.

Increasingly, warfare strategists are warning that satellites are vulnerable to attack, and militaries around the world are gaining the capability to attack space infrastructure. Space is contested, congested and competitive and is becoming a war-fighting domain. Satellite denial, either by electro-magnetic (EM) spectrum denial or direct attack is a potential tactic an adversary may use to compromise the ability for strategic co-ordination and intelligence gathering by deployed forces.

SDML provides a compelling solution for the satellite denied environment capability gap. The optical nature of SDML also makes it largely immune from Electronic Attack (EA) and other Electronic Warfare (EW) actions by adversaries that threaten conventional RF communications.

Software Defined Multifunction LIDAR

SDML is a completely novel Electro-Optical Infra-Red (EOIR) system which combines a number of covert real-time Light Detection and Ranging (LIDAR) based ISR collection capabilities and high-speed Free-Space Optical Communications (FSOC) link within the same hardware platform. SDML can switch between these capabilities 'on the fly'.

The key benefits of SDML include:

- **High speed communications.** Provides data transfer rates that are hundreds and potentially thousands of times faster than current Defence RF communications:
  - Tested at 1.5 Gbps over 18 km ground-ground link; and
  - Range of >100km between High Altitude Pseudo Satellites (HAPS).
- **Low probability of Intercept (LPI).** Optical communications involves point-to-point directed beam laser links, meaning it is covert by nature. This removes problems with RF spectrum capacity and reduces operational costs as no spectrum licence or de-confliction is required.

- **Low probability of Detection (LPD).** Both optical sensing and optical communications operating at 1550 nm wavelength are considered LPD despite being active techniques; the light emitting and returning to the sensor effectively operate at a wavelength and power that is difficult to detect outside of the laser beam footprint.
- **Operational flexibility.** The sensing mode in SDML is wholly defined in software, allowing the single payload to switch between a number of FSOC and ISR modes without physical reconfiguration. Modes can be changed remotely while the platform is airborne.
- **ISR sensing.** Using LIDAR and signal processing, SDML provides covert 3D mapping, vibrometry, optical Ground Moving Target Indicator (GMTI) and target marking capability 'modes'. These modes are in development.
  - Vibrometry. E.g. for engine/machinery detection and possible ID; state-of-readiness assessment. Sensitivity of ~1 μm in [1Hz-10kHz] band (noise equivalent displacement) at 17 km range;
  - Range finding. E.g. for altimetry; target coordinate generation.
  - 3D imaging LIDAR. E.g. target identification; battle damage assessment; mapping; optical, RF and ballistic viewshed analysis. Cross-range resolution under 40 cm, range resolution 15 cm, sample rate 10 kHz from HAPS (slant range 30 km);
  - Velocimetry. E.g. for optical GMTI.
  - Anemometry. E.g. for plume drift prediction; ballistic trajectory compensation.

SDML has the ability to switch between modes in real time under software control, analogous to switching TV channels; the sensing modality is no longer intrinsic to the hardware. Because the sensing modes are wholly defined in software, the technology permits addition of new modes and upgrades to existing ones at a later date, refreshing the original capital investment. This novel technology has the potential to be as disruptive in the EO domain as Software Defined Radio (SDR) has been in the RF.

Figure 1: Prototype SDML payload.

The SDML hardware has been developed into a lightweight HAPS payload which has unique size weight and power (SWaP) and environmental constraints. Environmentally qualified to fly up to 70,000 ft., it weighs only 4kg and consumes less than 50W of power. QinetiQ developed the SDML payload as part of a UK Ministry of Defence (MOD) Defence Science and Technology Laboratory (DSTL) Centre for Defence (CDE) themed competition in 2015. It progressed in a number of phases demonstrating the core technology including ground-to-ground 3D imaging capabilities and high data rate communications links.

The technology was integrated into a pair of Airbus Zephyr-S (UK MoD spec) HAPS, flight-capable SDML payloads.

In March 2021, a data rate of 1.5 Gbps was demonstrated over an 18 km horizontal path, close to ground, to demonstrate the potential to shift gigabytes (GB) of aerial imagery ISR in a few seconds. Transfer speed is planned to increase after further optimisation and technological advances.

Whilst operating ranges are constrained by atmospheric conditions, high altitude optical links achieve very long range connections as recent demonstrations of other FSOC inter-satellite and ground-to-satellite links have shown.

An SDML payload can be scaled for different operating ranges and, hence, platforms and mission types by integration with platform-specific ‘front end’ amplification and free-space beam expansion optics. Scalability across different platform types is made easier by designing in the first instance for one of the most constrained (as in SWaP) environments, that being HAPS deployment in the stratosphere.

In the UK, QinetiQ have built an optical ground station (OGS) for Low Earth Orbit (LEO) SATCOM based on SDML. QinetiQ are also investigating SDML for the Royal Navy for Carrier Combat Group applications.

Figure 2 shows 3D point clouds (pink and blue dots) acquired by a prototype variant of the SDML (also pictured) to demonstrate the 3D imaging capability. This data has been overlaid on Google Earth satellite photo imagery for visualisation purposes. The resolution of the SDML 3D imaging in this demonstration is equivalent to a HAPS SDML payload variant at 30km slant range. Resolution and range may be customised depending on the customers deployment requirements.

Figure 2: SDML 3D images (point clouds) of Targets of Opportunity. **Top left:** Severn Bank House (7.6 km). **Top right:** Croome Church (10.1 km). **Bottom left:** Worcester Cathedral (11.6 km). At our scaled-down power-aperture product, a 10 km target gives a photon flux at the receiver equivalent to 30 km slant range from a HAPS deployed at 23 km (75 kft) altitude. **Bottom right**: SDML equipment. (Satellite imagery: Google.)

Technology Solution

Satellite Denied Environment Communications

The core SDML technology provides a foundation to achieve a covert high-speed LoS or BLoS FSOC capability in a low SWaP package.

SDML FSOC makes use of invisible IR lasers, over long distances, using advanced telescopic optics. Each beam is directed at the target transceiver, and vice-versa so an SDML payload is required at each end.

In the example shown in Figure 3, a vehicle equipped with a single SDML payload would be aimed and aligned at either a loitering HAPS or distant manpack SDML tripod. The HAPS platform, with dual SDML payloads would provide wide area coverage and relay comms data to BLoS units or FOB/FOS. Direct LOS comms, between the vehicle and dismounted unit could also occur, carrying ISR data or secure voice. Switching between the two would involve re-aiming the SDML at the target. The SDML would then focus, perform fine pitch alignment and establish a link. All this would be invisible with LPI and LPD. As noted, SDML FSOC range is in excess of 20km horizontal which is close to the limit of visual range. The SDML payload could then be directed at a target of interest to conduct vibrometry, 3D mapping, target designation, or a combination of to gather ISR data on the target.

It could also be utilised in covert missions even when SATCOM is available to reduce RF signature.

Other Use Cases

A special forces mission could utilise some of the other modes of SDML, particularly vibrometry, target designation and 3D imaging. With a low-SWaP package and low-aperture telescopic optics, SDML could be mounted to a UAV for ISR missions. The UAV could be flown around a building or vehicle, gathering 3D and visual imagery. Vibrometry data could also be collected to determine occupancy via voice or engine noise signatures. There are numerous COTS heavy lift drones on the market that are used for law enforcement and search and rescue, such as Freefly ALTA 8 (6.8 kg payload capacity), Vulcan UAV Raven (10 kg payload) or Vulcan Black Widow. These or similar UAVs would be potential candidates to carry an SDML payload.

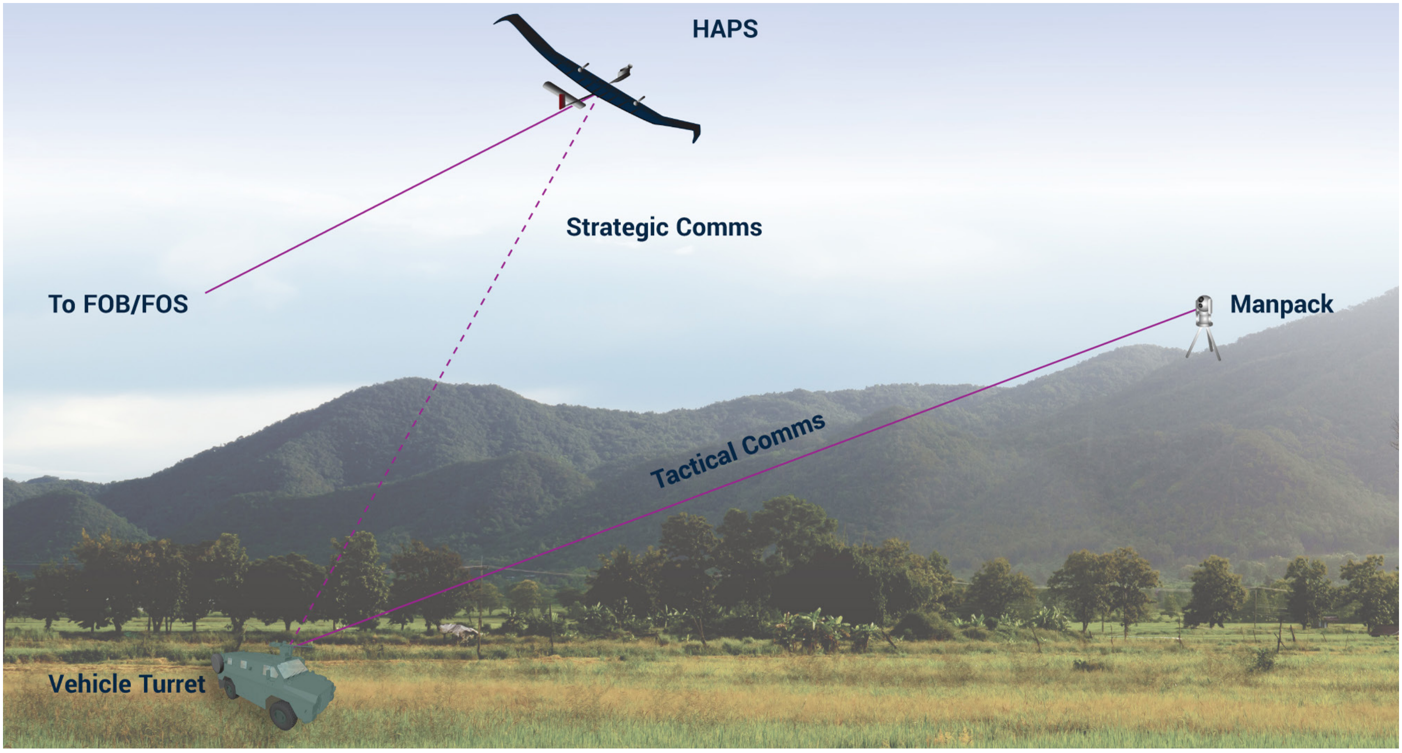


Figure 3: G2A strategic or G2G tactical comms scenarios in a satellite-denied environment.

In the Maritime domain, there is a need to maintain communications in an increasingly congested and contested EM environment. Alternate communications pathways, such as SDML, may offer a means of resilient, LPI line of sight communications when the operational situation dictates. Whilst deploying high power RF for communications or Synthetic Aperture Radar (SAR) on a HAPS may be possible, the emissions and active nature of both will make it very challenging for the platform to operate undetected or in the face of advanced EM jamming. Furthermore, a surface combatant operating under Emissions Control (EMCON) conditions would preclude the use of a HAPS overhead supported by high power RF or SAR. Emerging technologies including the employment of UAV in the proximity of surface vessels may also benefit from a small form factor, LPI, secure, line of sight communications medium that SDML presents.

System Solution

The current HAPS payload is not designed to withstand the environmental conditions of land based applications. A ground vehicle turret must meet significantly more demanding shock & vibration profiles; weight is not such an issue. On the other hand, requirements of a manpack have a different focus; low SWaP is critical. Adapting SDML to a man pack or vehicle turret or stabilised mount is possible through switching the front end to a suitable shock and vibration resilient set of optics (telescope) and integrating it with a stabilised pan/tilt gyro turret. On mobile or portable platforms, stabilised pan/tilt gimbal mounts provide alignment of the beam with the target when in motion.

FSOC data link speeds depend on the EO optics design, environmental factors (ambient surface heat/ scintillation, dust/smoke), link distance, alignment and motion. Although SDML has been tested to over 1.5 Gbps over a static link on a clear day in the UK, in adverse conditions, speed in the Mbps is still reasonably expected. This meets the data transmission capacity of current satellite links, and far exceeds that of HF, which is likely to be used in event of satellite denial.

Similarly, the resolution of 3D imaging (LIDAR) and vibrometry modes depend entirely on the gimbal (accuracy) and telescope (optical aperture). Performance requirements can be determined following a trade study into these factors.

Development of SDML fibre-optic and electronics componentry is ongoing and will lead to long-term improvements in the performance of SDML

QinetiQ has a pedigree in the development of custom stabilised gimbals and integration of other vendor gimbals, especially in the US. The application is predominantly for hyperspectral and LIDAR sensing as part of Multi-Int ISR.

QinetiQ can work collaboratively with the ADF to develop land based SDML solutions that meet the specific needs and priorities of the ADF.

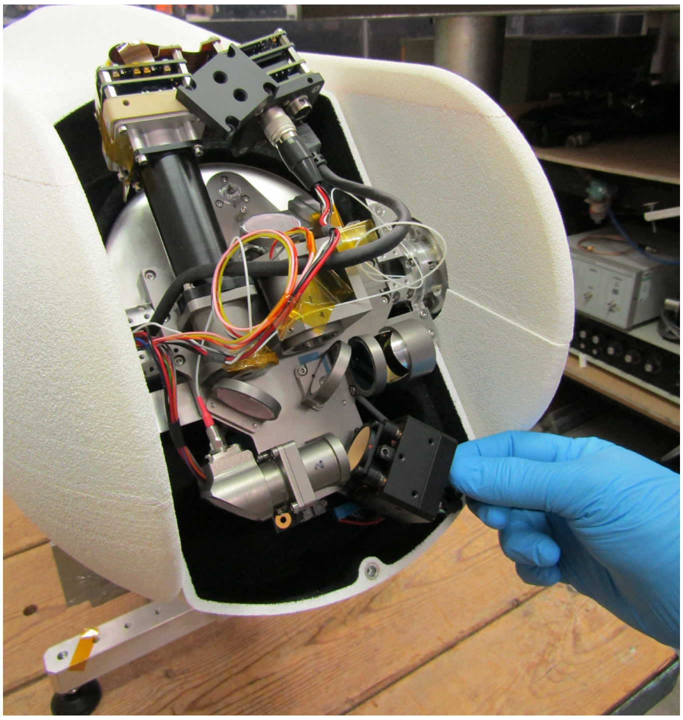


Figure 4: SDML optical front end.

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