Innovation in Optical Countermeasures

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Abstract

Defence and security require both invention and innovation. Invention is the opportunity to create completely new capabilities and solutions. Innovation is the opportunity to recognise that advances are being made in adjacent markets which can be exploited beneficially to meet the needs of defence and security customers. In this paper a case study is presented on a laser directed energy weapon programme whereby early stage feasibility concepts used open innovation. This led to the identification and exploitation of laser technology from an adjacent market and the application of phased array radar theory at optical wavelengths. Additionally, this project stimulated an underpinning research activity into novel phase locking and beam combination techniques. Currently, innovation programmes are receiving substantial support from a number of defence and security organisations globally and other open innovation defence and security photonics opportunities are presented.

The Role of Innovation in Defence

Defence Enterprise (defined here as Government, Industry and the Armed Forces) has traditionally embraced invention and there are many examples, such as jet propulsion[1], Global Positioning Systems[2] (GPS) and stealth materials.

What is less well articulated is that Defence Enterprise have also been innovative. This is seen frequently by our Armed Forces evolving their tactics. Defence equipment has also been developed through innovation. Through the Schneider Trophy[3] aircraft designs were developed which had a direct impact on the design of Italian and British combat aircraft in the mid 1930s.

A second example is the emergence of steam turbines for maritime propulsion. This case is worth highlighting in more detail, as many points are relevant today. Charles Parsons invented the modern steam turbine in 1884 and set up the Parsons Marine Steam Turbine Company in 1893. An experimental vessel, Turbinia[4], was built and launched in Summer 1894 (Figure 1).

Figure 1. Turbinia

[1] http://trace.tennessee.edu/cgi/viewcontent.cgi?article=2648&context=utk_chanhonoproj
[2] https://www.nasa.gov/directorates/heo/scan/communications/policy/GPS_History.html
[3] https://sites.google.com/site/aviationinamerica/home/schneider-pulitzer-thompson-bendix---the-sport-of-air-racing
[4] https://www.webcitation.org/5xujimKGb?url=http://files.asme.org/ASMEORG/Communities/History/Landmarks/5652.pdf

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Due to cavitation[a], the initial trials of Turbinia were disappointing and Parsons found it difficult to engage with the Admiralty. However, once the cavitation problems were solved[b], Turbinia turned up, unannounced, for the 1897 Navy Review at Spithead. In front of Royalty, Sea Lords and foreign dignitaries Turbinia steamed up and down the two lines of naval ships and evaded a Navy picket boat. Following this, two turbine powered destroyers, HMS Viper and HMS Cobra, were launched in 1899. By 1905 the Admiralty confirmed that all future Naval ships would be turbine powered and in 1906 the iconic Dreadnought was launched, with steam turbine propulsion. There are several points which are relevant to future defence innovation:

1. There was a driven individual (Charles Parsons) as a champion;
2. The Admiralty interest was eventually driven from an innovative demonstration;
3. Post 1897 the pace of adoption by the Admiralty was rapid even though there were set backs such as the losses of HMS Viper and HMS Cobra.

There is a risk that we fall into a trap of thinking that we are the only innovators. This is not the case as our adversaries also innovate effectively. This was evident from 2001 in the Global War on Terror[5] where concurrent threats were evolved rapidly, such as Improvised Explosive Devices (IEDs) which posed a significant evolving threat to coalition forces (Figure 2).

Figure 2. The impact of an IED attack.

Importantly, our adversaries apply different ethical considerations to coalition forces. For example, coalition forces are rightly constrained by ethical, governance and legal considerations which our adversaries in an asymmetrical campaign are not. This compounds the challenge of defeating the threat. Typically, solutions involve innovating more broadly and at a significantly faster rate than our adversaries.

Another factor that impacts the defence landscape are the advances in adjacent markets. In many instances more advanced technologies are available through other market sectors. To illustrate this consider semiconductors. Defence was one of the two early adopter markets (the other was space) that drove the development of this technology. The transistor was demonstrated in 1947 at Bell Laboratories. However, by 2003 it was reported that defence electronics had become a miniscule part of the semiconductor industry (<1%) but it is essential to national security[6].

As a consequence of the features of innovation outlined above in the case studies, innovation is crucially important for defence and security applications. Moreover, this importance is increasing with the emergence of new programmes in the US (Defense Innovation Unit Experimental[7] (DIUx)), Australia (Centre for Defence Industry Capability[8] (CDIC)) and

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[a] Cavitation is an effect whereby vapour cavities form in a liquid as a consequence of a forces acting on a liquid, such as a propeller, or screw. The net result is that cavitation reduces the efficiency of the propulsion system.
[b] The cavitation was reduced by building the first cavitation tunnel and conduction research which resulted in the replacement of a single turbine and propeller with three axial flow turbines to three shafts, each with three propellers.
[5] https://en.wikipedia.org/wiki/Timeline_of_the_War_on_Terror
[6] http://www.dtic.mil/dtic/tr/fulltext/u2/a524792.pdf
[7] https://www.diux.mil/
[8] https://www.business.gov.au/Centre-for-Defence-Industry-Capability/About-the-CDIC

Canada (Innovation for Defence Excellence and Security[9] (IDEaS)). In the UK the rising importance of innovation can be illustrated by searching for "innovation" in the defence reviews. In the 2010 Strategic Defence and Security Review[10] innovation was mentioned four times. The context here is important. On three occasions innovation was used to refer to the UK Government Department Business, Innovation and Skills[11]. The fourth mention was to advocate innovation from more agile small to medium size enterprises (SMEs). Yet five years later the 2015 National Security Strategy and Strategic Defence and Security Review[12] mentioned innovation 39 times. In the intervening period the value of innovation had been recognised and UK defence policy evolved to a £800m innovation fund[13]. Contemporaneously, with the launch of the innovation fund it was announced that MOD were assessing the potential of laser weapons through a £30m contract to produce a Laser Directed Energy Weapon Capability Demonstrator[14]. The foundations for this project were established nearly 20 years previously through an innovative feasibility study. This is described in the next section.

Open Innovation & High-Power Lasers

The aim of this section is to map out some of the key considerations and how, through open innovation, foundations were established for a laser directed energy weapon.

One early consideration was to minimise atmospheric attenuation. Whilst it is oversimplified, Figure 3 shows the percentage transmittance as a function of wavelength which allows favourable atmospheric "windows" to be identified where the transmittance is high:

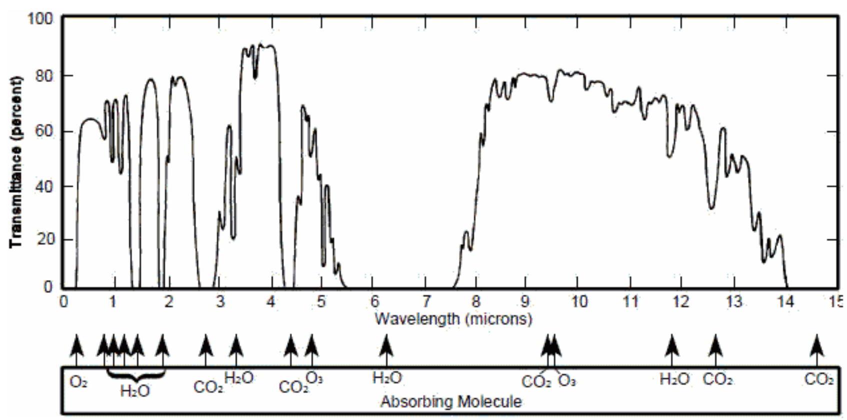

Figure 3. Atmospheric Transmittance

Based on the application requirements, there are other factors which are important as well as high transmittance, namely the availability of laser media that can be scaled to meet the power requirements. As a result of these requirements, initial studies considered 1μm and 1.5μm wavelengths.

Conducting research and development into the laser source was not viable. Therefore, advances in other market sectors were assessed i.e. open innovation. In the case of 1.5μm the underlying technology base was being developed

[9] http://dgpaapp.forces.gc.ca/en/canada-defence-policy/docs/summary.pdf
[10] https://www.gov.uk/government/publications/the-strategic-defence-and-security-review-securing-britain-in-an-age-of-uncertainty
[11] Now Business Energy & Industrial Strategy (BEIS)
[12] https://www.gov.uk/government/publications/national-security-strategy-and-strategic-defence-and-security-review-2015
[13] https://www.gov.uk/government/publications/advantage-through-innovation-the-defence-innovation-initiative-prospectus
[14] https://www.gov.uk/government/news/assessing-the-potential-of-laser-weapons

based telecommunications and the active laser media was in the form of a fibre. In the case of 1μm the underlying technology base was being developed for industrial process applications and predominantly the active laser media was in form of a bulk system, however, fibre-based systems were also emerging[15]. This trend was highly interesting as it indicated that fibre lasers had the potential to scale to high powers. The power for single and multi-mode fibres over time is shown as Figure 4[16].

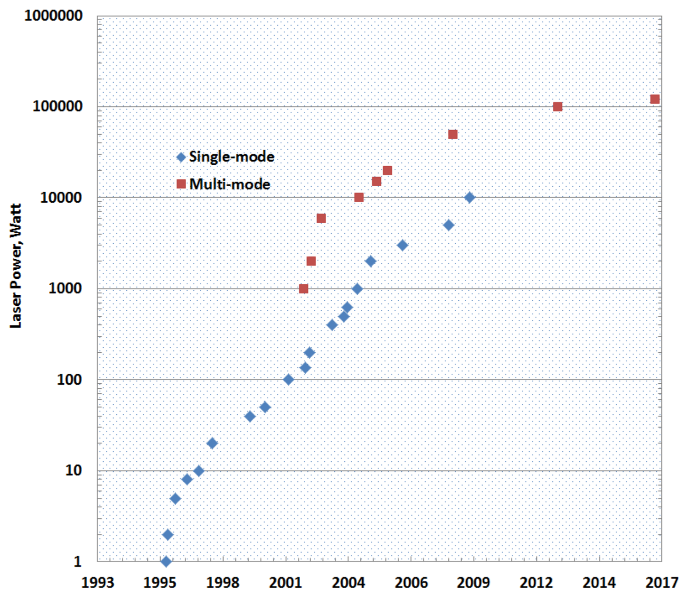

Figure 4. Fibre Laser Output Power Evolution

It is important to recall that the decision to pursue fibre lasers was taken in early 1998. Even at this time the power of single mode fibre lasers increased rapidly. This was supported by Academic opinion which indicated that fibre lasers had significant potential for further power scaling. The achievements shown in Figure 4 vindicate this opinion.

The next example of open innovation on this project was associated with the laser power scaling. Here the requirement was that the available power from a single fibre laser in the late 1990s was insufficient for the application being considered. The usual method of power scaling is to configure a laser oscillator with downstream amplifiers. Optical damage precluded this pathway and alternative power scaling methods were considered and one concept was a 2-dimensional (2D) array. Quite rapidly 2D concept evolved to phase locking the 2D array, a similar concept to phased array radar albeit at optical wavelengths[17].

Modelling of the phased array was undertaken which developed rapidly into phase manipulation to achieve high precision, low field of regard beam steering, an area of significant cost and complexity for mechanical beam steering systems. The modelling outcome demonstrated that the phased 2D array concept was feasible though a number of risks existed with phase locking, array fill factor and suppression of side lobes. To investigate these risks more fully a high-risk, inventive research programme was undertaken[18,19]. This is an important point, a systems lead study identified and specified the need for an inventive research project, alternatively, this was a good example of application "pull".

[15] https://www.theengineer.co.uk/spi-to-make-lasers-for-dod/
[16] www.ipgphotonics.com
[17] Introduction to Radar Systems, M I Skolnik, McGraw-Hill, 1981
[18] https://www.qinetiq.com/Blogs/2017/11/Dragonfire-Case-Study
[19] A multi-channel phase locked fibre bundle laser, D C Jones et al, Proceedings of the SPIE, Volume 7580, Id. 75801V (2010)

To summarise, an innovative feasibility study, nearly 20 years ago, laid the foundations for a Laser Directed Energy Weapon Capability Demonstrator. The specific innovations involved identification and exploitation of laser technology developed for an adjacent market and the application of proven radar theory at optical wavelengths.

Future Open Innovation Opportunities in Photonics

A large number of publications summarise future technology trends[20,21]. Many of these trends have the potential to be innovative technology sources for defence and security photonics applications, for example:

1. Autonomy. Autonomous platforms and systems have been pursued in non-defence and security markets, for example, transportation. Many of these systems require a prior knowledge of their environment and real time positioning, such as GPS. In defence applications provision of environmental data and availability of GPS may not be assured, therefore real time mapping and positioning are required. These functions could be provided by real-time imaging solutions. Some early work has explored some of these opportunities[22].
2. Smart Cities. A smart city is an urban area that uses different types of sensors and data collection to supply information which is then combined with contextual data (e.g. weather) and user preferences to optimise asset and resource management tasks. How can smart city sensors, systems and processing be used to deliver new defence and security solutions?

Conclusions

Defence and security require both invention and innovation. Invention is the opportunity to create completely new capabilities and solutions. Innovation is the opportunity to recognise that advances are being made in adjacent markets which can be exploited beneficially to meet the needs of defence and security customers. Additionally, innovation can stimulate the need for invention.

Effective innovation requires a broad scanning across multiple market sectors and technology applications. Though care is required in translating the methods, features, functions and benefits from one sector to another as language can quite different. Good innovators are effective translators. Based on experience, innovation is best delivered from a systems engineering function.

There is an expectation that innovation proceeds with pace. It can do. However, in the example presented in this paper a specific innovation took a generation before it became impactful. In these circumstances it is easy to blame the inability of a customer to make a decision and commit. Another factor is how the business case for the innovative solution is developed and presented. Based on hindsight, there was a weakness in the early phase laser directed energy concept studies; more emphasis should have placed on the return on investment / cost benefit analysis for the whole lifecycle i.e. development, acquisition and support.

Key Word List

Defence, Directed Energy Weapon, Innovation, Invention, Laser, Open Innovation, Security.

[20] https://www.gov.uk/government/speeches/eight-great-technologies
[21] https://www.gov.uk/government/publications/technology-trends-report
[22] https://www.gov.uk/government/publications/cde-themed-competition-autonomy-and-big-data-for-defence