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Experimental modelling with theoretical validation of liquid crystal display elements for UAV optimal (optical) stealth

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ABSTRACT

Advanced optical stealth technology is increasingly important in the role of aircraft platforms whether manned (e.g. F117A) or unmanned (e.g. X47B Pegasus). Here we consider the concept validity of using low power passive reflective display elements rather than high power active projection to achieve the same result. This paper presents practical consideration towards minimal radiated power, and power requirements using adaptive passive methods. Prism-coupling as a means of probing thin liquid crystal layers to obtain information on optical tensor parameters is possible using the Kraetschmann-Raether configuration. Leaky liquid crystal cells composed of a glass/ITO/aligning layer/liquid crystal/aligning layer/ITO/glass multi-layer structure support guided modes. Optical reflectivity as a function of incident angle and applied voltage are compared with theory generated from a Fresnel matrix formalism. Reflectivities are then simulated across an aircraft platform to evaluate the method for low power consumption and minimal radiated optical radiation.

Keywords: Surface plasmon resonance, environmental sensing, optical modelling

1. INTRODUCTION

This paper presents practical user consideration towards minimal practical power requirements with passive adaptive methods which afford stealth platform protection. Optical stealth technology today is seen as increasingly important in the role of manned and unmanned aircraft, with active projection or passive reflective display elements. Optical prism-coupling is an established method used to probe advanced electro-optical materials such as Liquid Crystal (LC) layers, to provide vital information on material optical parameters, and is one possible route to providing large switchable display surface areas. Leaky LC cells fabricated from: glass /ITO / alignment layer/ LC /alignment layer/ ITO / glass multi-layer structures support guided modes. Optical reflectivity as a function of incident angle and applied voltage are compared with theory generated from a Fresnel matrix formalism. Real achievable reflectivities may then be used to simulate contrast across an aircraft platform with over 60,000 pixel elements, to evaluate methods for minimising passive power consumption.

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1.1. History of Optical Stealth

Stealth, or **L**ow **O**bservable **T**echnology (LOT), is concerned with making *any* platform: Unmanned Aerial Vehicle (UAV), manned aircraft, ship, vehicle, *less* visible to Radar, Infra-Red or other detection methods. During World War One, Britain was losing many warships, so the Royal Navy, desperate for a solution, attempted to hide them though bizarre dazzle camouflage paints schemes of colourful and abstract cubist blocks and stripes, so vessels would 'blur' into a complex background of sea, sky and coastline. Normal Wilkinson CBE, primarily marine painter, was the first credited to use disruptive naval camouflage patterns. Dazzle or 'razzle-dazzle' camouflage was used widely at the end of World War One and to a lesser extent in World War Two, **fig. 1**., which shows HMS Uranus and HMS Jervis engaged in the Normandy landings. Detection whether it is visual, radar, or infra-red (heat) is largely about contrast. Clothing, airframes, ships or vehicles matching the background forms the basis of concealment. Addition of various coloured patterns makes it less likely to be detected in a complex environmental and forms the basis of disruptive camouflage. The German Air Force (1913) was the first to try to make aircraft invisible with a transparent monoplane of light colours, detectable at a height of 900ft. Today, such invisibly cloaked maritime stealth aircraft may thus also be hidden flying over their enemies, safely undetected.

Dazzle camouflage is entirely passive, and can only be changed by painting. Active methods alter appearance in near-real time to confuse enemies. Active or adaptive camouflage uses emerging technologies which blend objects into their surroundings with panels or coatings to alter colour, luminance and reflectivity. Active camouflage provides concealment from visual detection. One proven practical military application of this concept was during World War Two in efforts to defeat the U-boat menace. Aircraft trying to target surfaced submarines had a problem because German submarine lookouts could spot the dark silhouettes of incoming aircraft a large distance away, diving to the safety of deep water. By 1940 US researchers made aircraft effectively 'invisible', adjusting the brightness of lights on leading wing edges to hide them. Project Yehudi's Avenger bombers suitably camouflaged were able to reduce their own platform detection down to about 2 miles. In the same manner the prototype F-117A used distributed optical fibre lighting on wing surfaces to minimise contrast against background skies [**1**], now optimised with the X47B Pegasus UAV (**fig. 2**), recording sky and using lights below to blur outline, reducing contrast. However, projection requires high power levels, and consumption reduces endurance and other factors. The importance of endurance (106 responses) and power consumption (41 responses) to both the military and civilian Unmanned Aerial Vehicle communities, is seen from our upstream downstream UAV sensors research: **fig. 3**, on a scale from 1 to 5 where 1 is not at all important, to 5 very important. The reduced number of responses regarding power is indicative of the freedom to discuss power related issues.

Fig.1. The Normandy landings 6 June 1944 HMS Uranus and HMS Jervis, in the early morning with landing craft waiting to go in, painting by Norman Wilkinson, held at Britannia Royal Naval College © CR Lavers.

Fig. 2. X47B Pegasus.

2. THEORETICAL APPROACH

Conformable optical reflectivity element design uses Fresnel theory for multi-layer modelling of liquid crystals. Liquid Crystal cell model design allows optimal cell reflectivity changes to simulated real reflectivity across proposed Unmanned Aerial Vehicle platforms. A Fortran scattering matrix method **[2]** accounts for reflection / transmission coefficients at media interfaces, coupling incoming fields with a stable matrix for data fitting (**fig. 4**). Our method calculates reflectivity as a function of incident angle for multi-layer media as a series of isotropic slabs of thickness below a wavelength. Our scattering method **[2]** accounts for reflection / transmission coefficients at interfaces between media, coupling incoming fields with a stable matrix. (**fig. 4)** As demonstrated in **fig. 4**, the vectors a1 and b2 go into the matrix, and a2 and b1 come out. The forward moving vector a and the backward moving one b, the vectors in media 1 at the interface, have the subscript 1, whilst the vectors in medium 2 have the subscript 2. The elements in the vectors are modal amplitudes. Writing all these together in matrix form, generates what is known as the scattering matrix S. The input of the scattering matrix is the incoming waves, and the output is the outgoing waves and is a more stable approach than that taken with the more traditional transfer matrix approach.

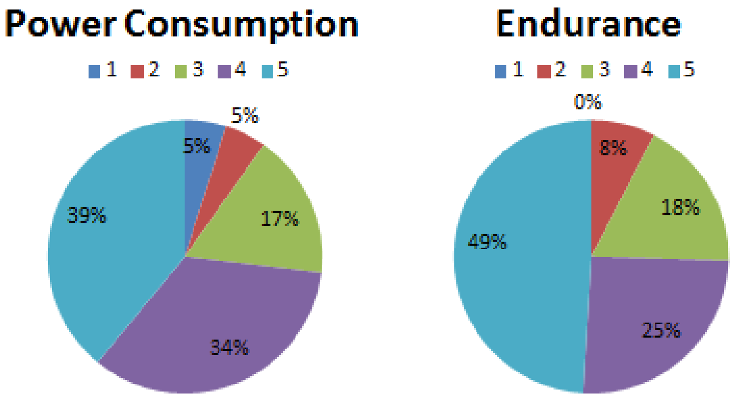
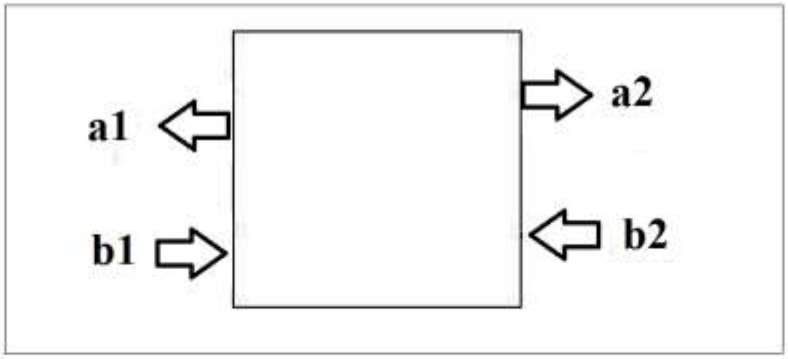


Fig. 3 Unmanned Aerial Vehicle platform military and civilian questionnaire responses.



$$\begin{bmatrix} b_1 \\ a_2 \end{bmatrix} = S \begin{bmatrix} a_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} R_1 & T^T \\ T & R_2 \end{bmatrix} \begin{bmatrix} a_1 \\ b_2 \end{bmatrix}$$

Fig 4. Scattering matrix approach.

Our method calculates optical reflectivity as a function of incident angle for multi-layer media as a series of isotropic slabs of thickness below a wavelength**.** Once an optical structure is modelled this permits optimised liquid crystal cell fabrication **[3]**. Real cell optical experimental data obtained from reflectivity monitoring is compared with theoretical modelling, permitting further LC cell design optimisation. Optimised LC cell reflectivity data as a function of voltage provides an estimate of real contrast variation for potential UAV skin covered with pixelated LC cells.

3. EXPERIMENTAL ARRANGEMENT AND RESULTS

3.1 SPR Experimental Arrangement

The Kretschmann experimental configuration (**fig. 5a**) records reflectivity from fabricated LC cells. A Helium Neon (He-Ne) laser operating at 632.8nm provided coupling to the Liquid Crystal cell guided modes, stepped in angle under computer control. A Frequency Modulated (FM) chopper permits signal and reference with Phase Sensitive Detection (PSD) using lock-in amplifiers to minimise noise. Experimental reflectivity data acquisition takes place with a National Instruments USB 6210. A LabView program controls a motorised rotation stage, recording diode reflectivities from sample / reference beams. A θ prism movement gives a 2θ diode turn, ensuring reflected beams strike a diode. As the stage rotates we record reflectivity data against steps. Cells are examined with the Krestchmann configuration. SCE8 liquid crystal cell data under applied voltage: 0 - 12V, recorded at 632.8nm, is shown (**fig. 5b**).

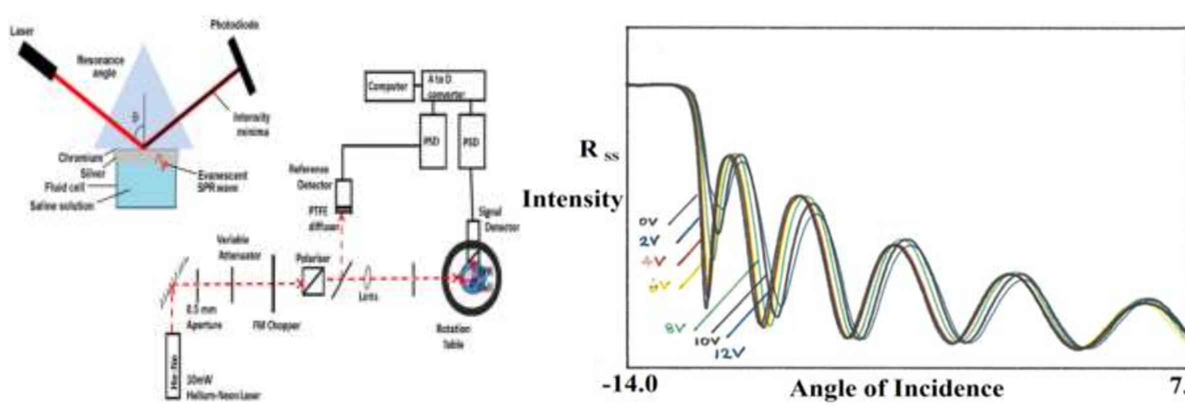


Fig. 5a. Optical reflectivity arrangement 5b. Experimentally recorded Rss reflectivities as a function of applied DC Voltage for the Ferroelectric Liquid Crystal SCE8 at room temperature.

4. OPTICAL PREDICTIONS AND DISCUSSION

Fig. 5b. shows the resulting reflectivity changes as a function of applied voltage. Such experimentally obtained reflectivity values allow us to predict the likely achievable adaptive contrast variation with a larger than likely to be used pixel test grid showing the possible minimum / maximum contrast and variation for **fig. 6a.** 0 V applied, **fig 6b.,** 6 V applied, and **fig 6c.** 12 V applied respectively with subsequent images generated in Matlab. Maximum White and Minimum Black chequers, with an alternating grid of maximum and applied voltage liquid crystal square values are observed.

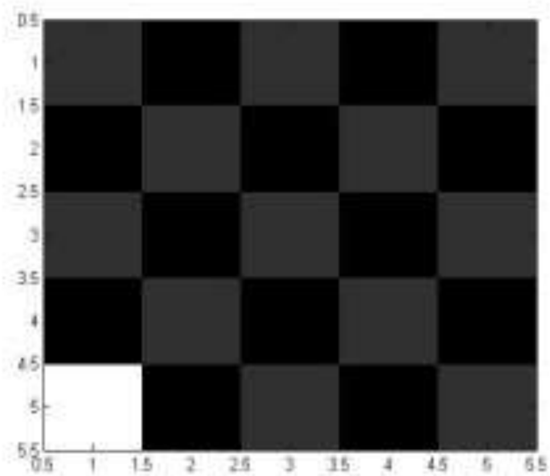


Fig. 6a: Matlab simulated pixellated test grid with Zero 0 V Applied Voltage.

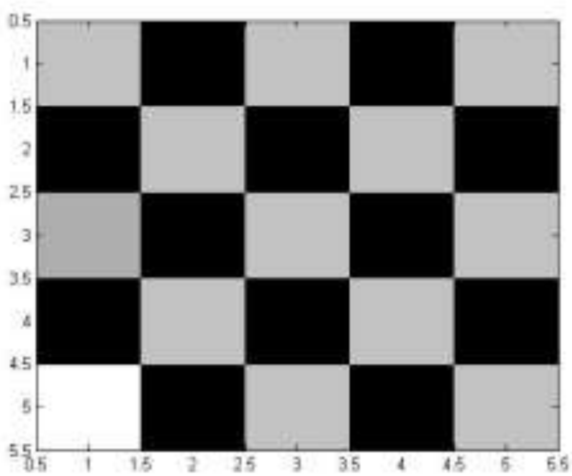


Fig. 6b: 6 V Applied Voltage

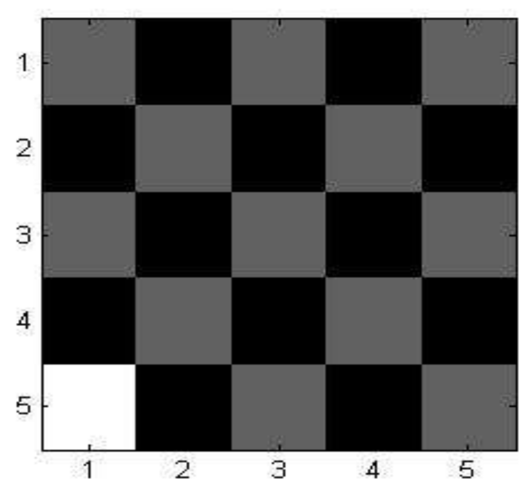


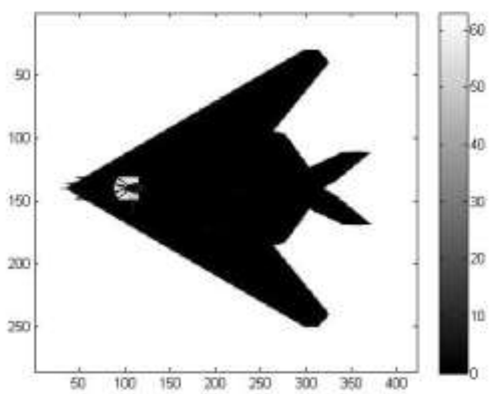
Fig. 6c: 12 Applied Voltage.

To model the likely contrast changes possible for a real platform we took a silhouette for the F117A Nighthawk, viewing model looking *down* on the platform, were entered into Matlab in an overall space of almost 120 000 today pixel elements, with 64 levels of brightness (0 to 63). The image space maximised contrast with necessary manual editing, with 0 level corresponding to the majority of the F117A silhouette and 63 level for the background, this is shown in **fig. 7a**. Normalised contrast may be calculated for target Intensity It against background Ib using the equation:

$$C = \frac{I_T - I_B}{I_T - I_B} \quad (1)$$

which for the initial F117A outline provides a maximum contrast of 1. This approach has been used successfully elsewhere to quantify specific space-based earth imaging assessments of before and after imagery assessment, using a combination of visible and near infra red imagery taking atmospheric absorption and scattering contributions into **[4-5**].

Simulated platform reflectivity elements at 632.8nm show approximately the maximum silhouette contrast conditions for 0 V applied, and 12 V applied, which are both given in **fig. 7b,** and **fig. 7c** respectively. It is seen that **Fig. 7b** closely matches **fig. 7a** in terms of overall platform contrast, whilst **fig. 7c** with 12V applied, has simulated a much reduced contrast against its background, making it much harder to 'see' the platform as a distinct object against its background. For future research a disrupted pattern will likely have a greater impact on platform visibility / invisibility.



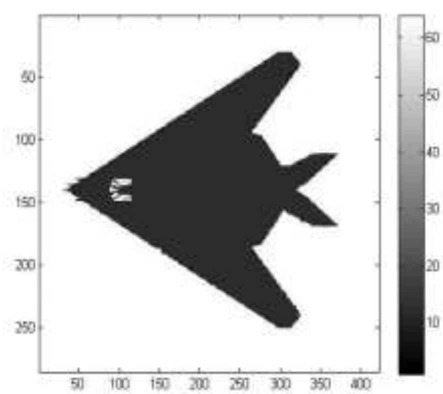


fig. 7a Maximum contrast F117A silhouette, fig. 7b. simulation 0 V applied

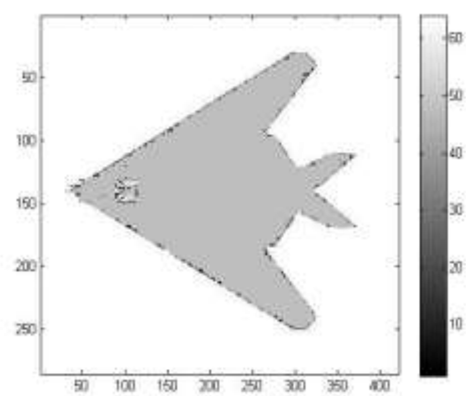


fig. 7c. simulation 12V applied

5. CONCLUSIONS

We have investigated the proof-of-concept validity of using liquid crystal display technology to achieve low cost platform optical stealth. Modelling and subsequent visualisation using Matlab of a prospective aviation platform, coated with a pixelated surface composed of a large number of liquid crystal cells shows that large scale changes in overall visual contrast are possible with potentially low voltage power supply systems, relying upon adaptive incident light illumination manipulation. Unmanned Aerial Vehicle camouflage, using liquid crystal cells in the range 0 - 12V applied voltage, provides significant contrast changes closely approaching theoretical maximum / minimum contrast conditions. Future Changing Character of Warfare Centre research in partnership with the Dartmouth Centre for SeaPower and Strategy will look at such emerging new technologies, with respect to the potential afforded by a new range of synthetic electro-optical materials with temperature, angle, voltage and wavelength dependent effects. When combined with disruptive contrast 'patch' applications UAV platforms will be afforded transformational capabilities. We will also look at how this will influence interactions and dynamics between human actors, the spatial and time domain, and any ethical and moral limitations such approaches may impose.

6. REFERENCES

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