Covert Optical Identification Friend-or-Foe Using Structural Colour Signatures

A Collaboration Whitepaper for Defence Photonics Research

Not a Funding Request

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This document is formatted as a collaboration whitepaper addressing a defence application domain subject to export control and classification constraints (see Section 6). The author is an independent systems engineer with no institutional defence affiliation; see Appendix C for a full transparency statement.

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1. Overview

Existing tactical identification friend-or-foe (IFF) solutions—active RF transponders, broadband near-infrared (NIR) markers, and chemical luminescent markers—each carry well-documented operational limitations. This whitepaper proposes a concept for covert IFF based on narrow-band, angle-dependent spectral signatures produced by structural colour patches fabricated using periodic dielectric nanostructures.

Three critical constraints bound the concept from the outset. First, covertness is relative to the adversary's sensor capability and offers no advantage against a peer adversary with shortwave infrared (SWIR) imaging. Second, no validated performance specifications exist; the preliminary estimates presented here require radiometric modelling before they can be treated as specifications. Third, the open collaboration model proposed may be legally incompatible with the export control requirements governing IFF technology, and this legal question must be resolved before technical work begins.

The patch itself is passive and requires no power. The complete system, by contrast, requires an active SWIR illuminator on the detection platform, making it an active system at the operational level. The SWIR illuminator is itself a detectable emission. ***[HYPOTHESIS]***

2. System Architecture

2.1 Structural Colour Architecture

The core of this concept is a structural colour patch fabricated using periodic dielectric nanostructures. In the structural colour literature, architectures of this class—typically fabricated via block copolymer (BCP) self-assembly or other nanolithographic techniques—produce wavelength-selective reflectance through constructive interference in periodic dielectric multilayers or photonic crystal geometries, rather than through chemical pigments or dyes (Boggild et al., DTU Nanotech; Vignolini et al., 2012; Stefik et al., 2015—full citations in Section 8).

Such a patch would, in principle, produce a narrow-band spectral-angular signature with several notable properties.

Passive at the patch level. The patch requires zero power. The detection platform, however, requires an active SWIR illuminator, making the complete system active rather than passive. The SWIR illuminator emission is itself detectable by an adversary with appropriate sensors, which has implications for platform survivability (see Section 6.5).

Covert against adversaries lacking SWIR imaging capability. Against a near-peer adversary equipped with SWIR sensors, the patch signature is detectable. Covertness is relative and time-dependent: adversary sensor capability evolves, and any covertness advantage may erode as SWIR technology proliferates.

Angle-dependent reflectance. The peak reflectance wavelength shifts with viewing angle due to the geometry of constructive interference in the periodic structure. This angular dependence could provide discrimination dimensions beyond a single spectral peak, but the information content—key space, number of distinguishable angular states, false-positive rate—has not been quantified and would require both modelling and experimental characterisation.

Stochastic manufacturing variation. BCP self-assembly introduces inherent randomness at the nanoscale. It has been suggested that this could form the basis of a physical unclonability function (PUF). PUF behaviour, however, demands demonstration that (a) the stochastic variation is sufficient to produce unique, distinguishable signatures across manufactured units, (b) the variation survives environmental degradation—abrasion, UV exposure, thermal cycling, moisture—and (c) the variation remains readable by the detection system after field exposure. None of these requirements have been demonstrated for structural colour patches. No challenge-response protocol has been defined. The PUF concept is speculative at this stage. ***[HYPOTHESIS]***

2.2 Preliminary Performance Envelope

The following are preliminary estimates, not validated specifications. No radiometric link budget, atmospheric absorption model, or signal-to-noise calculation has been performed. These estimates frame the design space for future modelling rather than establish system performance. ***[TARGET]***

Parameter	Preliminary Estimate	Status
Centre wavelength range	1000–1700 nm (SWIR band)	Includes atmospheric water vapour absorption bands near 1.4 μm and 1.9 μm; radiometric model required
Target patch size	< 58 cm² (approx. 9 sq. inches)	Referenced from US Army CCDC Soldier Center 2020 sources-sought notice
Detection range	Order of 100 m (illustrative only)	No link budget performed; could be significantly different in either direction
Target FWHM	< 40 nm (working assumption)	Placeholder from general photonic crystal literature; application-specific justification required

The detection range estimate is illustrative only. For a 50 cm² patch with roughly 10% narrowband reflectivity under a 100 mW SWIR LED illuminator, detected by a cooled InGaAs sensor, detection at ranges of order 100 m might be physically plausible. Factors not yet modelled include atmospheric absorption at the selected wavelength, solar SWIR background (daytime operations face substantially higher background than night operations), detector noise characteristics, illuminator beam divergence, and patch angular orientation relative to illuminator and detector. A proper link budget calculation is a prerequisite for any meaningful range estimate and is identified as the first quantitative task for future technical collaboration.

The FWHM target of less than 40 nm has been used as a working assumption for spectral discrimination against broadband environmental backgrounds. The required FWHM depends on the spectral signatures of common battlefield backgrounds—vegetation, soil, standard textile dyes, vehicle paints—in the SWIR band, which vary substantially with conditions.

Background spectral characterisation at the intended operating wavelength is required before a meaningful FWHM target can be set.

2.3 Technology Readiness Assessment

No formal technology readiness level (TRL) assessment has been performed. An informal estimate places the constituent technologies as follows.

Component	Estimated TRL	Rationale
Structural colour fabrication (lab scale, visible wavelengths)	3–4	Analytical and experimental proof of concept exists in academic literature, but not at SWIR wavelengths or required specifications
BCP self-assembly at textile-integrable scale	1–2	Basic principles observed; no known production facility for this application
Matched SWIR hyperspectral detection	2–3	Component technologies exist as commercial items (InGaAs sensors, SWIR illuminators) but no integrated detection system matched to structural colour IFF signatures has been demonstrated
Integrated system (patch + illuminator + detector + identification logic)	1	Concept only

The overall system TRL is approximately 1. This is a concept-stage proposal.

3. Technical Requirements

All applications listed below are subject to the export control and classification constraints described in Section 6. These are potential use cases, not validated applications.

Dismounted soldier IFF. Textile-integrable patches intended to be readable by friendly SWIR-equipped platforms. No detection timing, scan rate, or frame rate for moving-target identification has been specified. These would need to be defined as part of any operational requirements analysis.

Vehicle and equipment marking. Covert identification of friendly assets at longer ranges, where the larger available patch area may partially offset detection range limitations.

Supply chain verification. If the PUF concept described in Section 2.1 can be validated, combined IFF and anti-counterfeiting functionality could be explored. This application is contingent on PUF feasibility, which remains undemonstrated. ***[HYPOTHESIS]***

4. Implementation Approach

Before any technical work begins, one legal prerequisite must be resolved. The remaining questions define the critical path for collaborative research.

4.1 Legal Prerequisite

Export control and classification requirements. What are the specific regulatory obligations governing this research under ITAR (US), EAR (US), and UK Export Control Order 2008? If security clearance is required, the open collaboration model proposed in this whitepaper is not viable and the research approach must be restructured. A Technology Transfer Office consultation is the expected first step for any institutional partner. This must be answered before technical collaboration begins.

4.2 Priority Research Questions

Radiometric link budget. What is the detection range as a function of patch size, reflectivity, illuminator power, atmospheric conditions, solar background, and detector noise? This is the critical quantitative question. Until a link budget is calculated, the concept's operational viability cannot be assessed. This calculation should include atmospheric absorption modelling for the specific wavelengths under consideration.

Background spectral characterisation. What are the spectral signatures of common battlefield backgrounds (vegetation, soil types, standard military textile dyes, vehicle paints, skin) in the 1000–1700 nm band? This data is needed to set a meaningful FWHM discrimination target.

Detection architecture. Could existing SWIR hyperspectral imaging systems on military platforms serve as detectors, or would a purpose-built system be required? A matched-filter detector—a detection system optically filtered to pass only the expected patch signature wavelength, rejecting out-of-band background—would be simpler and potentially faster than full hyperspectral imaging, though at the cost of flexibility. The relative merits of these approaches depend on the results of the link budget analysis.

Environmental durability. How does the spectral signature perform under field conditions: dirt, rain, mud, blood, UV degradation, mechanical deformation (folding, stretching, abrasion of fabric), and temperature extremes (−40°C to +60°C)? Signature degradation in an IFF context has severe consequences (see Section 6.6).

Textile integration and manufacturability. Can the structural colour architecture be fabricated on or integrated into standard combat uniform fabrics? What manufacturing processes would be required, and at what scale? The number of research groups worldwide with relevant fabrication capability is small (estimated at fewer than ten to twenty groups), representing a significant supply chain and sustainability risk.

Detection timing. What scan rate and identification latency would be required for operationally useful IFF? What frame rate is needed for moving-target identification from a drone platform? These timing requirements must be defined before a detection architecture can be specified.

5. Context and Prior Art

Existing tactical IFF solutions span several categories. Active RF transponders (Mark XII, Mode 5) are operationally proven but complex, heavy, power-dependent, and susceptible to jamming and interception. Broadband NIR markers (GloTape, IR.Tools SandStorm, and similar products) are simple and widely fielded but visible to any party with basic night-vision equipment, providing no spectral selectivity. Chemical luminescent markers offer limited duration, single use, and no encoding capability. Spectrally selective NIR markers are reported to be under development by several manufacturers, though no unclassified performance data was identified during our search; these represent an incremental improvement path within existing NIR marker technology and may partially address the spectral selectivity gap without requiring a new detection architecture.

All currently fielded optical and infrared markers identified in our unclassified search are broadband. We did not identify, in unclassified sources, a fielded system that combines spectral selectivity, angle-dependent encoding, and physical unclonability in a single passive element.

This negative finding carries important caveats. Classified programmes—those conducted by DARPA, DSTL, national laboratories, and similar organisations—could not be searched, and classified prior art addressing some or all of these properties may well exist. This concept's novelty claim rests solely on the absence of unclassified prior art, which is a weak evidentiary basis in a domain where the most relevant work is classified by definition.

6. Security, Compliance, and Constraints

6.1 Export Control and Classification

Defence IFF is a classified, export-controlled domain. ITAR, EAR, and UK Export Control Order 2008 may govern this technology. The open collaboration model proposed—joint intellectual property, potentially international partners—may be legally incompatible with IFF technology development.

The most probable real-world outcome of approaching a university or defence institution with this concept is referral to a Technology Transfer Office for export control screening. Most international collaborators may be excluded under ITAR before technical work begins. This legal question must be resolved first, and the collaboration model may need to be restructured or abandoned depending on the answer. This is not a theoretical risk—it is the most likely first failure point for the proposed collaboration approach.

6.2 Peer Adversary Detection

The covertness argument does not hold against a near-peer adversary. NATO peer adversaries field SWIR-capable surveillance and reconnaissance systems. The system would provide a covertness advantage only against adversaries without SWIR imaging capability. Adversary sensor capability is not static; the operational covertness window may narrow over time as SWIR technology becomes more widely available. Any operational concept of employment must account for the adversary sensor threat as a dynamic variable, not a fixed parameter.

6.3 Unvalidated Performance Specifications

The preliminary estimates in Section 2.2 are not validated specifications. Without a radiometric link budget, atmospheric absorption model, background spectral characterisation, signal-to-noise calculation, and false-alarm rate analysis, the concept cannot be compared quantitatively to existing IFF solutions. The concept's viability is an open question, not an established conclusion.

6.4 System-Level Active Requirement

The patch is passive but the complete system is not. The detection platform must carry a matched SWIR illuminator, adding size, weight, power, and cost (SWaP-C) to the platform. No SWaP analysis has been performed for the illuminator subsystem. Existing broadband NIR markers share this dependency on platform-side illumination but require only broadband—simpler and cheaper—illumination sources.

6.5 Platform Signature from SWIR Illumination

The SWIR illuminator required on the detection platform is an active emission. An adversary with SWIR-sensitive sensors could detect the illuminator, compromising the detection platform's position. This represents a system-level emissions security (EMSEC) concern not addressed in the current concept. Any operational deployment would need to assess whether the illuminator emission is detectable at operationally relevant ranges by anticipated adversary sensors.

6.6 Fail-Safe Behaviour and Signature Degradation

If the patch signature degrades due to environmental exposure (dirt, damage, mechanical deformation), the failure mode is a missed identification: a friendly asset is not recognised as friendly. In a tactical IFF context, missed identification can lead to fratricide. There is no graceful degradation in IFF—a partial or unreadable signature is operationally equivalent to no signature.

This concept does not currently define a fail-safe protocol for degraded signatures. Possible mitigations—redundant patches, secondary identification methods, confidence thresholds with escalation procedures—have not been analysed. Any future development must address fail-safe behaviour as a primary design requirement, not an afterthought.

6.7 Manufacturing and Sustainability Risk

The system depends on structural colour fabrication expertise confined to a small number of academic research groups. BCP self-assembly at textile-integrable scale has no known production facility. The detection hardware would require custom integration even if constituent components (InGaAs sensors, SWIR LEDs) are commercially available. The concept depends on capabilities that do not currently exist in integrated form, and the expertise base is narrow. This creates a significant sustainability and supply chain risk for any programme built on this technology.

7. Dependencies and Next Steps

This whitepaper is issued as an open invitation to research collaboration, subject to the export control constraints described in Section 6. This project is not seeking funding at this stage. The areas of expertise sought are: defence photonics and electro-optical sensing; SWIR and hyperspectral imaging with radiometric modelling capability; military textile engineering; export control and defence technology transfer law; and physical security and authentication.

Potential collaborators should assess their own export control obligations before engaging in technical discussion. The first collaborative step is expected to be an export control assessment, not a technical discussion.

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8. References

Internal Project Documents

[PL1] *Project Labradorite: Commercial Applications of Synthetic Labradorescence* (Deep Research Report, February 2026). Internal document—not independently verifiable.

Peer-Reviewed Literature

[1] Vignolini, S., Rudall, P.J., Rowland, A.V., Reed, A., Moyroud, E., Faden, R.B., Baumberg, J.J., Glover, B.J., and Steiner, U. (2012). "Pointillist structural color in *Pollia* fruit." *Proceedings of the National Academy of Sciences*, 109(39), 15712–15715.

[2] Stefik, M., Guldin, S., Vignolini, S., Wiesner, U., and Steiner, U. (2015). "Block copolymer self-assembly for nanophotonics." *Chemical Society Reviews*, 44(15), 5076–5091.

[3] Boggild, P. et al.—DTU Nanotech, Technical University of Denmark. Work on periodic dielectric nanostructures and structural colour. *Note: The specific foundational publications from the Boggild group should be verified and added by a collaborator with access to the primary DTU Nanotech literature. This is a known gap in the current reference list.*

[4] Kinoshita, S., Yoshioka, S., and Miyazaki, J. (2008). "Physics of structural colors." *Reports on Progress in Physics*, 71(7), 076401.

Regulatory and Procurement

[5] US Army CCDC Soldier Center (2020). Sources-sought notice for wearable IFF solutions at less than 9 square inches. Identified via procurement database search; original document number not available.

[6] ITAR—International Traffic in Arms Regulations, 22 CFR 120–130. US Department of State.

[7] EAR—Export Administration Regulations, 15 CFR 730–774. US Department of Commerce.

[8] UK Export Control Order 2008—UK Strategic Export Controls. UK Department for Business and Trade.

Note on citation completeness: This reference list is not exhaustive. The paper would benefit from citations to InGaAs detector performance literature, SWIR atmospheric transmission models (e.g., MODTRAN), military IFF system specifications (to the extent available in unclassified literature), and PUF literature (e.g., Pappu et al., 2002, on physical one-way

functions). These gaps reflect the conceptual stage of this work and the author’s limited access to defence-specific technical libraries.

Appendix A: Document Metadata

Field	Value
Title	Covert Optical Identification Friend-or-Foe Using Structural Colour Signatures
Subtitle	A Collaboration Whitepaper for Defence Photonics Research
GUID	AG-2026-0225-4436
Version	1.0
Date	25 February 2026
Author	Aaron Garcia
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Origin Context	Developed from Project 43—Labradorite research programme. Concept originated from investigation into commercial applications of synthetic labradorescence, with defence IFF identified as a candidate application domain.
Status	Final Draft

Appendix B: Glossary

Abbreviation / Term	Definition
BCP	Block copolymer—a class of polymers used in self-assembly fabrication of nanostructures
CCDC	Combat Capabilities Development Command (US Army)
COTS	Commercial off-the-shelf
DARPA	Defense Advanced Research Projects Agency (US)
DSTL	Defence Science and Technology Laboratory (UK)
EAR	Export Administration Regulations (US Department of Commerce, 15 CFR 730–774)
EMSEC	Emissions security—the discipline of preventing unintended electromagnetic or optical emissions from compromising operational security
FWHM	Full width at half maximum—a measure of spectral bandwidth
IFF	Identification friend-or-foe
InGaAs	Indium gallium arsenide—a semiconductor material used in SWIR photodetectors
ITAR	International Traffic in Arms Regulations (US Department of State, 22 CFR 120–130)
NIR	Near-infrared (approximately 700–1000 nm)
PUF	Physical unclonability function—a hardware-based security primitive that exploits manufacturing variation to produce unique, unclonable identifiers
SWIR	Shortwave infrared (approximately 1000–2500 nm)
SWaP-C	Size, weight, power, and cost
TRL	Technology readiness level—a standardised scale (1–9) for assessing technology maturity

Appendix C: Methodology and Transparency Statement

Author Context and Expertise

This work is grounded in 30 years of multi-sector experience in Systems Engineering. The analytical framework reflects professional history, focusing on practical application.

Digital Methodology and Accessibility

In the spirit of transparency, I utilised a suite of Generative AI tools—specifically Claude, Google Gemini, and ChatGPT—to assist in the production of this paper. These tools were employed as force multipliers for data synthesis and editorial accessibility. As a writer with dyslexia, I leverage these models as assistive technology to refine grammar and streamline sentence structure.

Verification and Integrity

While AI assisted in processing data, the intellectual oversight is entirely human. I performed manual validation of all citations and accept full responsibility for the accuracy and originality of the final output.

Specific Disclosure

The structural colour literature survey, including identification of relevant architecture terminology and supporting references, was conducted with AI assistance. The author has not independently verified all cited references against their primary sources. Collaborators with direct expertise in structural colour photonics should verify the technical claims and citations against the primary literature.

Appendix D: Raw Author Notes

The following notes are preserved from the author's original concept development for context.

The concept for covert optical IFF emerged from the broader Project 43—Labradorite investigation into commercial applications of synthetic labradorescence. During that research, it became apparent that the angle-dependent, narrow-band spectral signatures produced by periodic dielectric nanostructures might have utility beyond decorative or commercial applications.

The defence IFF application was identified as a candidate because the core properties of structural colour—passive operation at the patch level, spectral selectivity, angular encoding, and stochastic manufacturing variation—map onto desirable IFF marker characteristics. The concept remains at the earliest stage of development and is presented as an invitation to collaboration rather than a solved problem.

The author has no institutional defence affiliation and limited access to classified literature. The concept's novelty claim is constrained by this access limitation, which is acknowledged throughout the document.

Appendix E: Change Log

This appendix records the editorial development of the document.

Version	Date	Description
0.1	February 2026	Initial concept whitepaper drafted from Project 43 research notes.
0.2	February 2026	Revised following internal review. Key changes: novelty claims qualified with unclassified-sources caveat; system description corrected to distinguish passive patch from active system; peer adversary detection risk documented; export control elevated to legal prerequisite; preliminary performance estimates added; known risks and limitations section added.
0.3	February 2026	Revised following second internal review. Key changes: section headers aligned to technical convention; pedagogical definitions replaced with inline technical context; reference list expanded with peer-reviewed sources; PUF claims qualified with explicit feasibility requirements; detection range reframed as illustrative only; FWHM target acknowledged as placeholder; architectural definitions expanded; platform EMSEC risk section added; fail-safe behaviour section added; manufacturing and sustainability risk section added; detection timing requirements identified.
1.0	25 February 2026	Publication-ready formatting applied. Document restructured to Type C technical specification format. All content integrated as clean narrative. Appendices A–E built per publication protocol.