NATIONAL MEASUREMENT SYSTEM

PHOTONICS METROLOGY PROGRAMME

APRIL 2004 – MARCH 2007

PUBLIC RELEASE VERSION

NMS Programme for Photonics Metrology, 2004 – 2007

1. Introduction

1.1 This document

This document describes the agreed National Measurement System (NMS) programme for Photonics Metrology for the period April 2004 to March 2007. It describes the overall aims and objectives of the programme, the organisation of the proposed projects into themes, the rationale for the proposed projects and their benefits and deliverables.

1.2 Aims and objectives of the programme

INTRODUCTION

The overall aim of the government supported NMS programmes is to maintain and develop, at a national level, an infrastructure that ensures measurement in the UK is valid, fit for purpose, consistent and internationally recognised. This infrastructure exists primarily to promote the UK's economic competitiveness and support regulatory needs, promoting innovation and improving productivity and quality of life.

The Photonics Metrology programme is an industry-focused programme. The specific aim of the programme is the continual development of a measurement infrastructure to meet the growing requirements of the UK's photonics industry. This will be achieved through improvements in accuracy in existing measurement areas, the development of novel techniques, software and instrumentation to support UK industry and activities to improve knowledge of measurement requirements and best practice in this area of technology.

As a market sector focussed programme within the NMS, Photonics Metrology is both dependent on the outputs of other NMS programmes and to varying degrees provides input into defining certain activities within the unit science programmes. Therefore, the formulation of this programme has been done with reference to the work of other NMS programmes and the capabilities they can offer, seeking where appropriate to include activity that has synergy with that of other programmes and NMS facilities.

BACKGROUND

Photonic technologies, broadly defined as the use of light (of all wavelengths) to convey or manipulate information, are rapidly diversifying out from optical telecommunications. Sectors making increasing use of photonic technologies include medical, aerospace, automotive, defence and general manufacturing. The wealth of techniques and devices developed for telecommunications are finding applications such as laser machining, sensing, bio-assays and medical diagnosis.

As photonic technologies have matured they have been taken up in applications where previously they may not have been considered sufficiently reliable or even able to meet the required standard of performance. Examples include novel and sophisticated display technologies such as light emitting polymers, sequential pulsed and 3d displays. The National Health Service has embarked on a major project to replace traditional methods of viewing medical images with electronic displays.

Despite this diversification and the current recession in the optical telecommunications sector, there can be no doubt that high capacity optical networks will have a major and growing impact in the future, both economically and socially. Internet traffic continues to grow at around 80% per year. The current surplus capacity of backbone networks will be consumed as the development of broadband access technologies accelerates.

The primary objective of the programme is to seek to balance the need to maintain capability in core areas with the desire to develop the measurement capabilities necessary to support the continuing uptake of photonic technologies across a broad range of industrial sectors.

1.3 Consultation process

An extensive consultation process has informed the preparation of this document. This was initiated by a report prepared by Scientific Generics, "Trend Spotting Forward Look for the Photonics Programme – Strategic Overview". This report was presented at a meeting held on 30 January 2003, hosted by DTI. A further presentation was given by NPL on the background to the current programme to give context for the evolution of a new programme. The results of the discussion at that meeting lead to a preliminary framework for the proposed programme, which has been further developed on the basis of detailed consultation. Those involved in the consultation process have included:

- NMSD
- MAC Working Group members
- Members of the NMS FOToN UK measurement club
- Contractors and staff involved in the current Photonics Metrology programme
- Key companies and individuals working in photonics technologies
- University research groups
- Faraday partnerships
- Programme managers and formulators of other NMS programmes including; Optical Radiation, Length, SS*f*M, KT, Electromagnetic and MfB
- Other NMIs including NIST and PTB

In addition a number of other meetings were held and studies undertaken. A Datacomms workshop was held at NPL and a displays workshop was held as part of an ORM measurement club meeting. A report of a study into the medical requirements for photonics related measurement was produced as NPL Report CETM S136 "Investigation of the Requirement for Photonics and Optical Radiation Measurements in Medical Applications".

2. Structure and themes for the programme

2.1 Introduction

Photonics has been identified as a key “enabling-technology” with a broad range of potential applications across a diverse range of industrial sectors. In developing the structure of the programme presented here, those measurement areas having a broad application across a range of sectors have been grouped into one theme.

The other technical themes address measurement issues of relevance to more specific industrial sectors. The first of these is telecommunications and Datacomms. The capability built up by the NMS in previous programmes is expected broadly to meet the measurement requirements for the long-haul optical telecommunications during the life of the programme. The programme will maintain capability in this area, which although currently undergoing a period of recession, will continue to have major economic and social impact in the future. Industry has turned to the challenge of improving access to the high capacity network, with the aim of increasing the use of broadband information and entertainment services. This is reflected by research and development activity in the communications theme, which also reflects the restructuring of the sector away from vertical integration towards a more conventional commodity market.

An area seeing a rapid increase in the introduction and development of photonic technologies is the medical and bio-tech sector. Activity in the third technical theme will concentrate on the measurements needed to support the growth of photonic applications in these tightly regulated and safety critical areas.

Knowledge Transfer (KT) is a key component of all NMS programmes. Reflecting the findings of the orientation report carried out at the start of the consultation process, the emphasis of KT delivery is for an outgoing regional and sector based set of activities. Activities in the KT theme will complement specific KT deliverables in the technical projects, ensuring comprehensive dissemination of the technical work of the programme.

Finally the above activities all need to be effectively managed and co-ordinated and the work that will ensure this is described in the final theme.

2.2 Themes and projects

Following from the above the structure of the programme is set out below:

2.2.1 Theme One: Photonic Enabling Technologies

Project 1.1 Refractive Index Measurements

Project 1.2 Measurements for Novel and Complex Photonic Components

Project 1.3 Laser Wavefront Sensing

Project 1.4 Metrics for Displays Usability

2.2.2 Theme Two: Photonic Communications

Project 2.1 Measurement Infrastructure for Optical Telecommunications

Project 2.2 Measurements for Optical Datacomms Technologies

Project 2.3 Measurements for Broadband Access Technologies

Project 2.4 Modelling and Measurements for Optical Networks

2.2.3 Theme Three: Photonics for Medicine and Biology

Project 3.1 Imaging with Displays

Project 3.2 Photonic Techniques for Medical Diagnosis

2.2.4 Theme Four: Generic Knowledge Transfer

Project 4.1 Presentation of Photonic Programme Outputs

Project 4.2 Dissemination of Good Measurement Practice

Project 4.3 Improvement of technology flow to and from NPL

2.2.5 Theme Five: Management

Project 5.1 Programme Management

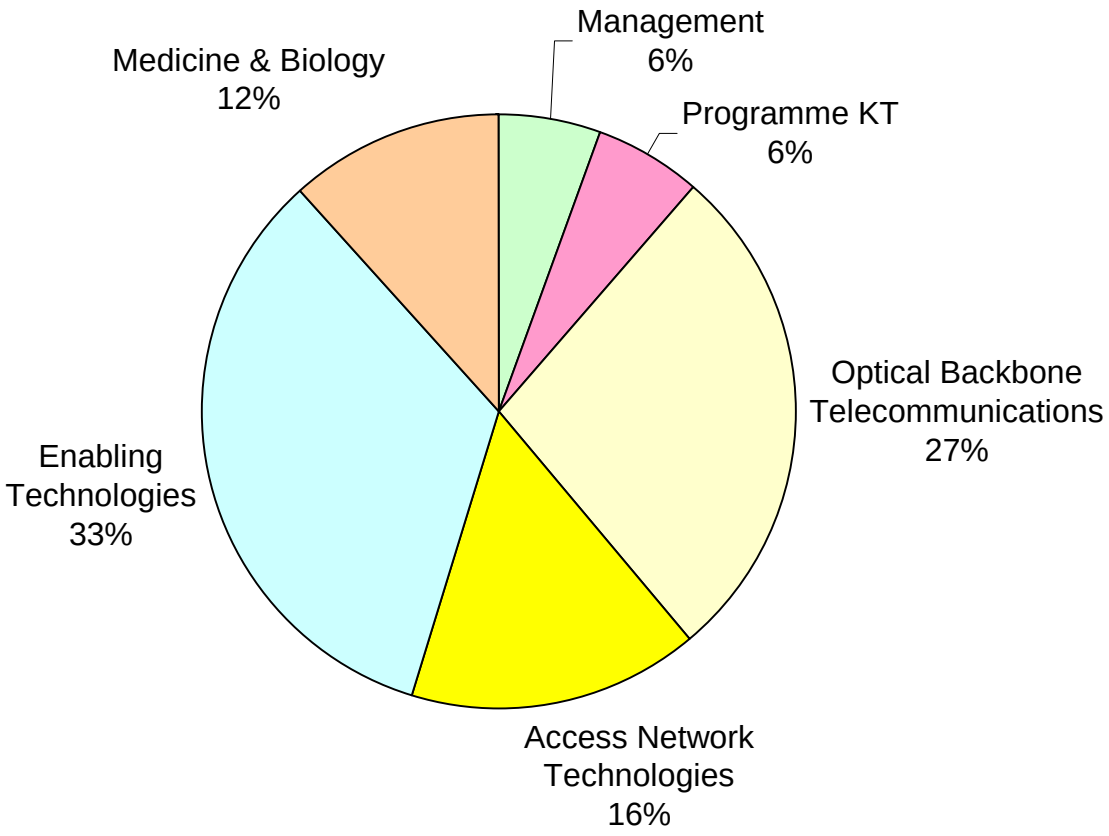
Project 5.2 Integration Activities

Project 5.3 Programme Formulation

2.3 Activity Breakdown

2.3.1 Activity by theme

The following chart shows the division of the programme by theme:

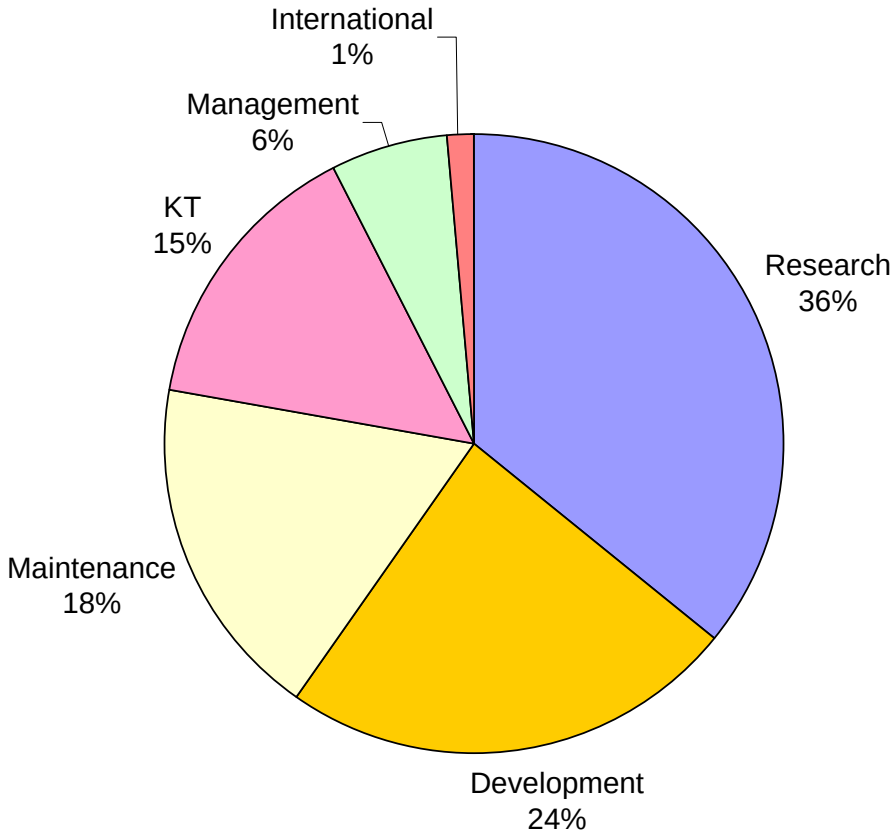


2.3.2 Activity by type

This programme includes a range of different types of activity, as follows:

- Maintenance
- Development
- Research
- Support for international traceability and regulation
- International liaison
- Knowledge transfer
- Programme management

The chart below shows the overall distribution of the activity types across the programme. As both are relatively small, support for international traceability and regulation and international liaison have been combined.



3. Theme and project descriptions

3.1 Theme 1 – Photonic Enabling Technologies

Under this theme work will be undertaken to develop measurement techniques and establish or maintain traceability in areas where the provision of measurement standards is essential for the full development of a range of photonic technologies with applications across a broad range of industrial sectors. In addition to the development work, knowledge transfer activities, including advice on best practice, will also help to ensure the exploitation of these technologies.

3.1.1 Project 1.1 – Refractive Index Measurements

INTRODUCTION

Refractive index is a key measurement parameter, necessary for the development of optical components and systems, and certainly within the photonics components industry the importance of accurate refractive index measurement has been highlighted [1]. However, this is by no means the only industrial sector requesting measurement solutions for refractive index based problems. Examples of some of these industries are; food, pharmaceutical/biotech, chemical, recording, cosmetics and forensic analysis. Here the interest comes from requirements for production and quality control, component testing, material identification and analysis, and the development of new materials.

NMS work in this area began mainly in support of the glass industry and developed traceability using the "Minimum Deviation" method [2]. This was done in conjunction with a number of other standards laboratories worldwide and produced a centre of excellence in refracted angle based methods. The programme also undertook pioneering work in the areas of Ellipsometry and Prism Coupling, which are used to measure the refractive index of thin films [3]. Recent work has reflected changing industrial need, and the broader application of refractive index measurement throughout industry, and has combined the above approaches to produce a new top level reference instrument for refractive index measurement: the *Reference Refractometer*. This still incorporates the minimum deviation method for traceability but also supports thin film work through a high accuracy prism coupling system. This not only supports industries such as telecommunications, where thin film measurement is of importance for advanced optical components, but also the biotechnology industry through the provision of a Surface Plasmon Resonance measurement system.

The above gives a solid basis for the NMS to tackle some of the fundamental issues facing refractive index measurement. Traditional measurement methods have always been constrained by sample geometry (i.e. prisms, plates of optical flatness < $\lambda/4$, films of particular thickness or RI range). However, there is a growing requirement for samples to be measured for refractive index that do not fall into the above categories. The telecommunications industry requires measurements of refractive indices that are higher than can be provided by refracted angle measurements. It would also be an advantage to characterise optical components in final format i.e. to probe through a microstructure and characterise refractive index profiles[4]. This capability would also be of interest to the biotechnology industry where the ability to characterise a three dimensional microstructure in a non-invasive way could lead to higher measurement accuracy in, for example, the areas of

Surface Plasmon Resonance and Optical Coherence Tomography[5]. A further example comes from the recording industry and plastic coatings for Compact Disks – it is extremely hard to obtain a optical flatness < $\lambda/4$ for a plastic.

This project builds on previously developed capability to address the measurement issues described above.

OBJECTIVES

- To maintain and develop the current Reference Refractometer to maximise capability for bulk and thin film measurement;
- To extend measurement capability to encompass high refractive index samples;
- To develop techniques to characterise 3-dimensional microstructures for refractive index profile;

RATIONALE

Refractive index is a key measurement parameter for applications that involve the use of optics or the analysis of a sample via optical means. Optics and optical techniques underpin a very diverse cross-section of British industry. The telecommunication market (UK size £45.5 billion[6]) is moving more towards the use of innovative optical components in order to increase efficiency within networks – refractive index is a key parameter behind the functionality of such devices [7,8]. The biotechnology and pharmaceutical industries (UK sizes £3.8 and £9.1 Billion respectively[8]) also require measurement of refractive index to facilitate the uptake of new techniques, such as Surface Plasmon Resonance and Optical Coherence Tomography, used for drug discovery and other medical applications. Other sectors require refractive index measurements for production and quality control, for example: the food industry (UK size £66.2 billion[8]), the chemical industry (UK size £42.0 billion[6]), the cosmetics industry (UK size £0.82 billion[6]) and the recording industry (UK size £0.17 billion[6]).

This project builds on existing expertise in the field of refractive index measurement and then focuses on refractive index measurement issues that are relevant to the above industrial sectors. The underpinning measurements would then support economic goals in the area of innovative product design, and cost savings in the areas of production and quality control. The impact on quality of life will come through a number of routes but most obviously in the biotechnology/pharmaceutical sectors via the increased uptake of new technologies in drug discovery and medical applications.

Knowledge transfer will be a key activity within this project. Apart from the discussions between collaborating universities and companies, full use will be made of measurement clubs, as well as attendance at conferences and publications within journals.

(1) NMSPU Survey, "Future UK Requirements for Traceable Measurement Services in Photonics", 1998 – 2001.

(2) "An improved recording refractometer for optical glasses in the wavelength range 300 to 2600nm", M.Debenham, G.D.Dew & D.E.Putland, Optica Acta, 1979, Vol. 26, No. 12, 1487-1503.

(3) "A Comparison of Thin Film Measurement by Guided Waves, Ellipsometry and Reflectometry", R.J.King & S.P.Talim, Optica Acta, 1981, Vol. 28, No. 8, 1107-1123.

(4) Refer to: “Measurements for Novel and Complex Photonic Components”, parallel project (1.2) proposed under current Photonics Programme formulation.
(5) Refer to: “Surface Plasmon Resonance (SPR) and Optical Coherence Tomography”, parallel project (3.2) proposed under current Photonics Programme formulation.
(6) Oxford Economic Forecasting and www.Profound.co.uk
(7) “2002 Global Forecast”, Photonics Spectra, January 2002
(8) “Integration – manufacturing of planar lightwave circuits”, D. Rauch, Lightwave, Oct. 2001

DELIVERABLES:

Ref	Title	Start Date	End Date
1.1.1	Provision of traceability and maintenance of measurement services for refractive index using refracted angle techniques	Apr - 04	Mar - 07
1.1.2	Provision of measurement techniques for refractive index > 2, for bulk and thin film samples	Jan - 05	Mar - 07
1.1.3	Investigation of methods for determining refractive index profiles within 3d microstructures	Apr - 04	Mar - 07
1.1.4	Knowledge transfer for refractive index measurements including writing of at least one scientific paper	Apr - 04	Mar - 07

3.1.2 Project 1.2 – Measurements for Novel and Complex Photonic Components

INTRODUCTION

Photonic components of increasingly complex design are being developed, at present primarily for optical telecommunications, but with future potential for more generic optical processing of information.

Knowledge of the near field intensity profile of components and fibres is key to understanding how light will propagate through a multi-component system. However, near field measurements are difficult to make and a common approach is to relate the more easily measured far field profiles to the near field by the use of suitable mathematical transforms. This project will survey the near field profiles of a range of components and test the validity of typical transforms and develop appropriate alternative solutions. A particular case that would be investigated is that where the intensity profile does not have circular symmetry.

The lack of reliable measurements and transforms of near field intensity is a serious barrier to the development of integrated optics systems. This project seeks to improve the accuracy of the 2d near-field profiler developed as part of the previous Photonics Metrology programme, and to test the validity of the current near/far field transforms when used with a range of components. The outputs of the proposed project will be an enhanced measurement and calibration service for components and recommendations on the use of transforms in asymmetric cases. This will allow valid calculations of parameters such as MFD and A_{eff} to be made, ensuring efficient operation of integrated optics systems.

OBJECTIVES

- To develop enhanced capability in order to measure the near field profile of a variety of components;
- To use modelling to link the measurement of near field profiles of components to far field results, refractive index profiles and transmission properties.

RATIONALE

The current downturn in the telecommunications industry has led to a shift in emphasis towards upgrading existing infrastructure in preference to deploying new optical networks [1]. Consequently, component manufacturers are being required to meet this new market with increasingly complex and innovative optical components, manufactured to new levels of precision [1,2]. It has been predicted that the market for Planar Waveguide Circuits (for example, Array Waveguide Gratings, Switches, Variable Optical Attenuators, couplers/splitters) will grow from its current £115 million mark to £2.8 billion by 2011 and the demand for Filter Elements (such as Interference filters and Bragg grating fibre) will mean that this area will net £330 million by 2011 [3]. One of the main driving forces behind this trend is the desire to increase capacity within existing networks via Dense Wavelength-Division Multiplexing (DWDM) [2,4,5] and the need to reduce costs by developing integrated subsystems with enhanced functionality [5,6]. The above factors led to the inclusion of advanced optical components within the Photonics Science Strategy document [7].

(1) *"2002 Global Forecast"*, Photonics Spectra, January 2002
(2) *"Integration – manufacturing of planar lightwave circuits"*, D. Rauch, Lightwave, Oct. 2001
(3) Lightwave (www.pennet.com) and ElectroniCast (www.electronicast.com)
(4) *"PLC platform addresses emerging component requirements"*, J.Bautista, K.Sullivan and B.Shine, Lightwave, Nov. 2000
(5) *"Integration of multifunctional planar lightwave circuits"*, A. Ticknor, Lightwave, March 2001
(6) *"Photonic integration combats network complexity"*, FibreSystems (Fibres.org), May 2002
(7) "*Report on Opportunities for Strategic Research in Photonics"*, A. Sinclair, M. Wicks and C. Wall, NPL Report CBTLM S66, August 2001

DELIVERABLES

Ref	Title	Start Date	End Date
1.2.1	Provision of enhanced near field / far field intensity profile measurement capability for advanced photonic components	Apr - 04	Sep - 06
1.2.2	Development of transforms for asymmetric near field profiles	Apr - 06	Mar - 07
1.2.3	Knowledge transfer for photonic component measurements including writing of at least one scientific paper	Apr - 04	Mar - 07

3.1.3 Project 1.3 – Laser Wavefront Sensing

INTRODUCTION

Developments in the application of lasers in industry are producing increasing demands for accurately characterised laser beams. At present the main requirement is in the area of free space optical telecommunications, where safety and service integrity will rely on accurate measurement of laser beam parameters. In the future, as laser machining matures into a widely applied technology across a range of sectors, there is likely to be an increasing requirement for traceable measurements of laser beam profiles.

In particular, there is new interest in characterising the spatial intensity and phase properties of laser wavefronts. The main techniques used to obtain phase information are based on wavefront shearing, such as Shack-Hartmann, Hartmann or diffractive optic techniques.

Some techniques are under commercial development by industry but the necessary protocols for establishing agreement between different techniques have not been investigated. Work concerned with traceability for interferometers, supported by the NMS Length Metrology programme, identified that this is likely to be a significant issue in the development of these instruments [1]. This is reinforced by publications, e.g. [2] and a study undertaken by a research organisation for DTI. Additionally, two topics identified in the recent DTI foresight initiative for 2003 require laser phase front measurement: Laser-enhanced material processing [3] and Biomedical and chemical manipulation [4]. No major national standards laboratory is currently establishing laser wavefront characterisation, only spatial intensity parameters are being investigated; therefore this project on wavefront characterisation is unique work.

This project will develop national traceability for the calibration of laser beam wavefront sensing and profiling instrumentation. An initial study of available techniques will be performed to identify the best method for realising this traceability. One approach is the development of reference sources with known and proven beam characteristics. These sources will be used to calibrate a transfer standard that will form the basis of a unique calibration service to industry for laser beam measurement instrumentation. Collaboration opportunities would be explored with UK organisations that manufacture their own beam profiling systems for laser based manufacturing equipment.

OBJECTIVES

- To develop a traceable measurement infrastructure for the calibration of cw laser wavefront measurement instrumentation;
- To develop and provide a measurement service for the calibration of laser wavefront instrumentation at discrete wavelengths over the range 532 nm to 1550 nm;
- To develop and provide a measurement service for the calibration of laser beam spatial profiling devices and beam propagation parameter devices (M^2 parameter);

RATIONALE

Developments in the applications of lasers in industry are producing increasing demands for accurately characterised laser beams. Examples include free space optical communications, high precision hole drilling at both the macro scale in large scale engineering to reduce wastage and at the nano level where UV lasers are employed to modify phase masks for semiconductor manufacture, or to construct precision medical devices with nanometer accuracy.

The increased interest in the use of Free Space Optics (FSO) as a method of transmitting data is due to its ease of installation especially in urban environments where cable-laying operations cause disruption to the existing local infrastructure, people or environment. RF bandwidth is restricted and expensive; this contrasts with FSO, which has the benefit of a substantial bandwidth with no licensing requirement. Wavefront sensing is an essential measurement for the continuous optimisation of this transmission process. At least six UK organisations are entering this field and a recent Smart Optics Faraday Partnership meeting identified the establishment of a measurement infrastructure for phase front measurement as a requirement for the successful introduction of FSO.

Current laser safety regulations do not effectively address the possible hazards due to the complex phase coherence factor and the beam width in an optical system. The establishment of reliable measurement methods and test instrumentation for these parameters is essential for accurate risk assessment. There are at least five international standards [5] that are beginning to consider this omission. The provision of these measurement facilities through the NMS will ensure the reliability of measurements made with calibrated test instrumentation. A survey carried out on behalf of DTI on wavefront distortion highlighted these specific needs for laser-based systems.

There is evidence that in the future the standard approach of quality control in laser machining by inspection of finished work will increasingly be replaced by online monitoring of laser parameters to ensure that the material-laser interaction at the work piece is optimised. Therefore the accurate knowledge of laser wavefronts and the M^2 parameter may be required for a diverse range of applications including semiconductor manufacture, process control, laser machining, TFT, fundamental research into frequency doubling, and the production and characterisation of optical components. UK companies have indicated the need for the spatial profile of laser beams used for cutting applications [6] and the Association of Industrial Laser Users have also highlighted the requirement to measure beam propagation parameters to achieve consistently the quality of manufacture required to meet profitability targets [7,8].

(1) NPL Report MOM(E)12 “Mach-Zender Interferometers for wavefront testing:construction and trials” Dr RF Stevens August 1994
(2) J.D.Briers, “Interferometric optical testing: an interlaboratory comparison”, J. Opt. A: Pure Appl. Opt. 1, 1-14,1999
(3) DTI foresight: 6.2 Laser-enhanced materials processing
http://www.foresight.gov.uk/servlet/Controller?action=eipndisplaymenuarea&docid=511&filename=6_2.htm
(4) DTI foresight: 6.1 Biomedical and chemical manipulation
http://www.foresight.gov.uk/servlet/Controller?action=eipndisplaymenuarea&docid=511&filename=6_1.htm
(5) International Standards ISO 11145, ISO 13694, ISO 11146, ISO 15367 series

(6) “Generation of flat-top focused beams for percussion drilling of ceramic and metal” Coutts et al. ICALEO 2002, http://www.oxfordlasers.com/Industrial/uchi/papertophat.htm
(7) “Beam Focusability Factor-A New Monitoring Tool For Increased Profitability” Lawrence I Green Spiricon Inc “The Laser User” magazine of the Association of Industrial Laser Users Sept 2002
(8) “Femtosecond laser beam quality for percussion drilling” Jonathan Magee National Centre for Laser Applications, National University of Ireland, Galway, Ireland “The Laser User” magazine of AILU, Dec 2002

DELIVERABLES

Ref	Title	Start Date	End Date
1.3.1	Investigation of the requirements and development of facilities for traceable measurements for wavefront sensing	Apr - 04	Mar - 05
1.3.2	Provision of calibration facilities, service and transfer standards for phase front accuracy	Apr - 05	Mar - 07
1.3.3	Provision of calibration facilities and service for laser beam profiles, including the M2 parameter	Apr - 05	Mar - 07
1.3.4	Report on applicability of current atmospheric modelling for FSO and development of facility for FSO systems	Jan - 05	Mar - 07
1.3.5	Development of peak power measurement facility and intercomparison	Jan - 05	Mar - 07
1.3.6	Knowledge transfer for laser wavefront sensing, including writing of at least one scientific paper	Apr - 04	Mar - 07

3.1.4 Project 1.4 – Metrics for Displays Usability

INTRODUCTION

New display technologies are being used in increasingly hostile environments, for example mobile phones and laptops used outdoors, and displays are even being incorporated into domestic devices such as fridges. In addition a rapidly growing volume of displays is being used in automobile, marine and aeronautical applications. Some of these applications are safety critical (such as car speedometers). It is therefore essential that a measurement of readability or viewability be available to manufacturers, users and suppliers of these displays. With the increasing number of “sunlight viewable” display applications for use in street furniture and kiosk applications, there is a need to consider both safety standards for the absolute luminance of the emissive light sources used and measures implemented to counter glare.

In previous programmes the NMS has built up an understanding of the key issues relating to readability and viewability of displays, especially during the previous Photonics Metrology programme. Research based around human-display interaction has been undertaken and generated significant interest from the UK displays community. Studies were undertaken to investigate the principles of daylight readability of displays, sensitivity to contrast and pulsed displays.

The NMS currently maintains comprehensive calibrated measurement systems for displays. These systems are vital to ensure traceable measurement and the calculation of realistic uncertainty budgets for displays.

OBJECTIVES

- To maintain existing displays measurement services;
- To develop techniques for lifetime measurement and definition;
- To develop daylight readability models;
- To research into the visual comfort of pulsed displays.

RATIONALE

The worldwide electronic displays market in 2003 is estimated to be worth £35 billion, with the European market being £11 billion, according to Global Industry Analysts Inc "Global Strategic reports" May 2002.

The current NMS display measurement services supports a wide range of customers, from calibration of military displays, to automobile manufacturers and art galleries. The range of services offered is comprehensive and specialised, and usually NPL are the only supplier able to offer the required accuracy and traceability. It is therefore very important to maintain these facilities to support UK industry.

The proposed research activity in the project reflects priorities for measurement in the displays sector arising from widespread consultation with industry, including a workshop [1] and a survey [2] commissioned as part of a previous Photonics Metrology programme. It will build on existing knowledge through investigations into the perception of pulsed light sources, sunlight readable displays and display lifetime, thus allowing recommendations to be published which can assist display manufacturers, integrators and users in identifying the limitations of their displays. Examples of these limitations include:

- Increased pixel densities can lead to the danger of ambiguity and misreading.
- Many displays become unreadable in daylight or sunlight
- The use of high speed refresh field sequential colour illumination systems to create single display cell full colour displays will increase the presence of display artefacts that may be unpleasant to view, or possibly even dangerous for sufferers of epileptic type problems.
- Misrepresentation and/or misunderstanding of display lifetimes can lead to unneeded and costly maintenance, over-specification of the display and/or unexpected display failure.

Work on displays in this project will be closely integrated with and complementary to related work in the Optical Radiation Metrology programme.

(1) A Focussed Workshop on Displays Measurement Research and Industrial Requirements. NPL 14th May 2003

(2) NPL Open Report CETM 42 "A Study of the Measurement Requirements within the UK Displays Market Place" May 2003

DELIVERABLES

Ref	Title	Start Date	End Date
1.4.1	Maintenance of existing displays measurement services	Apr - 04	Mar - 07
1.4.2	Development of the definition and measurement of display lifetime	Apr - 04	Mar - 07
1.4.3	Development of daylight readability models	Apr - 04	Mar - 06
1.4.4	Research into the visual comfort of pulsed displays over 60Hz, for both foveal and peripheral vision	Apr - 06	Mar - 07
1.4.5	KT activities for displays metrology including writing of at least two scientific papers	Apr - 04	Mar - 07

3.2 Theme 2 – Photonic Communications

Under this theme the measurement services and capabilities developed in previous programmes to support the optical telecommunications sector will be maintained and where necessary incremental developments will be made. In addition work will be undertaken to develop measurement capability applicable to the range of broadband access technologies essential to ensure full use of the optical telecommunications infrastructure.

3.2.1 Project 2.1 – Measurement Infrastructure for Optical Telecommunications

INTRODUCTION

Over the course of previous programmes, the NMS has developed an extensive capability to support the measurement requirements of the optical telecommunications industry, particularly the long haul sector using predominantly single mode fibre. Although this industrial sector is currently in recession, there is no doubt that high capacity optical networks will have a major and growing impact in the future, both economically and socially. Technology developed primarily for optical telecommunications will also find applications in more generic optical storage and manipulation of information. Feedback from industry is that capability is in general adequate for the needs of the period of this programme and probably sometime beyond it.

OBJECTIVES

- To maintain the measurement capabilities and services necessary to support the optical telecommunications sector;
- To reduce the proportion of Photonics Metrology programme activity in this area through improved efficiency and removal of support for little used services;
- To make improvements to measurement capability where necessary.

RATIONALE

The UK NMS has a perhaps unique range of capabilities in measurements for optical telecommunications. Despite the current slow down in the market for high capacity networks, the amount of data being carried over networks is continuing to grow steadily and high capacity networks will continue to be vital to both economic success and improved quality of life. Therefore current NMS capabilities should be maintained and in a limited number of cases enhanced. The measurement services to be maintained for optical fibre and components are:

- Chromatic dispersion
- Mode field diameter
- Effective area
- Spectral attenuation
- Cut-off wavelength
- Polarisation mode dispersion (PMD)
- Numerical aperture
- Optical length

- Attenuation coefficient uniformity
- Geometry
- Polarisation dependent loss
- Polarisation extinction ratio
- PMD in restricted bandwidth

For test equipment the services to be maintained are:

- Fibre optic power meters
- Optical spectrum analysers
- Wavelength meters

Experience during the previous programme has shown that access to capability and understanding of measurement via the NMS is often of greater value than a specific calibration service. Two examples are non-linear properties of optical fibres and the characterisation of optical fibre amplifiers. In such cases whilst a capability and understanding of measurement will be maintained, full measurement services will no longer be supported. Specifically the services that will not be supported are:

- Characterisation of optical fibre amplifiers
- Non linear parameters
    - n_2
    - SBS
    - SRS

The recent adoption of a saturated acetylene absorption line around 1550nm as a primary wavelength reference provides direct traceability in this wavelength region. The incorporation of a realisation of this reference developed under the NMS Length Metrology programme will simplify and improve the traceability route for wavelength standards made available to the optical telecommunications sector through the Photonics Metrology programme.

The latest generation of measurement instruments is increasingly making use of an application programming interface (API) in place of well established means for computer control of instruments such as GP-IB and RS232. A standard API could be used, for example in internet enabled measurements, but also more generally in instrument control. This work will be undertaken in collaboration with the SS*f*M programme.

DELIVERABLES

Ref	Title	Start Date	End Date
2.1.1	Maintenance and enhancement of measurement services and existing capabilities for optical fibre, wavelength standards and test equipment for optical telecommunications	Apr - 04	Mar - 07
2.1.2	Development of a standard API for instrument control	Jul - 04	Mar - 07
2.1.3	Knowledge transfer for optical telecommunications, including writing of at least four scientific papers	Apr - 04	Mar - 07

3.2.2 Project 2.2 – Measurements for Optical Datacomms Technologies

INTRODUCTION

Despite the present economic conditions, digital data transmission constitutes the bulk of the growth of information traffic worldwide. Telecommunication and data communication (Datacomms) networks can be divided into; long haul, Metro-networks/Wide Area Networks and access technologies/Local Area Networks. The overcapacity in the long-haul networks will be used within the lifetime of this programme but no significant expansion is expected in this area during the life of the proposed programme

In order to realise the full benefits of the highly developed optical backbone, emphasis is being switched to the development of effective access technologies. Access technologies and LAN (local area networks) are high volume/low cost, highly price sensitive areas and it is likely that a variety of different solutions will be adopted, e.g. copper, fibre-to-the-kerb, fibre-to-the-home, RF or wireless LAN as appropriate in each case, to minimise deployment costs.

Data rates to individual users are currently 10/100 Mb/s but are not expected to exceed 1 Gb/s in the short term. For Networks, data rates of 1 Gb/s are currently being deployed and components for 10 Gb/s are available for deployment.

To support the deployment of such networks there is a requirement for measurement in the optical domain of parameters relevant to the effective transmission of data, such as jitter and the effects of optical/electrical (OE) and electrical/optical (EO) conversion. Work in this area would be complementary to work already prioritised in the Electromagnetic Metrology programme.

OBJECTIVES

- To provide measurement support and UK National Facilities for the validation of data communications equipment for manufacturers and installers;
- To support UK industry through the adoption and improvement of international specification standards for Datacomms testing.

RATIONALE

The Information and Communications Technology (ICT) sector worldwide is expected to grow from £38 billion in 2002 to £45 billion by 2005 [1] with a European market of £600 million for test and evaluation in this area [2]. The Government's Foresight studies suggest policies must be designed to achieve internationally agreed open standards in electronics, computing and telecommunications [3]. This proposed project will support the aims of this suggested government policy.

Wide consultation with industry through NMS user clubs such as FOToN UK, professional bodies, and instrument manufacturers has identified NMS measurement support for access technologies including Datacomms to be important. As work on the data transmission aspects of such networks is relatively new and the technologies are rapidly evolving the NMS and industry have a limited understanding of the relative importance of current and emerging

measurement issues in this area. Hence this proposal has some built-in flexibility for prioritising and maximising the impact of the Datacomms work via the proposed industry steering group.

Establishing appropriate capabilities within the NMS will enable instrument manufacturers and users to have confidence in such measurements. This will provide industry with practical and effective support at the design, verification and manufacturing stages of systems. The main dissemination route for the results of this project will be through measurement capabilities and advice to industry through NMS measurement clubs, publications and input to standardisation bodies working in this field. The techniques in the project are leading edge so parts of the dissemination will be through scientific publications and conferences.

The main beneficiaries of this project will be network operators, system and component manufacturers, maintenance companies and test instrument manufacturers. It is anticipated that parts of this project will be undertaken in collaboration with industry to ensure that the project is focused on industry priorities and to maximise the impact of the work.

(1) BT Group, 28 November 2002,
http://www.btplc.com/Investorcentre/IndustryAnalysts/Servicesforanalysts/index.htm
(2) BT Exact, 12 November 2002,
http://www.btexact.com/whatsnew/newsreleases?doc=42703
(3) "Let's get Digital" Foresight report, Dec 2000,
http://www.foresight.gov.uk/servlet/Controller/ver=170//LetsGetDigital.pdf

DELIVERABLES

Ref	Title	Start Date	End Date
2.2.1	Report on the assessment of measurement requirements for optical datacomms	Apr - 04	Aug - 04
2.2.2	The development of a measurement infrastructure and knowledge base for optical datacomms	Aug - 04	Mar - 07
2.2.3	Knowledge transfer for optical datacomms including the writing of at least one scientific paper and attendance and presentation at two conferences	Apr - 04	Mar - 07

3.2.3 Project 2.3 – Measurements for Broadband Access Technologies

INTRODUCTION

Despite the present economic conditions, digital data transmission constitutes the bulk of the growth of information traffic worldwide. Telecommunication and data communication (Datacomms) networks can be divided into; long haul, Metro-networks/Wide Area Networks and access technologies/Local Area Networks. The overcapacity in the long-haul networks will be used within the lifetime of this programme but no significant expansion is expected in this area during the life of the proposed programme

In order to realise the full benefits of the highly developed optical backbone, emphasis is being switched to the development of effective access technologies. Access technologies and LAN (local area networks) are high volume/low cost, highly price sensitive areas and it is likely that a variety of different solutions will be adopted, e.g. copper, fibre-to-the-kerb, fibre-to-the-home, RF or wireless LAN as appropriate in each case, to minimise deployment costs.

The successful deployment of these networks requires the establishment of techniques for the characterisation of multimode optical fibres, both silica and polymer. Such fibres are certain to play a significant role in the delivery of broadband access to homes and small businesses as well as finding growing applications in the aviation, automotive and other sectors.

OBJECTIVES

- To establish and provide UK national traceability for the characterisation of multimode silica and polymer optical fibres (POF);
- To support UK industry through the adoption and improvement of international specification standards for multimode fibre measurements, particularly in the emerging area of polymer optical fibres.

RATIONALE

The Information and Communications Technology (ICT) sector worldwide is expected to grow from £38 billion in 2002 to £45 billion by 2005 [1] with a European market of £600 million for test and evaluation in this area [2]. The Government's Foresight studies suggest policies must be designed to achieve internationally agreed open standards in electronics, computing and telecommunications [3]. This proposed project will support the aims of this suggested government policy.

The use of Polymer Optical Fibre (POF) technology is relatively new but it is already finding applications such as automotive, consumer electronics, industrial controls and interconnections. Currently the worldwide market for POF data communications is forecast to grow from £319 million in 2002 to more than £1.2 billion in 2006 [4]. The UK has some 20 academic and other organisations that are developing POF technology and competing for a share of this market place [5].

The profitable use of POF technology requires effective standardisation. This has already been demonstrated in the automotive sector by the adoption of the MOST standard and this approach should be adopted for other areas such as Datacomms. It is recognised by industry experts [6] that consortia such as the POF trade organisation in the USA and POF consortium in Japan facilitate this process. To safeguard UK interests, it is important that the UK has a credible voice in this international arena. This NMS project will support UK participation in establishing a European equivalent. The credibility of that input will result from the practical experience gained in developing measurement techniques, thus enabling the successful introduction of this new technology.

Wide consultation with industry through NMS user clubs such as FOToN UK, professional bodies, and instrument manufacturers has identified NMS measurement support for access technologies including multimode and POF to be important. The expertise gained through

previous NMS programmes has enabled a good understanding of the likely measurement requirements for multimode and POF optical fibres and these are detailed in the deliverables.

The main dissemination route for the results of this project will be through measurement capabilities and advice to industry through NMS measurement clubs, publications and input to standardisation bodies working in this field. The techniques in the project are leading edge so parts of the dissemination will be through scientific publications and conferences.

The main beneficiaries of this project will be network operators, system and component manufacturers, maintenance companies and test instrument manufacturers. It is anticipated that parts of this project will be undertaken in collaboration with industry to ensure that the project is focused on industry priorities and to maximise the impact of the work.

(1) BT Group, 28 November 2002,
http://www.btplc.com/Investorcentre/IndustryAnalysts/Servicesforanalysts/index.htm
(2) BT Exact, 12 November 2002,
http://www.btexact.com/whatsnew/newsreleases?doc=42703
(3) "Let's get Digital" Foresight report, Dec 2000,
http://www.foresight.gov.uk/servlet/Controller/ver=170//LetsGetDigital.pdf
(4) "POF market and technology assessment", May 2003, Information Gatekeepers Inc.
(5) "POF – A brief review of their development and a study of POF measurements", D Kalymnios, University of North London, NMS Photonics Programme report, July 2002
(6) Hans Poisel, Director of the POF Application Centre, Germany

DELIVERABLES

Ref	Title	Start Date	End Date
2.3.1	Development and provision of calibration services for silica and polymer multimode optical fibres under user specified modal launch conditions including spectral attenuation, bandwidth and NA	Apr - 04	Mar - 07
2.3.2	Knowledge transfer for multimode access technologies, including writing of at least one scientific paper and attendance/presentation at two conferences	Apr - 04	Mar - 07

3.2.4 Project 2.4 – Modelling and Measurements for Optical Networks

INTRODUCTION

Following recent developments in industry, the capability to reliably predict network and subsystem performance is increasing. Cost pressures and a developing change in the structure of the industry, away from vertical integration are driving these requirements. In certain areas those installing or upgrading networks do not always have the information they require to realise the full potential of a network or to understand its limitations.

OBJECTIVES

- To develop an understanding of the relationship between the measurements made on individual components and the performance of networks incorporating such components;
- To disseminate information to enable both the development of existing networks and deployment of new networks.

RATIONALE

Studies comparing the theoretical capacity of networks, given the nominal fibre and equipment performance, with the realised capacity derived from measurements on installed systems will be undertaken to address the issues of relating network performance to measurements of fibre and components. Many of the measurements made on fibres and components are done using continuous sources, although in practice they will be used with pulsed sources, in order to carry data. This leads to high peak powers in networks, and the effect of non-linearities on network performance are therefore important and should be incorporated into models of network performance. This project will draw on work produced in other parts of the programme, for example projects on time resolved measurements (Datacomms) and component characterisation, and will be undertaken in close collaboration with organisations able to provide access to optical networks, perhaps with established experience in network modelling.

As existing networks are developed through the addition of equipment, not necessarily sourced from the original installer, there is an increasing risk of unexpected performance outcomes. Therefore it is important that the results of this project are effectively disseminated and that there is awareness in industry of the support available through the work of the programme.

DELIVERABLES

Ref	Title	Start Date	End Date
2.4.1	Development of a capability to advise industry on specifications, measurements and models needed to reliably predict the performance of installed systems	Apr - 04	Mar - 07
2.3.2	Knowledge transfer for network modelling, including the writing of at least one scientific paper	Apr - 04	Mar - 07

3.3 Theme 3 – Photonics for Medicine and Biology

Photonic techniques are making an increasing impact in the medical sector and related biological applications. As well as using photonic techniques for diagnosis and treatment, the medical sector is increasingly reliant on displays, again for use in both diagnosis and treatment. This theme will build on a range of capabilities developed within the NMS to provide the measurement infrastructure essential to allow the adoption of novel techniques in this safety-critical and tightly regulated sector.

3.3.1 Project 3.1 – Imaging with Displays

INTRODUCTION

Electronic techniques are being increasingly applied in the medical and other sectors for image capture, image processing and image display. Digital imaging has clear advantages over traditional hard copy images like X-ray films, particularly in terms of the sharing of images between staff and even amongst different hospital locations. A great deal of work is being undertaken in the area of reliable, clear digital images; for example a major project is underway that has the aim of having a totally electronic picture recording and archiving system by 2006 across the National Health Service (PACSnet). This project within the Photonics Metrology programme will look at the metrological requirements for medical imaging and aims to share best practice in calibration of displays for medical images.

Activity in this project will be closely co-ordinated with relevant work in the Optical Radiation Metrology programme.

OBJECTIVES

- To investigate the measurement parameters that must be defined to ensure the suitability of displays for medical applications;
- To disseminate best practice to ensure the proper use of displays in critical medical applications.

RATIONALE

3d displays are finding increasing applications in the medical sector where the integrity of the image and the human response to it is critical. The assessment of the image quality of 3d displays is not well understood. Basic measurement capabilities are necessary to underpin work to fully assess the performance of 3d displays. The capabilities required are for basic factors such as dimensional and colour accuracy.

For applications such as remote surgery the human interaction with the display is critical to the well being of the patient. In other applications such as video games, the comfort of the viewer is of key importance. An evaluation of the measurement parameters that determine the integrity and comfort of a 3d image is required.

Electronic displays are increasingly being used in medical applications in place of traditional images such as X-ray film. The advantages are in the ease with which information can be shared and stored. However, the screen quality used to display medical images is of

fundamental importance to the overall effectiveness of diagnosis. It is vitally important that softcopy images seen on a display screen do not compromise the original image quality and lead to misdiagnosis. The suitability of displays for medical imaging may depend on high resolution, true colour representation and spatial accuracy of the displayed image. The importance of, and the measurement requirements for, assessing the importance of true colour imaging, readability of grey scale images, pixel count and the effect of ambient lighting will be investigated.

DELIVERABLES

Ref	Title	Start Date	End Date
3.1.1	An investigation into human interactions with 3d imaging systems	Apr - 04	Jul - 06
3.1.2	An assessment of the measurement requirements of displays used for medical imaging and implementation of suitable solution(s)	Apr - 04	Mar - 07
3.1.3	Knowledge transfer for medical displays including writing of at least one scientific paper	Apr - 04	Mar - 07

3.3.2 Project 3.2 – Photonic Techniques for Medical Diagnosis

INTRODUCTION

The use of photonics and optical radiation in medical applications is set to increase dramatically over the next few years [1]. This leads to some exciting new opportunities to apply the experience gained by the NMS within the area of photonics, in particular to two biotechnology techniques: Surface Plasmon-Resonance (SPR) and Optical Coherence Tomography (OCT).

There are few techniques that can provide information about the binding of biological molecules. Probably the most widely applied are the techniques of Isothermal Calorimetry (ITC) and Surface-Plasmon Resonance (SPR) [2,3]. Indeed, SPR has been so successful as a measurement technique for this application; it is now viewed as the “gold standard” for the measurement of biological interactions and particularly interaction kinetics. Surface-Plasmon Resonance for biomolecules relies on the measurement of the changes in refractive index and film thickness that occur when a biomolecule interacts with an immobilised receptor molecule. In order to increase the sensitivity of the technique to these binding interactions, this receptor molecule is bound directly to a gold surface, which allows the refractive index changes to couple with surface plasmons within the gold layer. With the addition of microfluidics to allow sample delivery to the surface, these changes can be monitored in real time to provide reaction kinetics and enable association/dissociation constants to be measured. These parameters provide an indicative measure of the binding interactions, and therefore provide a mechanism to monitor the fidelity of interaction, perform screening for interactions and allow the biological activity of some classes of biomolecules to be measured without the requirement to undertake cell-based or animal assays.

The current standard for high-resolution medical imaging is ultrasound, which detects the density of different tissue from backscattered sound waves. OCT uses infrared light waves

that reflect off internal microstructures within biological tissues. The technique is based upon optical low coherence reflectometry, which is used to investigate losses and reflections inside photonic components. It essentially analyses the interference pattern generated by two arms of an interferometer. Imaging depth is limited to 0.5 – 3 mm [5] in opaque tissue due to optical scattering of the near infrared light source operating at around 800 nm. By using a low coherence optical source such as a broadband LED, high depth resolution (~10 μm) can be attained. From the interference patterns obtained at each lateral and longitudinal position a 3-dimensional image of the sample can be built. Variations of the technique exist such as Doppler OCT for the measurement of flow velocity, polarisation-sensitive OCT that can measure depth resolved birefringence and spectroscopic OCT for the determination of target chromophore distributions. Parallel OCT has been developed that allows high-speed image capture for 3d video imaging. Although OCT has many potential medical imaging applications it has already found a significant use in ophthalmology. Current research has applied OCT to perform *in vivo* biopsy for the detection of many diseases including early stage cancer. However, higher resolution is required.

Both of the above techniques have a reliance on the knowledge of optical parameters, such as refractive index profiles, as they vary throughout the depth of a sample, and the changes to these parameters as reactions take place. As part of the refractive index project within the previous NMS programme work has already taken place on the parallel problem of refractive index measurements of thin films, and in this project the work will expand to look at 3d refractive index profiling of microstructures. As part of an NPL SR project the Reference Refractometer has been modified so that basic SPR measurements are possible. The Long Pass Interferometer, which was constructed to investigate optical components for telecoms provides the basis of an OCT instrument. This project takes the knowledge and experience developed in the areas of refractive index measurement, and component measurement for telecoms, and applies it to the issues of traceability and reliability that currently surround, and limit, the use of the SPR and OCT techniques.

OBJECTIVES

- To investigate the areas of uncertainty affecting the reliability of SPR and OCT results;
- To investigate possible traceability chains for both SPR and OCT linking into existing research areas within the NMS;

RATIONALE

Surface-Plasmon Resonance (SPR) has been used as the *"gold standard"* for protein-protein, protein-DNA and protein-small molecule interaction measurements since its introduction in the late 1980s. There is range of commercially available instrumentation, with BIAcore being the market leader. The SPR technique is designed to give precise information about the binding constant between two species, which is related to biological activity. The technique has therefore been adopted as an alternative to some biological assays, and as such is widely applied within the biotech and pharmaceutical industry, although currently lacks traceability, or indeed a clear understanding of the measurement requirements and uncertainties [7-9]. This has lead to doubt as to the validity of current SPR data and a requirement for standards and methodology development.

Optical Coherence Tomography (OCT) is an exciting new imaging technology finding applications in monitoring blood flow in human skin, early detection and diagnosis of malignant tumours and to monitor thermal damage all *in vivo*.[5,6]. Although a powerful technique that can include spectral, polarisation and phase resolution to add information, images are still only as good as the models from which they are computed. These models are again limited by the knowledge of the optical properties of inspected tissue (refractive index etc.). Data comparisons are therefore difficult since there are no standard artefacts such as calibrated tissue phantoms against which models can be tested. This will hinder the widespread use of OCT as a clinical technique. There are also a number of safety issues associated with the high power broadband sources used for the highest resolution OCT.

The lack of rigorous metrology in these areas, leading to doubts over measurement reliability, is a major barrier to the exploitation of these methods for applications that require regulation (for instance biopharmaceutical QC and diagnostics). This project will look at ways to bring metrology to these areas, thereby increasing confidence and allowing these techniques to progress and be used to their full potential. This has a direct impact on quality of life issues through the increased uptake of these technologies for drug discovery and economically through increased instrument sales.

The formulation of the work within the area of Surface-Plasmon Resonance has been carried out in conjunction with the formulation of the Measurements for Biotechnology Programme (2004-7). Project PM6 "Improved Comparability for Protein Interaction Measurement" seeks to perform inter-comparisons between a variety of different techniques (including SPR) used to look at protein interactions; the work in this project provides the infrastructure support for this process. Whereas this project seeks to investigate the instrumentation/physical-based aspects of the uncertainties within these measurements, the biological aspects will be handled within the MfB Programme. The SPR and OCT work packages proposed within this project have strong interlinks with the "Refractive Index" project (Project 1.1) within this Photonics Metrology programme.

The definition of the scope of this project is the result of input from a number of universities and companies and dissemination of results through this network will be one of the key knowledge transfer routes. The link between the Biotechnology and Photonics groups at NPL will also allow wide dissemination via measurement clubs, conventions and journals.

(1)*"Investigation of the Requirement for Photonics and Optical Radiation Measurements in Medical Applications"*, NPL Report CETM S136, P. Tomlins.
(2)*"New Choices for SPR"*, E. Zubritsky, Anal. Chem., pp 289A, April 1, 2000
(3)*"SPR of Ultrathin Organic Films"*, A. Frutos & R. Corn, Anal. Chem. pp 449A, July 1, 1998
(4)*"Ultrahigh Resolution and Spectroscopic OCT Imaging of Cellular Morphology and Function"*, Boppart, S. A. et al, Proc. Inter-Institute Workshop on In Vivo Optical Imaging at the National Institutes of Health. Ed. Gandjbakhche AH. September 16-17, pp. 56-61, 1999.
(5)"*Phase-resolved Optical Coherence Tomography and Optical Doppler Tomography for Imaging Blood Flow in Human Skin with Fast Scanning Speed and High Velocity Sensitivity*", Zhao, Y. *et al*, Optics Letters, Vol. 25, No. 2, *pp* 114 – 116, January 2000.
(6) "*Imaging Thermally Damaged Tissue by Polarization Sensitive Optical Tomography*", de Boer, J. F. *et al*, Optics Express, Vol. 3, No. 6, *pp* 212 – 218, September 1998.
(7)*"Surface Plasmon Resonance (SPR) for Biosensing"*, C.Lawrence & N. Geddes, Handbook of Biosensors and Electronic Noses: Medicine, Food and the Environment, CRC Press Inc., 1997
(8)*"Analysis of Molecular Recognition using Optical Biosensors"*, R.J.Leatherbarrow & P.R.Edwards, Current Opinion in Chemical Biology, 1999, 544-547

(9)*"Protein microarrays and proteomics"*, G.MacBeath, Nature Genetics, Suppl V32 (Dec 2002), pp526-532.

DELIVERABLES

Ref	Title	Start Date	End Date
3.2.1	An assessment of the measurement uncertainties affecting SPR and OCT measurements, enhancement of SPR facilities for the measurement of commercial SPR chips and a measurement intercomparison with industry and universities	Apr - 04	Mar - 07
3.2.2	Provision of OCT measurement and traceability facility	Oct - 04	Mar - 07
3.2.3	Knowledge transfer for medical displays including writing of at least one scientific paper	Apr - 04	Mar - 07

3.4 Theme 4 – Generic Knowledge Transfer

Under this theme Knowledge Transfer will concentrate on the dissemination of the results of the programme via NMS Club meetings, regional clusters, seminars, workshops, training courses, industry groups, technical and trade publications and conferences. The theme will also facilitate the exchange of ideas between those working on and formulating NMS programmes and the end users of the programme outputs via secondments, guest workers and collaborations.

3.4.1 Project 4.1 – Presentation of Photonic Programme Outputs

INTRODUCTION

This project aims to disseminate the outputs of the NMS Photonics Metrology as widely as possible through a range of activities that are detailed below. This project both supports and complements the knowledge transfer activities detailed in each of the proposed technical projects.

OBJECTIVES

- To effectively and widely disseminate the outputs of the NMS Photonics Metrology programme;
- To support and complement the KT activities within each technical project.

RATIONALE

The technical work undertaken in the programme is only of value if the results of it are effectively disseminated to the target users in industry. The methods by which this is achieved can be wide ranging.

Club activities provide direct contact between the programme and its users in industry, academia and other NMIs. The club forum allows successful transfer of programme knowledge to users and a friendly environment to encourage feedback. There are many clubs at NPL covering a wide range of industrial sectors and it is intended that these clubs will be used to focus on a much wider range of industries using photonic technologies.

Even during a period of recession, FOToN UK, primarily focussed on the optical telecommunications sector has been well supported. It will continue to provide a forum for knowledge transfer in this sector, but will also be broadened in scope to support the application of the technologies developed for optical communications to other sectors.

Current government policy has led to the development of strong regional groups in the photonics sector. Targeting KT activities on these groups is an effective way of reaching a wide range of companies working across the spectrum of photonic technologies. It would be of particular benefit to SMEs and start-ups that cannot afford the cost of time and travel to national or sector based meetings. This activity will also support the aims of project 4.3 by giving those working on the programme the opportunity to learn at first hand the issues concerning industry.

Popular promotional activities such as attending industry based workshops and meetings, exhibiting at trade exhibitions and writing in trade journals increases the outreach of dissemination to a much wider industrial audience of technicians, engineers and managers that would otherwise not be exposed to the work carried out in the programme.

Newsletters have proved a very useful and successful way of reaching a wide audience and motivating them to visit the NPL website. They are also useful handouts for visitors. It is not our intention to develop a newsletter specifically for photonics but to utilise existing NPL newsletters. This will limit costs but also ensure that we are targeting new industry sectors with relevant photonic technology news without bombarding them with too much literature.

There is clearly a requirement to continuously maintain and extend the photonics part of the NPL website to ensure that the widest audience is reached. Links to the FOToN website will be maintained ensuring international coverage.

Websites such as the IOP's optics.org and fibres.org have a very large international audience. Featured company status provides facilities for companies to advertise and present news and articles on new facilities and products on a monthly basis. This would provide access to a new and wider audience.

Active involvement in national and international conferences and the production of technologically relevant peer reviewed papers is a key mechanism of demonstrating the UK NMS's leading position in the field of photonic metrology and for disseminating information about advances made in the Photonics Metrology programme.

DELIVERABLES

Ref	Title	Start Date	End Date
4.1.1	Enhancement and broadening of club activities by attendance and organisation of four interclub meetings and two meetings per annum for FOToN	Apr - 04	Mar - 07
4.1.2	Delivery of Programme outputs through meetings, workshops, trade journals and peer reviewed technical papers for each project. Attendance of at least four meetings/workshops/regional group seminars per annum, delivery of at least one trade journal article per annum and co-ordination of scientific papers through project KT	Apr - 04	Mar - 07

3.4.2 Project 4.2 – Dissemination of Good Measurement Practice

INTRODUCTION

To complement project 4.1, this project concentrates on targeted and where possible, interactive dissemination of best measurement practice in specific technical areas. Again the activities in this project will complement and support the knowledge transfer deliverables of technical projects.

OBJECTIVE

- To disseminate good measurement practice to targeted audiences in specific technical areas.

RATIONALE

Good practice guides are an effective way of explaining and demonstrating the major elements of traceability, calibration and measurement for a specific technology/technique. This method of dissemination has been very successful in the past, allowing measurement laboratories and industrial users to adopt good design approach and measurement practice.

In the current and previous programmes liaison with other NMIs has led to the adoption of best measurement practices by standardisation bodies and it is intended that this should continue.

The industrial requirement for training in best measurement practice for photonics technologies has varied over recent years. However, with the uptake of new technologies in different industrial sectors, the demand for training is on the increase again. The NMS will provide support for external training courses through the provision of supporting material.

The existing telephone/fax/e-mail technical support provided for customers is a key mechanism for enabling knowledge and expertise used in this and previous programmes to solve real technical problems in industry as well as raising the awareness of the wide range of work carried out. It promotes the use of best measurement practice. It is proposed that this continues but efficiency measures be put in place to ensure the process is run smoothly within a rapid response time.

DELIVERABLES

Ref	Title	Start Date	End Date
4.2.1	Promotion of best measurement practice through delivery of two best practice guides, input to International and national standards and support to external training courses	Apr - 04	Mar - 07

3.4.3 Project 4.3 – Improvement of Technology Flow to and from NPL

INTRODUCTION

The aim of this project is to encourage direct engagement of those tasked with delivering the Photonics Metrology programme with the end users of the programme outputs and those in industry, academia and other NMIs that can both benefit from and inform the future development of the programme. This project will complement the work of the other projects in this theme.

OBJECTIVES

- To encourage and facilitate contact between those delivering and those using the outputs of the Photonics Metrology programme;
- To utilise opportunities such as standards bodies and conferences to increase the flow of information to inform the development of photonics metrology;

RATIONALE

Direct interaction and collaboration between the photonics team and workers in other research or calibration laboratories, scientists and engineers in industry is one of the most effective ways of improving the information and technology flow both in and out of NPL and others delivering the programme. Short term secondments of key scientists to other research/calibration organisations leads to a better understanding of the different techniques and methodologies used, broadens the technical outlook of the scientists and benefits the host organisations by the implementation of improved methods and procedures. Technical collaborations and visits to industry enable an appreciation of real life problems and benefits future programme development and establishes personal networks for future interaction, to the benefit of industry and the NMS.

Representation on international metrology committees is an effective method of ensuring that the UK plays an active part in influencing changes and developments in international standards and regulations that may affect industry interests and competitiveness. It is also a mechanism for identifying technical/regulatory areas where additional guidance or training may be required for industry.

In the past NPL has provided strong support for the European COST activity, in organising the biennial conference OFMC. This conference has always been well attended and has been an important arena for international discussion of research and measurement within photonics technologies, providing a good technology flow both in and out of NPL and the Photonics Metrology programme. There is currently no more funding available from the COST initiative. Therefore it is proposed to continue supporting this conference and organise at least one during the period of the programme.

DELIVERABLES

Ref	Title	Start Date	End Date
4.3.1	Develop collaborations with at least four universities and companies and encourage two short term secondments of NPL staff to industry and other NMIs	Apr - 04	Mar - 07
4.3.2	Representation and support on relevant national and international metrology and standardisation committees	Apr - 04	Mar - 07
4.3.3	Organisation of at least one national/international conference on photonic technologies	Oct - 04	Sep - 05

3.5 Theme 5 – Programme Management and Development

3.5.1 Project 5.1 – Programme Management

INTRODUCTION

The NMS Photonics Metrology programme provides the top-level measurement infrastructure for traceable measurements for photonic technologies the UK. Delivery of the programme relies on both NPL and other organisations.

Successful, efficient and economical delivery of projects in the programme relies on effective management. This depends on systematic monitoring and control of progress and resources. Co-ordination of the technical work between projects is essential to ensure that no delays are propagated through the programme due to interdependencies. Programme management also provides the interface between project managers and the customer, collating progress reports from project managers and contractors.

OBJECTIVES

- To deliver the Photonics Metrology programme on time, to budget and to the required quality;
- To ensure continuous and reliable access by UK users to the top-level metrology infrastructure for photonics metrology;
- To ensure effective and efficient co-ordination of project partners and subcontractors working on the programme;
- To encourage co-funding of the programme (cash or in-kind) by other organisations, to enhance the impact and influence of the programme;
- Provision of regular progress reports to NMSD, with recommendations on any need for programme amendments resulting from changing circumstances;
- Provision of programme-related information, data and advice to NMSD, as required.

RATIONALE

This project provides overall coordination functions for the NMS Photonics Metrology Programme, monthly and annual reporting on progress, and general liaison with NMSD. It includes strategic discussions with other NMIs about European and worldwide provision of standards for photonics metrology.

Within the core Programme carried out at NPL, the Programme Manager plans, manages, and coordinates manpower resources, non-staff resources and capital requirements needed to ensure Programme is delivered on schedule, liasing with NMSD as necessary.

At project level, project managers are expected to incorporate necessary financial, operational, and quality management tasks within their technical projects.

An important requirement of this project is regular reporting of progress to NMSD. Progress is monitored using the appropriate project management tools and through regular project reviews. The outputs of the monitoring process are fed into monthly invoices and reports,

annual reviews and annual reports to NMSD and the appropriate Measurement Advisory Committee (MAC) Working Group.

DELIVERABLES

Ref	Title	Start Date	End Date
5.1.1	Programme management to include monitoring meetings and science strategy reviews	Apr - 04	Mar - 07
5.1.2	Annual reporting including delivery of annual and impact report	Apr - 04	Mar - 07
5.1.3	Co-ordination with and monitoring of subcontractors within the programme	Apr - 04	Mar - 07

3.5.2 Project 5.2 – Integration Activities

INTRODUCTION

As a market sector focussed programme within the NMS, Photonics Metrology is both dependent on the outputs of other NMS programmes and to varying degrees provides input in defining certain activities within the unit science programmes. The degree of activity in photonics metrology varies widely across NMIs. To ensure effective delivery of the Photonics Metrology programme close liaison is required with both the other programmes in the UK NMS and other NMIs.

OBJECTIVES

- To maintain close links with other NMS unit science programmes;
- To liase with NMS SS*f*M and KT programmes;
- To co-ordinate activities with other NMIs.

RATIONALE

Much of the work within the Photonics Metrology programme is linked with basic research work that has or is currently being developed within the unit science NMS programmes. As a market sector focussed programme, the Photonics Metrology programme both draws on the output of other NMS programmes and provides outputs complementary to those programmes. Close co-ordination is required with relevant activities within the unit based science programmes. As is the case with all NMS science programmes, the Photonics Metrology programme should maintain close liaison with the NMS supporting programmes, SSfM and KT.

The support for photonics metrology varies significantly across NMIs. It is therefore particularly important that there is visibility and understanding of the capabilities of NMIs in this area.

DELIVERABLES

Ref	Title	Start Date	End Date
5.2.1	Co-ordination of input and export of technology to and from other NMS unit science, KT, MfB and SSFM programmes and other NMI's through monthly/quarterly meetings, telephone and email	Apr - 04	Mar - 07

3.5.3 Project 5.3 – Programme Formulation

INTRODUCTION

Formulation of the next Photonics Metrology programme requires a continual dialogue with industry and other users in the UK to determine future requirements for reduced uncertainties, broader measurement ranges or completely new and novel measurement services. It is also important to identify requirements that have been superseded or which can now be delivered on a purely commercial basis. Evidence to support the formulation of the new programme needs to be assembled and structured coherently, to enable DTI and its advisory group to prioritise the final content of the programme.

Focus group meetings, one-to-one discussions with companies / universities / public sector organisations, desk-based market research and the accumulated experience of the programme staff are the principal mechanisms employed to define present and future needs. This culminates in the organisation of the required work into a logical structure and the production of a draft programme for public comment. Following on from this a detailed costing and project definition activity is necessary before a review and prioritisation exercise conducted by the Photonics Working Group for NMSD.

OBJECTIVES

- To determine present and future requirements for photonics metrology in the UK;
- To produce a draft Photonics Metrology programme for public comment;
- Production of a final draft programme with deliverables and prices for review by NMSD and the Photonics MAC Working Group.

RATIONALE

Programme formulation starts with an Orientation phase, consisting of a wide-ranging assessment of the present and future needs for photonics metrology in the UK. This includes contact with existing users within the UK, reviews of relevant reports and areas identified in the government led technology foresight process, and discussion with trade organisations and industry representatives.

The output of the Orientation phase is discussed at an Orientation meeting, involving key industry representatives, DTI officials and senior programme staff. This meeting sets the agenda for the remainder of the formulation process.

The next phase is one of more detailed Information Gathering, involving focus group meetings, discussions at measurement club meetings, web-based questionnaires, and one-to-one meetings with companies and other users. It typically results in a set of requirements much larger than is affordable, which is then whittled down to around 115-120% of the affordable size, by discussion with the programme's Measurement Advisory Committee (MAC) Working Group. This draft programme is structured into themes and projects, and is released via the World Wide Web for public comment.

In a third phase, of Project Definition, the feedback from public comment is taken into account in refining the content of the programme, defining and pricing deliverables, discussing potential partnerships and sub-contracting options, and assessing risks and exploitation opportunities. A meeting is held of the MAC Working Group, to prioritise the contents of the draft programme and reduce it finally to an affordable size.

Advice and back up is provided to DTI, in taking the programme through the necessary DTI approvals processes.

DELIVERABLES

Ref	Title	Start Date	End Date
5.3.1	Orientation report	Jul - 05	Dec - 05
5.3.2	Consultation phase	Jan - 06	Aug - 06
5.3.3	Project definition document	Nov - 06	Feb - 07

4. Glossary

API	Application Programming Interface
BER	Bit Error Rate
CETM	Centre for Electromagnetic and Time Metrology (NPL)
COST	European Co-operation in the field of Scientific and Technical Research
cw	continuous wave
DTI	Department of Trade and Industry
DWDM	Dense Wavelength Division Multiplexing
EO	Electrical/Optical
FOToN UK	Fibre Optic Technology Network (NMS Measurement Club)
FSO	Free Space Optical Communication
GP-IB	General Purpose Interface Bus
IOP	Institute of Physics
IR	Infrared
KT	Knowledge Transfer
LAN	Local Area Network
M^2	Parameter describing the departure of energy distribution in a laser beam from an ideal Gaussian profile
MAC	Measurement Advisory Committee
MERA	Metrology in the European Research Area (EC funded devolution project)
MfB	Measurements for Biotechnology
MOST	Media Orientated Systems Transport
MProMS	Computer based system used to report progress on NMS programmes
n	Refractive Index
n_2	Non-linear Refractive Index
NIST	National Institute of Standards and Technology (USA)
NMI	National Measurement Institute
NMS	National Measurement System
NMSD	National Measurement System Directorate
NMSPU	National Measurement System Policy Unit
NPL	National Physical Laboratory
OCT	Optical Coherence Tomography
OE	Optical/Electrical
OFMC	Optical Fibre Measurement Conference
ORM	Optical Radiation Metrology
OTDR	Optical Time Domain Reflectometer
PMD	Polarisation Mode Dispersion
POF	Polymer Optical Fibre
PTB	Physikalisch Technische Bundesantalt (Germany)
RF	Radio Frequency
RGB	Red Green Blue
RS 232	Standard computer serial interface
SBS	Stimulated Brillouin Scattering
SME	Small / Medium Enterprise
SPR	Surface-Plasmon Resonance
SRS	Stimulated Raman Scattering
SS*f*M	Software Support for Metrology
TFT	Thin Film Transistor
UV	Ultra-violet
WAN	Wide Area Network