The 2003 – 2006 Electrical Programme

David Adamson and Bob Clarke

Centre for Electromagnetic and Time Metrology (CETM), National Physical Laboratory (NPL), Teddington, Middx, TW11 0LW, UK. E-mail: mailto:David.Adamson@npl.co.uk

Introduction

The objective of this session is to obtain input into the formulation for the forthcoming 3-year National Measurement System Programme for Electrical Metrology which is funded by the Department of Trade and Industry (DTI). The DTI funds several Programmes on a 3-year cycle in order to maintain and develop the UK's metrological infrastructure. Much, but not all, of this work is carried out at NPL and the objective of this is to ensure that industry and other beneficiaries have access to the measurement standards required at the level of accuracy which is required. The Electrical Programme is divided into two Themes: RF & Microwave and DC & Low Frequency. Another related programme is the Time Programme. Both these programmes are due to end at the end of September 2003 and the process of formulating the next programme, which will run from 2003 to 2006, is underway.

Part of the formulation process is to gather the input from industry and academia regarding the measurement standards which will be required in the next 5 years or so, the way in which the standards and associated technical knowledge should be transferred to the beneficiary communities, and to quantify the benefits that will arise from the provision of these standards. The objective of this session, therefore, is to obtain useful input into the formulation process. In this meeting we are focussing on the RF & Microwave aspects but input for the DC & Low Frequency or Time & Frequency aspects is also welcome. A separate programme for Photonics exists and this will be entering the formulation stage within the next few months so input to that is also welcome.

Background

The current NMS programmes support work in several areas which are relevant to workers in RF & Microwave and it is useful to give brief details of the existing programme as a background to the main objective, which is to identify what should be in the forthcoming programme. The main areas of work are as shown below:

Technical area	Work and outputs
CW Power	Provides calibration services for power sensors of all sorts from low frequencies (below 1 MHz) to 50 GHz in all the normal coaxial connectors with uncertainties in 7mm line from 0.25% at 10 MHz to 0.7% at 18 GHz and in waveguide from X band (8.2 to 12.4 GHz) with uncertainties of 0.9% to W band (75 GHz to 110 GHz) with uncertainties of 2.5%. Maintain the systems and standards to do this. Improve uncertainties of measurement. Improve frequency coverage. Participate in international intercomparisons.
Non-CW power	Research into traceability for non-CW waveforms such as GSM and CDMA. Calibration service is available for DECT and GSM. Includes research into traceability for such things as CCDF, crest factor, EVM ....
Medium power	System to provide calibrations at higher power levels. Maintain this system.
Noise source measurements	Calibration of noise sources from 10 MHz to 50 GHz in coaxial lines with uncertainties from 1% to 5% over the 10 MHz to 26.5 GHz range. Calibration of waveguide noise sources from 2.6 GHz to 100 GHz with uncertainties of 1.1% to 1.5% in the 33 GHz to 50 GHz band as an example. Maintain the systems to do this. Improvements to standards to provide lower uncertainty. Improvement to systems to provide better frequency coverage. Participate in international intercomparisons.
Amplifier noise measurements	Develop techniques to measure complex amplifier noise parameters, including cryogenic LNAs. Develop low frequency radiometer which can also be used for low frequency (<10 MHz) noise source calibrations.
Phase noise measurements	Methods of improving phase noise measurements. Develop phase noise capability for higher frequencies (above 110 GHz).
Antenna noise	Methods to measure noise of systems where the LNA and the antenna are integrated (eg mobile phone antennas). Methods to measure G/T for large ground station antennas.
PIM (Passive InterModulation)	Develop, in collaboration with industrial partner, an improved understanding of PIM measurement uncertainties. Hope to launch UKAS PIM measurement service in industry (not at NPL).
RF impedance	Measurement facilities extended downwards to 30 kHz Calibrations not using Shorts, Opens and Loads (SOL) Automatic adaptive calibration to minimise uncertainty
Microwave impedance	Measurement facilities extended to 110 GHz Coaxial 2.4 mm and K-connectors supported Many customers from around the world
Technology, and knowledge, transfer	Biannual ANAMET meetings Power splitter measurement comparisons Training course on ANA uncertainties
Internet calibration	ANA facility launched Extended to 26.5 GHz in coax (Type-N, APC-7 and 3.5 mm) Extended to 40 GHz in waveguide

Technical area	Work and outputs
Vector measurements uncertainty analysis	Rigorous treatment of uncertainties for ANAs Modelling and simulation techniques for ANA uncertainties Applicable to multiport ANAs
Attenuation in coaxial lines	Providing measurement services for attenuation in most common 50 Ω coaxial lines from 10 kHz to 50 GHz. The dynamic range and uncertainty are frequency dependant and are summarised in the table in Paper 1. Current activities include extending the dynamic range and reducing measurement uncertainties.
Attenuation in Waveguide	Providing measurement services for attenuation in most common rectangular waveguide from 2.4 GHz to 110 GHz. Supported waveguide sizes, dynamic range and uncertainty are summarised in the table in Paper 1. Current activities include automating the millimetre wave systems to improve the service in WG25 and WG27.
Electromagnetic Materials Measurement	Extension of thin film dielectric measurements (10 to 100's of micrometres) to the whole of the RF & MW range. Traceable variable temperature measurement facilities for dielectric resonators and laminas at microwave frequencies. Enhancement and improvement of uncertainties for re-entrant cavity and open resonator measurements. Publication of data on high loss dielectric reference liquids. Running the EMMA: Club, 6-monthly meetings, Technical Notes published, measurement intercomparisons.
SAR Standards	Facilities for calibrating implantable SAR probes at frequencies close to 400, 900 and 1800 MHz, enabling probe sensitivity, isotropy linearity and spatial resolution to be measured traceably. Facilities for calibrating SAR liquids.
Electromagnetic field mapping	Enhancement of Optically Modulated Scatterer facilities: 1-metre cube scan volume, new smaller 5-mm dipole sensor. Extend facility to cover field strength measurements close to dielectrics, including measurement of surface waves Miniature and robust electro-optic sensors for mapping RF & MW electric fields and for use as travelling standards
Microwave Antennas	Extend the frequency range upwards to 110 GHz and down to 250 MHz
Calibration of large microwave antennas	Implement spherical near-field scanning
Microwave EMC antennas	Implement swept frequency measurements for N-Type fed antennas from 1 to 18 GHz.
Power Flux Density and Field Strength	Improve measurement uncertainties in the range 250 MHz to 2.45 GHz
On-Wafer	1. Construction of NPL fully automated on-wafer probing station including TRL measurements to 110 GHz in three bands (0-50, 50-75, 75-110 GHz). 2. Quantification of uncertainties and variations in measurement on two probe and ISS manufacturers for SOLT, LRM and LRL techniques. 3. Initial design of NPL standard with Glasgow University on GaAs substrate.

Technical area	Work and outputs
Laser Power and Energy	Coverage at particular wavelengths from the UV (248 nm) to the Infra Red end of the spectrum (10.6 μm). Current projects involve construction of new secondary standards to improve usability and reduce measurement uncertainty. Provide traceability for the fibre optic power measurements. Constructing improved standards to allow higher fibre optic powers (1.5 μm wavelength) to be measured traceably than has previously been possible. Participate in international intercomparisons.
Antenna factor, gain and patterns	Provide calibration services for rod antennas 100 Hz to 100 MHz, and tuned dipoles, biconical, log-periodic and bilog antennas in the range 20 MHz to 5 GHz to uncertainties as low as ±0.3dB. Measurements of balun balance and return loss. Provide services to measure the gain and radiation patterns of antennas in the VHF/UHF ranges.
Site evaluation	Provide services to evaluate EMC test sites to EN50147-2, EN50147-3 and EN61000-4-3. Maintain national standard 60 m ground plane facility.
Electro-optic sensor and 2GHz calculable dipole	Develop a miniature electro-optic field sensor for SAR measurements in the frequency range 300 MHz to 3 GHz with sensitivity lower than 1 V/m (in cooperation with Tokin Corporation). Develop a version of the calculable dipole to cover the frequency range 1 GHz to 2 GHz.
EMC measurements in GTEM cells	Determine the uncertainties of measurement for EMC emission and immunity testing in GTEM cells up to 6 GHz. Suggest techniques for minimising measurement uncertainties. Joint project with York EMC Services.
Fully anechoic room and Stirred mode chamber	Develop techniques to measure free-space antenna factor in the NPL 9m fully anechoic room, from 20 MHz to 5 GHz. Set up a stirred mode chamber. Develop theory to enable reduced uncertainties for under moded operation. Do measurements to test the theories. Contribute to IEC draft standard 61000-4-21.
Pilot antenna factor intercomparison	Pilot a BIPM intercomparison of antenna factors, for dipole like antennas in the frequency range 20 MHz to 2 GHz, for monopole antenna and loop antennas in the range 10 kHz to 30 MHz.
IEC EMC standards	Assist UK industry by contributing to National Committee meetings for IEC sub-committees CISPR/A and SC77B, by vetting measurement methods and reducing measurement uncertainties.
Good Practice Guides	Guides to Dielectric Measurement and to Field Strength Measurement are being written.
International Activities	NPL is the Pilot laboratory for new Key Comparisons of Attenuation at 60 and 5000 MHz. Scattering Coefficients 2 – 18 GHz, Coaxial Noise up to 1 GHz and Antenna Factor at 300 and 900 MHz. NPL has piloted three other comparisons including one on power at 75 and 94 GHz for which the final report has recently been accepted by CCEM.. A new Euromet comparison on Pulse Rise Time .. piloted by NPL has been agreed. NPL has participated in 5 other Key Comparisons piloted by other NMIs.

New programme

The new programme will evolve from the base of the current Programme but it is likely that there will be new activities to meet the rapidly changing needs of RF and Microwave technologies. Maintenance of the existing systems and standards consumes a large proportion of the current programme. At present, the UK runs one of the world's leading laboratories for measurement standards in the RF & Microwave area and this situation has arisen largely because there has been a sustained need for such standards in UK and, increasingly, European industry.

As a consequence of this history, the UK NMS is equipped with an extensive capability which appears to meet the main needs of the industry of five years ago very well! Those needs have probably not gone away but new needs have arisen and these have only partially been addressed. We find ourselves approaching the new programme with the need to add a significant amount of new capability but unlikely to have any additional funding to do so. Therefore a new programme must achieve one of the following options:

1. Continue to provide the existing fundamental needs and develop these incrementally in terms of uncertainty and coverage. Maintain all existing systems. Meet new needs to some extent, constrained by available funding.

2. Seek additional support through industry co-funding. This would allow the existing useful capability to be maintained and incrementally developed while still allowing new work to be undertaken and additional industrially relevant standards to be developed

3. Discard some of the existing systems and develop new capabilities focussed on new needs.

4. Reduce maintenance of existing systems as much as possible while taking into account that these are the ones which directly support the calibration services! Discard less used systems and abandon the calibration service. This would free up some funds to be used for innovative research to meet new standards and measurement techniques.

Option 1 does not seem to allow enough forward looking work to be done to meet the longer term needs of industry. It is similar to what has been done in the last programme, which did include the development of world leading capabilities in standards for GSM and DECT. The measurement techniques developed for this application can be used for a wide variety of other 2.5G and 3G measurands and there does seem to be a need for these. New work on on-wafer measurements has also been included in the current programme. However, there has not been as much innovative and new work as might be considered desirable to position the National Measurement System meet the longer-term requirements

Option 2 is achievable in part. The DTI looks very favourably on projects which are co-funded by industry in part, whether this be financially or in kind. Such co-funding need not be as much as 50%. Another option is to work collaboratively with other standards laboratories in Europe through Euromet.

Option 3 is interesting because it is noticeable that new, or developing, standards laboratories across the world, without exception, choose to develop the same sorts of capabilities as the UK has, although usually to a poorer level of uncertainty. However, the major standards laboratories in RF & Microwave (NIST in the US and PTB in Germany) are facing the same dilemmas as the UK and are considering dropping some areas of work completely. Due to the interaction of many parameters in RF & Microwave, it is very difficult to cut one area out without affecting another and so there is a demonstrable need for a wide capability, preferably co-located.

Option 4 carries with it the challenge of prioritising which systems and services are to be pruned and cut and which are to be maintained. However, prioritisation is necessary whichever option is chosen.

Inevitably, the final solution will be a combination of the options described above; ensuring a balance of meeting industry's current needs whilst undertaking research projects aimed at meeting future requirements.

Industry drivers

A full list of industry drivers is impractical but the following list includes many of the main features:

Increasing need for traceability across areas previously treated separately:

- Electro-optic transducers (modulators and photodiodes).
- Traceability for measurements made in one domain and presented in another such as time and frequency domain.

Security:

- Higher frequency needs such as millimetric and Terahertz imaging.
- Femtosecond pulses for imaging etc.

Lower uncertainty:

- Industry is now using their "primary" standards on the production line to achieve required uncertainty.
- Improved resolution of instruments – sometimes better than available calibrations.
- RF & Microwave connectors are not good enough – improved connectors or improved transmission media? Use dielectric guide for high frequencies?
- Internet enabled metrology can reduce end user uncertainty – electro-optical and opto-electrical extensions. Use for materials measurements,

Lower cost calibrations:

- Particularly for EMC.
- EMC techniques are now being provided above 1 GHz.

On-wafer measurements:

- A great deal of industry's real work is on – wafer and yet most standards are not.
- Impedance in the current programme.
- Need for other parameters.
- Evaluation and quality control of substrates

Non-linear measurements:

- Many real systems require non-linear behaviour to be measured.
- Particularly in the communications industry.
- Non-linear network analyser system exists – it has limited traceability.
- Requires ultrafast pulse techniques for traceability
- Oscilloscopes available or under development to 100 GHz.
- Standards for non-linearity based on non-linear materials

Communications:

- Need to understand accuracy issues in communications measurements.
- Ultra wideband systems – power, peak power, safety and interference.
- Radar cross section – not the measurement but the uncertainty analysis.
- Field probes for SAR in 3G conditions.
- Standards for EMC which address digital communications.
- Jitter measurements and bit error rate measurements.

Improved use of Automatic Network Analysers:

- Characterisation of opens and shorts for ANAs.
- ANA checking box – a set of verification devices to automatically perform a check?
- Time domain reflectometery.

EMC measurements:

- Higher frequencies (above 1 GHz).
- Reverberation chamber techniques and other non-antenna techniques.
- Different ways of calibrating chambers.
- Isotropy of probes at higher frequencies.
- Characterisation of non-screened cables in EMC when they can't be earthed at chamber penetration.

Materials:

- Lossy materials, magnetic materials at RF & Microwave and millimetre wave frequencies.
- Understanding of uncertainty for minimally invasive techniques (eg optically modulated scatterer)
- Evaluation of low loss materials for fixed-frequency resonators and functional materials for tunable applications .

Important synergies

Future RF & Microwave needs will require synergies with other areas to be exploited:

- Very important work with the ultrafast area where time domain traceability can be provided. Essential for non-linear measurements and for measurement of complex waveforms.
- Important links with the photonics area in matters such as photodiodes and modulators. Also, more integrated test equipment will require both microwave and optical traceability.
- O/E phase/group delay – an important parameter that draws on electrical risetime, O/E techniques and RF & MW impedance measurements.
- Potential important links between laser power and energy and RF power.

Future research trends

- Atomic and Quantum Metrology for RF & MW Guided Wave Standards
- MEMS (e.g. for power measurement by radiation pressure or AC/DC transfer)
- Micromachining for accurate matched components
- On-wafer technologies
- THz and Terabit Technologies
- Optics for RF & MW Metrology, especially field measurement and mapping
- Third & Fourth Generation Telecoms
- Tunable filters for telecoms based on dielectric resonators.
- lower loss, higher permittivity, homogeneous dielectric ceramics.
- Traceability for the gap region between DC & LF and RF & MW
- Digital techniques for traceable RF metrology
- Impedance traceability for higher frequencies not using air-lines.

Themes for the new programme

It is too early to specify what the themes for the new programme will be but the following main areas can be proposed:

1. Health & Safety (including Power Flux Density, SAR, Laser Power & Energy).
2. EMC (including EMC antennas, reverberation techniques etc.).
3. Precision antenna metrology.
4. Materials, including functional materials.
5. Fundamental RF & Microwave parameters (including power, noise, attenuation and impedance).
6. Specific industrial topics (including 3G measurands, laser power in fibres, antenna noise, passive intermodulation and others as suggested by industry)
7. Maintenance / calibration service support.
8. Knowledge Transfer

Alternative ways of splitting the programme could be considered, however. The list below is a method which has been used in the past:

1. Free-field (including antennas, EMC, power flux density and materials).
2. Guided Wave (including power, noise, attenuation and impedance).
3. Ultrafast (including fast pulse metrology and laser power and energy).

And another method might be:

1. Measurements for mobile communications.
2. Measurements for fixed link and broadcast communications.
3. Measurements for radar and security.
4. Measurements for Health and Safety.
5. Measurements for EMC.

The specific division into themes need not be an important issue, provided all necessary aspects are covered in the programme. However, themes can be valuable as methods of linking related work and of making sure that the industry needs are adequately covered. The difficulty with any structure is that there will inevitably be parts of the work which are difficult to fit into any given theme but which are important and must not be left out.

Conclusion

The formulation process for the next NMS programme is an important opportunity for industry input. It allows industry to ensure that the programme includes the work which will lead to the standards necessary to support R&D over the coming few years. In order for this to be successful, input from industry is very important and the session at ARMMS is one of several in the consultation phase of programme formulation.

During the two days of the conference we will be attempting to collect opinions on the programme at our table in the exhibition area and in the final session we will wish to gather these opinions and discuss the issues. Please make sure you get your say – it's your chance to ensure that the NMS work supports you!