Trigger

Economic, demographic and socio-cultural developments in a rapidly changing society drive the development of new technologies in the fields of health care, security, traffic management, environmental monitoring, advanced industrial production, quality testing and communication. This roadmap represents the underpinning electrical metrology in the radiofrequency to terahertz range that is required to support these developments.

The above mentioned technologies are triggered by the civilized desire to further improve the quality of life and by the demands of modern society for unlimited information exchange at any time and at any place. Smart architecture, highly integrated systems, intelligent systems, near and far field communication, virtualization, multimedia applications, decentralized automation and peer to peer collaboration are some of the buzz words related to actual and future technical implementations.

The common trend in all these developments is the increasing complexity of the systems and the increasing rates in data exchange. Metrological support is needed to assure the reliability, safety and efficiency of the technologies and to cover higher frequencies in the electromagnetic spectrum. Metrological support is even imperative to enhance the competitiveness of the European industry in the RF to THz sector and to lead the European economy into a bright future.

The necessary developments in RF to THz metrology to support all this consist of three main branches summarized under distinct targets.

Targets

1. Improvement and extended scales of units for RF quantities

Improvement of single quantities and employment of novel quantities are ongoing tasks and will be the basis for all metrology applications on future complex RF systems. The focus of the target includes establishing traceability, reducing the uncertainty (both incremental and step changes in precision measurements) of existing quantities. This is a necessary component for the complex measurement scenarios that are increasingly important, e.g. characterization of non-linear components and systems.

New nano-devices (e.g. graphene, Carbon Nano Tubes, biological macro molecules, organic electronics) as well as traditional improved high power transistors demand measurements at extreme impedances. These measurements are today not supported by the NMIs and thus they have questionable traceability leading to troubles with integration between manufacturers, lower yield in production and longer time to market.

The ever increasing performance of semiconductor devices means that today systems working above 100 GHz are interesting not only for sophisticated applications like satellite remote sensing or radio astronomy but also for mass production products like imaging applications for security, or communications. However the development of these new products is hampered by the level of measurement technology. In many cases new instruments are just being made available and traceability is poor or simply non-existent making measurements very difficult to compare or unreliable. The development in these high frequencies also means adoption of other kinds of transmission line techniques include dielectric waveguide, antennas on a chip, Sommerfeld waves, thin-film microstrip lines,
micro-coax, quasi-optical propagation, etc. At the NMI level much work is needed to provide accurate traceable measurements for these new transmission lines.

The frequency range between lower (audio) and higher (microwave) frequencies of the spectrum is another problematic area, where both measurement techniques used at lower and higher frequencies show rapidly increasing uncertainties. Measurement methods and traceability paths need to be established. Wireless energy transfer is a developing area of wireless application where improved traceability is needed to ensure energy efficiency, safety and interference measurement.

To establish traceability for EMC (Electromagnetic Compatibility) testing, novel EMC devices used for inter-laboratory comparisons are in great demand. Besides, techniques used for the performance evaluation of alternative EMC test methods, methods used for comparing test results from different conditions, and techniques for determining the uncertainty of EMC measurements are sorely needed. Possible interference of wind power plants with radar surveillance and terrestrial navigation systems needs to be investigated. Wind power plant project work needs approved rules based on measurement results.

Calibration and traceability of derived measurement quantities will be requested by industry.

Near- and far-field radio communication links are of increasing importance. These systems often include large-scale integrated electronics with processor clock frequencies in the GHz range. Such systems are potentially vulnerable by sources of intentional electromagnetic interference (IEMI). Measurement tools, detection of high power microwaves (HPM), and prevention strategies and technical solutions have to be developed to address these EMC aspects.

2. Multi-parameter characterization of RF systems

In addition to the continued need to improve and extend scales of units for RF quantities, there is a clear push towards multi-parameter characterisation of a range of RF systems. In order to support this push, metrology is required to underpin the development, enhance the capability and provide traceability to SI across a range of diverse future applications.

As the use of smart and reconfigurable antennas continues to grow with wireless technologies becoming ubiquitous, there is the requirement to provide efficient antenna calibration algorithms, such as near-field to far-field transforms and rapid pattern-testing methodologies. Propagation effects to determine the characterisation of radio channels with multiple-in, multiple-out systems (MIMO) systems become important, as does the need to provide electromagnetic field scanning to verify signal paths, and to validate antenna models and interference paths in new situations and applications (for example wind turbine versus radar, intelligent transport systems, vehicle to vehicle communications). Determination of propagation effects in wider frequencies, such as the THz range, will also be required for a range of parameters.

New requirements from leading-edge high-frequency industrial electronics applications is driving the requirement for multi-parameter high frequency measurements in a range of situations both in the laboratory and on-site, such as high-speed differential measurements, electronic calibration units, balanced and unbalanced measurements, and on-wafer. Requirements for multi-parameter on-wafer measurements of next generation devices are also emerging, with the need for non-linear, active device, PIM (passive intermodulation) and high power requirements being required simultaneously (or in parallel) to test and validate such devices. Underpinning metrology is required for automatic calibration and self-validation for on-site measurements, to provide confidence in advanced RF technological systems.
The range of complex measurements required in both the time-and-frequency domains will continue to grow, for example microwave and EMC antenna measurements, communications instrumentation, and power flux density measurements, including spatial resolution. In all cases the propagation of uncertainties between the domains (e.g. transforms, correlations, covariance matrices) continues to be of importance and must be addressed, with specific challenges for communication parameters such as modulation signal parameters and error vector magnitude.

In healthcare, the drive for ambient assisted living will ensure new technologies such as wireless heartbeat monitoring and detection of a range of human physiological parameters (including stand-off detection) will be developed. There will also be increasing use of wireless body area sensors and antennas (body worn networks) to disseminate information on-body, off-body and body-to-body. For example the use of wireless patient monitoring (wireless networks and RFID), medical diagnostics (RFID, implant communications, RF imaging and MRI) and therapeutics (hyperthermia and targeted drug delivery) will require different but essential underpinning metrology support to be fully implemented and trusted by consumers. There is a need to develop the metrology for safety of RFID systems (tags on liquids and metals, precision localisation, vehicles and rolling stock RFID), and emerging road charging, collision avoidance and other transport and logistical electromagnetic technologies.

Multi-parameter electromagnetic measurements of materials will continue to develop from the macro-to-microscopic world (e.g. scanning microwave microscope, functional materials etc). As traceability for future spectrometers continues to be developed, there is a need to build up a reference data library, with uncertainties, for practical dissemination across the range of applications which depend on different devices and samples.

The use of microwave and terahertz imaging will grow to enable industrial processes to be monitored on-site, semi or fully-autonomously, and be integrated with distributed sensors to provide quality control, improve efficiency and satisfy health and safety.

Finally in other areas, the need for accurate rf and microwave measurements in the 60 - 500 GHz region to support earth observation and climate monitoring is becoming increasingly important within Europe, pushing radiometry, noise and other measurements to their limits as laboratory specifications are required in space and in-situ across the globe. Furthermore, multi-parameter distributed measurements for providing environmental monitoring (regulatory) and security (e.g. detecting toxic aerosols in air) are also emerging. There will be growing requirements to measure security scanners, both the electromagnetic exposure (safety limits), and performance analysis (comparison of different scanners).

3. Metrology for large-scale fully-automated complex RF systems

Within the next decades, the development of large-scale, fully-automated and complex systems in the microwave to millimeter and sub-millimeter wave frequency range is expected. Metrology has to support this development by adequate measurement methods, calibration capabilities, and traceability to SI units. This will be accompanied by both continuously increased frequency and dynamic ranges of RF physical quantities on the one hand, and the usage of multiple physical quantities by sensor and data fusion on the other hand. Automatic calibration, validation, self-referencing and error-correction methods will greatly improve the safety, security, and availability of systems. Validated benchmarks and complex on-site measurement systems are required to underpin confidence in the functionality of highly advanced RF technological systems. Automated expert systems facilitate the design, installation, operation, and quality and conformity assessment of such systems.
The next-but-one generation of short-range communication systems will make use of frequencies up to 300 GHz. Due to short-wave propagation effects these frequencies behave like optical waves including blocking, reflection, diffraction, scattering, and bending. Furthermore, the transmitted power may be limited to avoid health effects and to take the safety limits into account. Therefore, new concepts for wave direction and re-routing in automated and reconfigurable networks are expected to enable ultra-high data rates with extremely high operational availability.

Industrial processes may also be reconfigured according to lean production and facility management. Sensor networks over-the-air will replace hard-wired cabling to be in line with modern production scenarios also addressing new and rapid production roll-outs. Automatic means of transportation are envisaged making use of precision 3D-localization systems.

Air and road traffic surveillance as well as railway control systems will be developed further in order to reduce pollution, idle time and latencies. A significant raise of traffic is anticipated, where the vehicles for individual mobility will be powered by electrical instead of combustion engines. Car-to-car communications and collision avoidance systems will reduce the risk of accidents, forming a cooperative network of vessels thus reducing the clearance distance to allow for higher throughput of highways, railways, etc. including autonomous driving.

Near-field communication will be implemented for personal identification and access control (identity card) and e.g. for cashier systems used in over-the-counter situations (bakery etc.). Fully automated logistics will be supported by identification and proof of origin for safety reasons (e.g. spare parts for aircrafts). Future cashier systems will scan the shopping cart and automatically register all items without removing them from the cart. Postal mail, luggage, and cargo will be inspected by sophisticated security systems. Fully automated security systems will be used to scan travellers at airports and railroad stations for dangerous items, but will also improve security in public buildings using stand-off detection.

Systems for ambient assisted living (AAL) will include home robots that can identify and follow the person to take care for. This includes RF monitoring of bio-signals such as heart beat rate and others, automatic ambulance calls, and home support (help, cleaning), but will also support communication with remote operators. Again, many aspects of secure near-field communication are involved which need metrological support.