

Progress Report on Rf and Microwave Metrology at the PTB on the Occasion of the 19th Meeting of the GT-RF

High Frequency and Fields

1 Electromagnetic fields, EMC

The measurement uncertainty of radiated EMC tests has to be obtained for the case that the device under test is present in the field generator. Currently the EMC standards evaluate the empty field only neglecting the varying coupling of the device under test with the field generator. Calculations of surface currents on simple test objects in a free-space environment give insight to this problem. The data obtained numerically are compared to measurement results obtained in GTEM cells, anechoic chambers and reverberation chambers. Larger systems are quite often assembled on the site from parts. Very often the EMC compliance to immunity requirements is tested only on the single parts, but not on the whole system. We are currently designing such a test system for a broad frequency range and sufficient field strength levels. (Thorsten.Schrader@ptb.de)

The assembly of a measurement setup for calibration of magnetic field probes up to 1 GHz is finished. A symmetrical parallel plate line with optimized balun and tapers is used as a standard field generator. For the validation of the low and frequency-independent VSWR a traceably calibrated E-field probe is utilized. The H-field is then calculated from the E-field using the free-space wave impedance. The frequency range of electrical field probe calibration is extended up to 18 GHz. In order to obtain a traceable electrical field strength the transmitter antenna factor is needed for 1 m distance. We use the definition of the antenna transmitter factor based on scattering parameters including all the losses within the setup. The antenna factor is determined from a 3-antenna measurement exploiting the far-field boresight gain with subsequent near-field correction based on the method of moments. (Thorsten.Schrader@ptb.de)

The type of field strength monitors changes from the detecting principle to an antenna setup including a spectrum analyzer for baseband operation. We reviewed methods for calibration of such devices. In 2005 we organized a workshop on measurements of pulsed radar and UMTS signals among the national measuring teams representing local authorities. A practical training course was conducted at the University of the Federal Armed Forces in Munich. We started first considerations on how to obtain traceability both for line-conducted as well as radiated communication signals. (Thorsten.Schrader@ptb.de)

A new shielding effectiveness measurement method based on a directional coupler has been developed at PTB. The planar samples for which the shielding effectiveness is supposed to be measured are brought between two separate halves of the four-port device. It allows for easy access of the shielding properties of the material using a fast vector network analyzer measurement. Measurements on a multitude of possible shielding materials have been performed and compared to simulations based on the method of moments. Measurements and simulations show a good agreement. The method requires a reference material for the quantification of the shielding effectiveness. Further work regarding the choice of a proper shielding material and relating material properties to measurement results is under way. The method has already been applied successfully to examine the shielding effectiveness of panel assemblies used for the construction of shielded rooms and sprayed metal surfaces used as reflectors. (Thomas.Kleine-Ostmann@ptb.de)

2 High-frequency measurement techniques

During the last year, several activities have been performed at PTB's RF power measurement facilities. First, a new waveguide calorimeter has been built and put into operation for the 40 to 60 GHz frequency range (R500), and currently the gap down to 40 GHz is bridged by a 33 to 50 GHz waveguide (R400) setup. Simulations with finite-element based solvers have been performed to both verify and enhance the uncertainty of PTB's coaxial calorimeters (3.5 mm and 2.92 mm). With the new R400 calorimeter, comparison measurements will give valuable information about the validity of the coaxial 2.92 mm calorimeter modelling. Finally, the direct comparison power measurement capabilities will be expanded up to 40 GHz within 2007. (Rolf.Judaschke@ptb.de)

At PTB, different vector network analyzers (VNA) are under operation for both reflection and transmission measurements. For traceable reflection measurements, the "quarter wavelength" airline

correction method is applied for coaxial devices up to 40 GHz. Currently, new sets of coaxial airline standards (2.92 mm and 1.85 mm) are in-house manufactured. An extension of the airline calibration method up to 67 GHz is scheduled for 2008. For very high precision measurement of well-matched terminations up to 4 GHz, 7 mm airlines of extraordinary precision have been manufactured in 2006. Furthermore, a novel method for the determination of complex residual error parameters is evaluated which enables a second order error correction to reduce the measurement uncertainty down to the established "quarter wavelength" uncertainty. Another activity is the uncertainty evaluation of electronic VNA calibration units in comparison with conventional precision and economy calibration kits. Here, especially long-term and temperature stability is of special interest. Currently, VNAs for frequencies up to 110 GHz (1mm coaxial) are evaluated, and within the next months, the a new system is going to be purchased. (Rolf.Judaschke@ptb.de)

PTB operates a primary standard for the risetime of electrical signals, which allows for the calibration of the risetime of high-speed oscilloscopes with a nominal bandwidth of 50 GHz or 70 GHz. The expanded uncertainty of the risetime measurements is typically 1.2 ps. The standard is based on ultrafast electrical pulse generation with photoconductive switches and electro-optic sampling of electrical transients. The risetime calibration of 50 GHz oscilloscopes was validated by a bilateral comparison with NPL in the framework of the EUROMET Project 641. The distortion of the calibration pulses due to the electro-optic probes used for the measurement of the electrical transients was determined and appropriate correction procedues are being developed at present. (Mark.Bieler@ptb.de)

A capacitive MEMS system that should enable a direct substitution of RF voltages by a dc voltage is under construction. The micromachined silicon structure consists of a torsional seesaw-like actuator, assembled from three stacked wafers. As a result of recent measurements, the sensor has shown to be suitable for rf voltage detection. From systematic measurements with applied rf voltages from the low kHz region up to several MHz, an equivalent circuit has been derived which shows RC low pass filter properties due to the high resistivity of the silicon substrate. This problem will be solved in a redesigned version of this sensor. (Jan.Dittmer@ptb.de)

3 On-wafer microwave measurements

- In cooperation with NPL, the repeatability and reproducibility of on-wafer scattering-parameter measurements were investigated. Standard calibrations like e.g. SOLT, TRL, and LRM were employed on commercial impedance standards substrates, and good agreement was found, despite different instrumentation.
- The wideband microwave properties of standard coplanar microwave probes were investigated using popular one- and two-port measurement methods. We illustrated the importance of accurate standard definitions and demonstrated the impact of the substrate material on the probe characteristics in a frequency range up to 50 GHz.
- Two possible variants of the Through-Reflect-Line (TRL) calibration were implemented in software and compared against each other. Possible steps in calculating the transmission line propagation constant, which is obtained as a by-product of the algorithm, and the VNA correction coefficients were investigated.
- Capacitance measurement methods based on on-wafer scattering parameter measurements in the frequency range 50 MHz to 50 GHz were applied to coplanar waveguides fabricated on different substrate materials. Uncertainties obtained from repeated measurements were calculated, and a typical experimental standard deviation on the order of 0.01 pF/cm was found. Also, the effect of capacitance uncertainties on the reference impedance of Thru-Reflect-Line (TRL) calibrations was demonstrated.
- An uncertainty budget of the electrical properties of coplanar waveguide calibration standards, which can be used for on-wafer TRL calibrations, was established. The impact of dimensional control, technology parameters and material measurement uncertainties on the complex and frequency-dependent characteristic impedance and propagation constant was investigated for typical microwave substrates and technologies.
- In cooperation with NIST, the in-phase/quadrature covariance matrix representation of the uncertainty in complex numbers and vectors was introduced. This representation offers a complete description of the uncertainty in a complex number, and yet maintains much of the convenience of the magnitude/phase uncertainty representations in common use in the microwave industry.

- In cooperation with the University of Twente, The Netherlands, the potential of SiRN trenches to reduce substrate losses in CMOS-grade wafers was explored with the aid of interconnect characterization methods. A variety of different fabrication parameters is currently under investigation.
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