□
□

□

CHARACTERIZATION OF THE MEASUREMENT UNCERTAINTY FOR THE ELECTROMA□NETIC CONDUCTED AND RADIATED EMISSION TEST

MOHD ERDI BIN AYOB

A thesis su□mitted in fulfillment of the re□uirement for the a□ard of the
Degree of Master of Engineering Technology

Faculty of Engineering Technology
Universiti Tun Hussein Onn Malaysia

APRIL 2□□

For my beloved mother and father for their endless love, support and encouragement.

ACKNOWLEDGEMENT

First and foremost, I wish to express my ultimate gratitude to my parents for their love and support throughout my entire life in chasing my dreams. A special thanks to my lovely wife, daughters and sons for their patience and understanding having indirectly involved throughout the completion of my study.

My sincere appreciation to my supervisor, Prof. Madya Dr. Jumadi Bin Abdul Sukor for his guidance, support, word of wisdom, patience, encouragement and for his confidence in me for the entire duration of this research. He has been my inspirations to overcome great challenges and serve as a role model when I was serving the department right from day one in the FTK in 2012.

Also, I would like to extend my heartfelt appreciation to my co-supervisor Prof. Dr. Mohammad Zarar Bin Mohamed Jenu for giving me the opportunity to serve the EMCenter over the last 10 years and also for his outstanding ideas who sparked this EMC research in UTHM.

Last but not least, to my colleagues in UTHM and UTeM, I owe them a great deal of gratitude for helping me in multiple ways. Finally, this appreciation goes to the people who have involved directly and indirectly towards the completion of this thesis.

[illegible]

Electromagnetic Compatibility or EMC is the ability for the product or equipment under test (EUT) able to operate in its intended environment with causing undue interference or being unduly affected by it. The requirement for non-interference has been known for many years but it is only now with the introduction of legislation that we are seeing a major growth in demand for testing. The USA with its FCC regulations has for some time tried to control emissions from certain types of equipment. Japan has also had a voluntary code (VCCI) and Europe, after some delay, fully introduced mandatory regulations at the end of [illegible].

The ultimate importance of an EMC testing is to ensure the EUT is not affected by the other operating EUT and vice versa. These conditions apply for both conducted (CE) and radiated emission (RE). Other areas are now introducing regulations and it seems likely that the system will spread to encompass the whole world in the future. Currently, measurement of an equipment under test (EUT) shall cast a doubt when the result is close to the specification limits. In the common practice, the MU is taken as an informational purpose only in the report and not for the EUT status. The implementation of the measurement uncertainty for the reporting is crucial since the EUT might fail the EMC test if the passing margin is below the International Special Committee on Radio Interference (CISPR) standards.

In acquiring the MU for the judgement criteria, comparison with the standards and inter-laboratory comparison shall take place. These include the standard classification for the EUT type, expanded uncertainty estimation to the CISPR standard (U_{CISPR}), EMC equipment factor estimation and proficiency test with the other accredited EMC laboratory using the Z-Score method. The inter-laboratory comparison used the same calibrated signal source which emits the stable broadband emission. Finally, the cumulative results are to be taken as a laboratory expanded uncertainty U_{LAB}□ 2u$_c$□y□. The thesis focused the application of the expanded uncertainty deployment for the □udgement criteria for the finali□e EUT status.

The expanded uncertainty for □oth measurement CE and RE are □.□□□dB and □2 – □.□□dB respectively □hich are □ell □elo□ the CISPR standard □.□– □2 dB. On the other hand□the inter□la□oratory comparison □et□een t□o EMC la□oratories□EMcenter UTHM and EMC Singapore EPSON Ptd Ltd □SEP□have sho□n that a□out □□.□□□for the Z□score analysis □hich met the CISPR re□uirement for the Z□score □□□.□□□. Thus□ □oth expanded uncertainty and Z□score results met the CISPR re□uirement □hich is re□uired for the accreditation of an ISO □□□2□ □eneral re□uirements for the competence of testing and cali□ration la□oratories□.

Finally□the □ork further presented relating to the actual measurement of a sampled EUT of □□units of CE and □□units for RE. The measurement of the EUT comprises the □P margin to □e compared □ith the CISPR limits and the U_{LAB}. For the EUT to □e completely pass the EMC test□□oth condition CISPR limits and U_{LAB} must □e met. A novel method has □een implemented in the emission results to satisfy □oth conditions □hich later□to determine the EUT status and summari□ed in the final reporting. In CE measurement□a□out 2□.□□□ of non□compliant EUT have a □P margin □elo□ than the U_{LAB} □ □.□□□dB and □□.□□□ of non□compliant EUT □hich have a margin □elo□ than the U_{LAB} □ □2 □□.□□dB for RE measurement. Prior to the ne□ method□these EUT have passed the EMC test □y taking only the □P emission compared to the CISPR limits. Again□□y having the novel method□it is clearly verified the status of the EUT □y taking the □P margin compared to the U_{LAB} as an additional verification to the EUT status.

Thus□a good verification prior and after the entire measurements □hich 2□involved the: □□comparison to the CISPR standard□2□inter□la□oratory comparison using the Z□score method□and□□□actual measurement to the passed EUT. These results sho□ed a good performance□usefulness and highlight the potential □enefit of incorporating the measurement uncertainty for EUT □udgement criteria.

□ □ □ □ □□□□□□□□□□

□

□

□

□□□□□ □□□□□□□□

□

□

□

□

□

□

□□□□□ □□ □□□□□□□

□

□

□

LIST OF SYMBOLS AND ABBREVIATIONS

AF	Antenna Factor
AMN	Artificial Mains Network
CE	Conducted Emission
CE	Conformité Européenne (European Conformity)
CISPR	Comité International Spécial des Perturbations Radioélectriques
dB	Decibel
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EUT	Equipment Under Test
FCC	Federal Communication Commission
GPIB	General Purpose Interface Board
GRP	Ground Reference Plane
GTEM	Gigahertz Transverse Electromagnetic
HPF	High Pass Filter
ILC	Inter-laboratory Comparison
ISO	International Standard Organization
LF	Low Frequency
LISN	Limited Impedance Stabilization Network
MCMC	Malaysia Commission for Multimedia and Communication
MU	Measurement Uncertainty

OATS	:	Open Area Test Site
PT	:	Proficiency Testing
QP	:	Quasi Peak
RE	:	Radiated Emission
RF	:	Radio Frequency
SAC	:	Semi Anechoic Chamber
VHF	:	Very High Frequency

[illegible]

[illegible]

[illegible]

The Electromagnetic Interference (EMI) in electrical and electronics within the stipulated radio spectrum often exists and not directly visible from the outside of the equipment. It deals with the generation, transmission and reception of the unintended radio signals. This interference phenomenon can be described in a coupling model which are the source, coupling path and victim. In order for the interference to take place from the source, the coupling path can be radiative or the radiated emission (RE), conductive, capacitive and inductive for conducted emission (CE) [illegible]. Since it occurs over a broad spectral range from very low frequencies up to millimeter wave range and above, the manufacturer is obliged to declare the conformity with the achieved goals of the required directive, a harmonized and compatible level regarding the emissions and immunity of the equipment [2]. The directive has been recognized in the US in [illegible] by introducing the FCC article [illegible] subpart [illegible] on emission restrictions for computers [illegible]. The EMC standards clearly specify the limits and what is to be measured – the "measurand" and to define the method for measuring it. Nowadays, advancement in technology, consumer demand and enforcement requirements on an accredited lab test has resulted in acquiring ISO [illegible] General requirements for the competence of testing and calibration laboratories, certification [illegible].

All household products which are meant for the export market are required to pass the CE and RE tests. This is to ensure that such household product or the equipment under test (EUT) can satisfy the local regulatory requirement which is to be used in the designated country. The basic requirement of the test requires the voltage disturbance device and a proper impedance with noise isolation to the EUT as shown in Figure □□. In this case□the measuring device is an Electromagnetic Interference □EMI□receiver □hich controlled via an EMC soft□are through a general□purpose interface □oard □□PIB□. On the other hand□the limited impedance sta□ili□ation net□ork □LISN□provides the impedance matching and noise isolation from and to the EUT. The transient limiter degrade the voltage distur□ance from the EUT at □□□dB to protect the EMI receiver □□□. On the other hand□the RE test is done at higher fre□uency range than the CE. The LISN is replaced □y the measuring antenna as sho□n in Figure □2 □□□. □ hile the voltage distur□ance radiates from the EUT□the antenna captures this distur□ance through its antenna elements.

The EMC measurements system deals □ith an advanced hard□are □ith an a□undance of technical parameters and multiple connectors □hich may lead to the measurement imperfection or errors if it is not addressed correctly. It is an unavoida□le and most likely □ill □eopardi□e the final measurement result. Therefore□the result of the measurement only approximates to the true value of the measurand and is completely valid once it carries a statement of the uncertainty for that approximation.

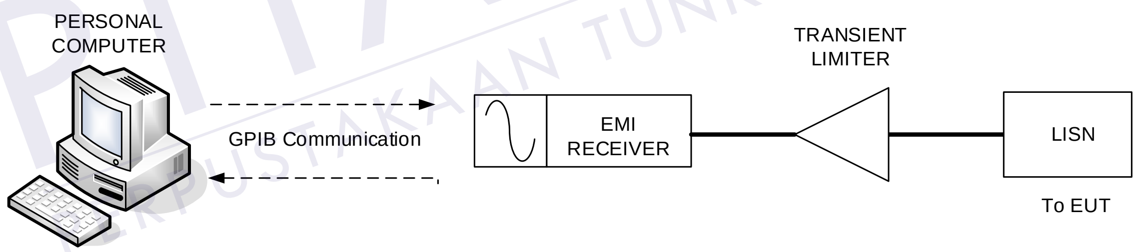

Figure □□: Test Setup for the conducted emission □CE□□□□.

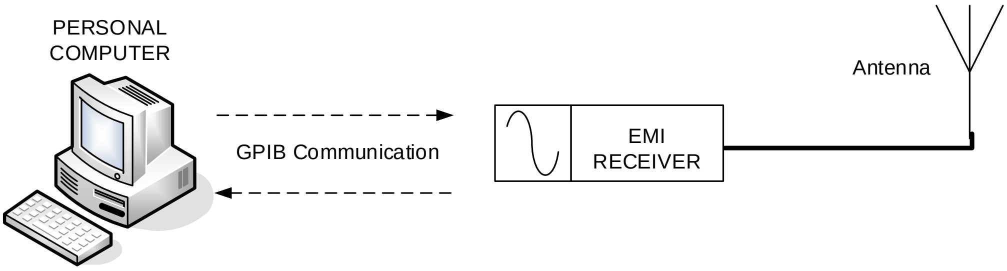

Figure □2: Test Setup for the radiated emission □RE□□□.

In general□errors of measurement may have t□o components□□□□a random errors □Type A□and □2□systematic errors □Type B□□□. The type A evaluation for the uncertainty is □ased on the statistical or calculation □hich is normally done under repetitive measurements. On the other hand□type B evaluations is □ased on scientific □udgement using multiple information such as previous data□operator experience□ manufacturer specifications□data from hand□ooks and cali□ration certificates □□. The uncertainties exist from these t□o components □□. Figure □.□sho□s the random errors value around the mean. Random errors arise from random variations.

A series of measurement □hich is taken under the same condition produces a scattered value around the mean. It cannot □e eliminated □ut increasing the num□er of o□servation and deriving a mean value may reduce the uncertainty due to their effect. Then□in Figure □.□□systematic errors arise from systematic effect at any given □uantity□remains unchanged □hen a measurement is repeated under a constant condition such as the cali□ration error. It can □e reduced □y applying a correction factor to the data.

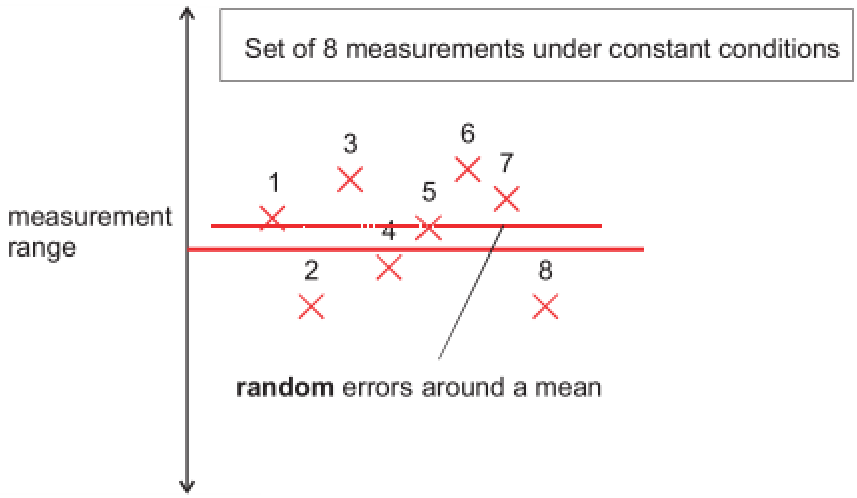

Figure □.□: Random errors □□.

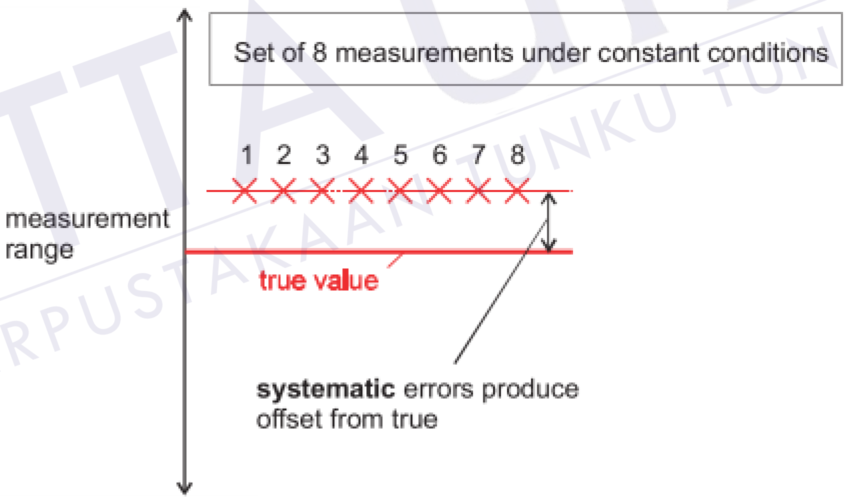

Figure □.□: Systematic errors □□.

By esta□lishing the measurement uncertainty □MU□□udget such as in Ta□le □.□□all e□uipment□device□connectors and ca□les are classified as an input □uantities *xi* and to □e evaluated □y a proper method according to the standards or procedure if availa□le and each is expressed as a standard uncertainty□$U(x_i)$. The standard uncertainty components are com□ined to produce an overall value of uncertainty kno□n as the com□ined standard uncertainty□$U_C(y)$ and the la□oratory expanded uncertainty U_{LAB}. The expanded uncertainty is required to meet the needs of international standards to provide a greater level of confidence by multiplying a coverage factor of k and shall be calculated as $U_{LAB} = k.u_c$ [illegible].

Table [illegible]: Sample of measurement uncertainty budget [illegible].

[illegible] x_i	Ux_i	[illegible] d[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Receiver reading	V_r	[illegible]	Normal	[illegible]	[illegible]	[illegible]
Attenuation: LISN-receiver	a_c	[illegible]	Normal	2	[illegible]	[illegible]
LISN voltage division factor	F_{AMN}	[illegible]2	Normal	2	[illegible]	[illegible]
Combined standard uncertainty	$U_C(y)$		Normal		[illegible]2[illegible]	[illegible]2[illegible]
Expanded uncertainty. Normal (k[illegible])	U_{LAB}	k=2				[illegible]

[illegible]

EMC testing is a series of various test which is inclusive the emission and immunity test as well as radiated and conducted for both. Those tests are needed to be fully complied and it is a mandatory requirement for most of the markets including the Australia, China, Europe, Japan, Korea, New Zealand and the U.S. With the vast and rapid growth in the electric and electronics, it has been known to be one of the main driven factor for the EMC testing laboratory to be accredited. Accreditation is a formal recognition for the EMC testing laboratory to be competent with the implementation of the quality system in accordance to the ISO/IEC [illegible]2[illegible].

Based on ISO/IEC [illegible]2[illegible]: 2[illegible] Clause [illegible] Note 2 stated that, upon accreditation, participation in the inter-laboratory comparison (ILC) for the proficiency testing (PT) is mandatory for CE and RE using samples or items of known value to determine the MU, limits of detection and confidence limits. It is crucial to characterize all known input quantities (x_i) and laboratory's expanded uncertainties (U_{LAB}) prior to the PT exercise to takes place.

According to the numbers of actual EMC's sample reports from a several accredited test houses in Appendices E, F, [illegible] and H, it is clearly seen that the MU is used as an informational purpose only which is inadequate to determine the status of the EUT which has the emission level ≥ U_{CISPR} or close to the emission limits. Therefore, in this context of research the MU is applied in the final measurement so that the EUT status could be correctly addressed whenever the EUT has exceeded the quasi peak (QP) with the MU limits.

[illegible]

This project aims to make the measurement uncertainty useable to the final measurement with the approach verified in the EMC Standards. By having a numerous manual and automated data collection, it will be carefully cross-checked for its integrity according to the standards. By introducing more analytical and various statistical methods for the data analysis, it will be able to minimizing the uncertainty values. To achieve the aforementioned aim, the following objectives shall be implemented:

i) To obtain the input quantity (x_i) voltage specifically for CE and RE.

ii) To obtain the laboratory MU (U_{LAB}) within the CISPR standard (U_{CISPR} = [illegible] dB for CE and [illegible].2 dB for RE).

iii) To perform a statistical comparison between two EMC test sites for the ILC to satisfy the Z-score requirement in accordance to the ISO/IEC [illegible] standard.

iv) To evaluate the MU value to the final QP measurement with the comparison to the QP limits.

[illegible]

The scopes of this research study are as follows:

i) Characterization of the measurement uncertainty input quantities *xi* for CE and RE in household and information technology equipment for the EUT through standard measurement and calibration certificates.

ii) Obtaining the measurement uncertainty (U_{LAB}) and to compare with the standards (U_{CISPR}) for Semi Anechoic Chamber based on the CISPR [illegible]2:

□□□□□□□□□□□□

□□□ P. Russer, "EMC measurements in the time□domain," *2011 XXXth URSI Gen. Assem. Sci. Symp.*□pp. □–□□□2□□□.

□2□ D. Hansen, "20 Years of professional experience in international EMC□labs," *2002 3rd Int. Symp. Electromagn. Compat.*□2□□2.

□□□ R. G. Bill Holz, "The Engineer ' s Guide To Global EMC Requirements : 2007 Edition," Intertek, 2007.

□□□ International Standard Organi□ation□*General requirements for the competence of testing and calibration laboratories*□2nd ed. S□it□erland: ISO□IEC □□□2□□ 2□□□.

□□□ B. S. Institution□*Specification for radio disturbance and immunity measuring apparatus and methods Part 4-2 : Uncertainties , statistics and limit modelling — Measurement instrumentation uncertainty*. United Kingdom: BS EN □□□□□ □2□2□□□.

□□□ U. K. A. Service□*The Expression of Uncertainty in EMC Testing*. La□□□□2□□2.

□□□ S. Bell□*A Beginner's Guide to Uncertainty of Measurement*□2nd ed. National Physical La□oratory□□□□.

□□□ Schaffner□*EMC Measurment Uncertainty, a handy guide*. Schaffner EMC System Ltd□2□□2.

□□□ E. Accreditation□*Evaluation of the Uncertainty of Measurement In Calibration*. France: EA□□□2 M□2□□□.

□□□□ J. Medler, "Uncertainty contribution of the EMI test receiver in RF disturbance measurements," *2010 Asia-Pacific Int. Symp. Electromagn. Compat.*□pp. □□□–□□□□2□□□.

□□□□ B. S. Institution□*Specification for radio disturbance and immunity measuring apparatus and methods Part 2-1 : Methods of measurement of disturbances and immunity* —. United Kingdom: BS EN □□□□□2□□□2□□□.

□□2□ International Electrotechnical Commission□*Specification for radio disturbance and immunity measuring apparatus and methods Part 2-3 : Methods of measurement of disturbances and immunity – Radiated disturbance measurements*. S□it□erland: IEC CISPR □□2□□□2□□□.

□□□□ Y. Akiyama, K. Kakuda, and T. Shimasaki, "Deviations of conducted distur□ance voltages measured □ith AMN due to differences in height of the AMN and its grounding conditions," pp. 501–□□□□2□□□.

□□□□ P. Nicolae, S. M. Ieee, C. Stoica, M. S. Student, and G. Mihai, "Conducted

Emission Measurements for a Laptop," pp. 2–□2□□□.

□□□ A. Racasan□C. Munteanu□□. Topa□C. Pacurar□C. He□edean□and C. Marcu□ "Home appliances conducted electromagnetic emissions analysis and mitigation methods," *2015 9th Int. Symp. Adv. Top. Electr. Eng. ATEE 2015*□ pp. □□□–□□□□2□□□.

□□□ M. Alexander, M. Salter, and D. Cheadle, "Near□field validation of calcula□le dipole antennas in a fully anechoic room from 2□MH□to □□□□MH□□□ith applications to validation of EMC test sites and calibration of EMC antennas)," vol. 2□pp. □□□–□□□□2□□□.

□□□ C. R. Paul□*Introduction to Electromagnetic Compatibility*□2nd ed. □iley□2□□□.

□□□ E. M. N. Mark I. Montrose□*Testing for EMC Compliance: Approaches and Techniques*. □iley□2□□□.

□□□ A. Technology and E. F. Sarajevo, "Proficiency testing and interlaboratory comparisons in laboratory for dimensional measurement," vol. 16, no. 1, pp. □□□–□□□□2□□2.

□2□□ ANSI □AS□ National Accreditation Board□*Guidance on Proficiency Testing / Inter-laboratory Comparisons*. USA□2□□□.

□2□□ M. Lin, "Evaluation for Test Competence," *Electromagn. Compat. 1998. 1998 IEEE Int. Symp.*□vol. 2□pp. □2□–□2□□□□□.

□22□ L. E. Kolb, "Statistical Comparison," *Electromagn. Compat. 1996. Symp. Rec.*□ pp. 2□□–2□□□□□□.

□2□□ International Electrotechnical Commission□*Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*. S□it□erland: CISPR 22□2□□□.

□2□□ K. Osabe and T. Kato, "Consideration of data evaluation criteria for radiated emission test in the PT program," *Int. Symp. Electromagn. Compat. - EMC Eur.*□ pp. □–□Sep. 2□□2.

□2□□ K. Osabe and T. Kato, "Proposal for evaluation method of proficiency test results on EMI measurement," *2013 IEEE Int. Symp. Electromagn. Compat.*□ pp. □□□–□□□□Aug. 2□□□.

□2□□ A. V. High, F. Line, and I. Stabilization, "Effectiveness Evaluation of Devices for AC Mains Ca□le Termination Control to Improve Reproduci□ility of Radiated Emission Measurement," pp. 818–□2□□2□□□.

□2□□ P. Mullner, W.; Austrian Res. Centers GmbH □ARC, Austria; Kriz, A.; Preiner, "Comb generator measurement techniques," *Electromagn. Interf. Compat. 2008. INCEMIC 2008. 10th Int. Conf.*□pp. 2□□–2□□□2□□□.

□2□□ T. Toh, "Electromagnetic Interference Laboratory Correlation Study and Margin Determination," *IEEE Trans. Electromagn. Compat.*□vol. □□□no. 2□pp. 2□□–2□□□2□□□.

□2□□ W. Di Mullner, A. Di Kriz, H. Di Haider, and G. Kolb, "Conducted and Radiated Com□ Generator Measurement Techniques," *2007 7th Int. Symp. Electromagn. Compat. Electromagn. Ecol.*□pp. 2□□–2□□□2□□□.

□□□ K. Osabe, R. Watanabe, A. Maeda, and M. Yamaguchi, "Inter□la□oratory Comparison Result as the Proficiency Testing Program of EMI Test Sites in Japan," *2007 IEEE Int. Symp. Electromagn. Compat.*□pp. □–□□2□□□.

□□□ A. Ales, F. T. Belkacem, and D. Moussaoui, "Laboratory line impedance stabilisation network: Experimental studies," *2011 10th Int. Conf. Environ. Electr. Eng. EEEIC.EU 2011 - Conf. Proc.*□pp. □–□□2□□□.

□2□ Q. Cui and Y. Lu, "The influence of different measurement antennas on the radiated emission measurement," *2011 Int. Conf. Electron. Commun. Control. ICECC 2011 - Proc.*□pp. □□□□–□□□□2□□□.

□□□ □. □. □uimar□es□M. H. C. Dias□and J. C. A. dos Santos, "Proficiency testing of electromagnetic compati□ility □EMC□ la□s in Bra□il □y measurement comparisons," *Meas. Sci. Technol.*□vol. 2□□no. □□□p. □□□□□□2□□□.

□□□ P. Wilson, "On correlating TEM cell and OATS emission measurements," *IEEE Trans. Electromagn. Compat.*□vol. □□□no. □□pp. □–□□□□□□.

□□□ International Electrotechnical Commission□ *Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides*□2nd ed. S□it□erland: IEC □□□□□□□2□□2□□□.

□□□ I. of E. and E. Engineers□*American National Standard for Methods of Measurement of Radio Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz*. USA: C□□.□:□2□□□.

□□□ K.□O. Muller, "Speeding up quasi peak weighting EMI tests," *IEEE 1991 Int. Symp. Electromagn. Compat.*□no. □□pp. □□□–□□2□□□□.

□□□ M. E. Ayob, "Conducted Emission □K□□FT938," Parit Raja, 2011.

□□□ R. Anuar, "Radiated Emission □AHM65PS12," Parit Raja, 2014.

□□□ P. Da Silva Hack and C. S. Ten Caten, "Measurement uncertainty: Literature review and research trends," *IEEE Transactions on Instrumentation and Measurement*□vol. □□□no. □. pp. 2□□□–2□2□□2□□2.

□□□ D. Heirman, "Uncertainty Considerations in Stating Pass / Fail CISPR Uncertainty Approach CISPR Approach to Uncertainty CISPR □alues for Ucispr First Application of Ucispr First Application of Ucispr ISO □IEC □□□2□□," *Electromagn. Compat. 2008. EMC 2008. IEEE Int. Symp.*□pp. □–□□2□□□.

□2□ A. Marinescu□Y. E. □ulersoy, and G. Schmid, "An interlaboratory comparison for mobile phone SAR," *IEEE Int. Symp. Electromagn. Compat.*□pp. □2□□–□222□2□□□.

□□□ M. Ishii, H. Yoshida, Y. Danjo, S. Kurokawa, and K. Fujii, "A study on the characteristics of semi□anechoic cham□ers below 30 MHz," *IEEE Int. Symp. Electromagn. Compat.*□vol. □□pp. □□□–□□□□2□□□.

□□□ A. Degraeve, K. Armstrong, J. Peuteman, and D. Pissoort, "Development and construction of an EMC demonstration unit," pp. 422–□2□□2□□□.

□□□ M. A. and □. Y. M. A. Rafi□□"Effect of Shielding g , Grounding , EMI Filt ters & Ferrite Beads on Rad diated & Conducted Em missions," *Recent Adv. Sp. Technol. (RAST), 2013 6th Int. Conf. on, Istanbul*□pp. □□□–□□□□2□□□.

□□□□ R. W. Beatty, “Insertion loss concepts,” *Proc. IEEE*□vol. □2□no. □□pp. □□□–□□□□□□□□.

□□□□ J. Tsai, L. Lin, Y. Tsai, and C. Chen, “Estimate the measurement uncertainty of broadband antenna (30MHz to 1GHz) calibration system,” *2010 Asia-Pacific Int. Symp. Electromagn. Compat.*□pp. □□□–□□□□2□□□.

□□□□ M. Samoto□N. Samoto, H. Shimanoe, I. Makino, and K. Shimada, “A Su□stitution Method for Antenna Cali□ration □y the Use of Broad□and Antenna (30 to 1000 MHz),” no. 1, pp. 691–□□□□2□□□.

□□□□ A. Technologies□*Measurement Guide Agilent Technologies EMC Series Analyzers*. USA□2□□□.

□□□□ D. Zhao, G. Teunisse, and F. Leferink, “Design and implementation of conducted emission reference source,” *2014 IEEE Int. Symp. Electromagn. Compat.*□pp. □2–□□□2□□□.

□□□□ J. Song, H. T. Hui, and Z. W. Sim, “Investigation of Measurement Uncertainties and Errors in a Radiated Emission Test System,” *IEEE Trans. Electromagn. Compat.*□vol. □□□no. 2□pp. □□□–□□□□Apr. 2□□□.

□2□ M. Zingarelli and R. Grego, “Improving EMC measurement uncertainty □ith digital EMI receivers & optical fiber technology from 10 Hz up to 6 GHz,” *10th Int. Symp. Electromagn. Compat.*□pp. 2□–□□□2□□□.

□□□□ I. Turer, M. Uysal, M. C. Akmehmet, and A. D. Bagdat, “Normalized site attenuation measurement of a semi□anechoic chamber in multiple test zones,” *Int. Symp. Electromagn. Compat. - EMC Eur.*□pp. □–□□Sep. 2□□2.

□□□□ H. M. Hironari Tanaka, Ikuo Makino, Hiroyuki Shimanoe, “An Evaluation of using Small Biconical Antennas in Normalized Site Attenuation,” pp. □□□–□□□□2□□□.

□□□□ J. Tsai, M. Donglin, Y. Tang, K. Huang, and L. Lin, “Improvement of the mutual coupling effect between Biconical antenna and antenna mast,” no. 1, pp. □2–□□□□2□□□.

□□□□ D. B. Hibbert, “Interlaboratory Studies ,” *Encycl. Anal. Sci.*□vol. □□pp. □□□–□□□□2□□□.

□□□□ I. N. A. Board□*Policy on Proficiency Testing*. Ireland: PS□□2□□□.

□□□□ International Standard Organi□ation□ *Statistical methods for use in proficiencytesting by interlaboratory comparisons*. S□it□erland: ISO □□□2□□ 2□□□.

□□□□ E. P. Nicolopoulou, I. F. Gonos, I. a. Stathopulos, and E. Karabetsos, “Two interla□oratory comparison programs on EMF measurements performed in Greece,” *IEEE Electromagn. Compat. Mag.*□vol. □□no. 2□pp. □□–□□□2□□2.

□□□□ R. □ogt□Ardat□e□□U. Lundgren, S. F. Romero, and F. Leferink, “On□Site Radiated Emissions Measurements in Semireverberant Environments,” *IEEE Trans. Electromagn. Compat.*□p. □□□2□□□.

□□□□ C. Caro□□i□A. Bonci□M. Cati□C. Panconi□M. Borsero□and □. □i□io□ “Experience on proficiency testing in Italy □ith emphasis on radiated emission measurements from 30 MHz to 1 GHz,” *IEEE Int. Symp. Electromagn.*

Compat.□vol. 2□□□–Septm□pp. □□□–□□□□2□□□.

[□2□] B. Zhang, Z. Yuan, and J. He, "Comparison on the test results between rever□eration chamber and anechoic chamber," *2012 Asia-Pacific Symp. Electromagn. Compat.*□pp. □□□–□□2□May 2□□2.

[□□□] S. Chakrabarti, D. Dan, and G. Suresh, "Uncertainty analysis for conducted emission measurement," *2008 10th Int. Conf. Electromagn. Interf. Compat.*□ 2□□□.