

DEVELOPMENT AND TRACEABILITY OF METROLOGICAL STANDARDS ON RADIO FREQUENCY AND EM FIELD IN NMIJ

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Abstract: NMIJ has started its activity on the mission for the preparation of the national standards from 2001 fiscal year in the AIST. Some of radio frequency standards of power, voltage, attenuation, antennas are prepared and the others are under development to be disseminated for calibration service.

Key words: Metrology, Standard, Uncertainty, Traceability, Calibration

1. Introduction

The system of weights and measures is necessary in any nation for trade and industry. The NMIJ has been preparing the standards of many physical quantities from the SI units through many combined units in Japan. About electromagnetic quantities, the national standards for the frequency range of radio wave from a few MHz to higher than a hundred GHz had not been prepared for the calibration service yet, even though some of them were prepared only in the past.

There are some fundamental quantities for the measurement in radio wave region. They are power, voltage, noise, impedance and attenuation respecting transmission lines. About the spatial quantities they are electric and magnetic fields and antennas as a transducer from spatial quantities to circuitry values.

The NMIJ is developing national standards for these physical quantities and is also preparing the calibration system by which the traceability to the national standards is ensured in the Japan Calibration Service System (JCSS).

In the paper, some standard systems developed and under development are introduced with the traceability to the higher level standards up to SI units.

2. Electromagnetic Standards

2.1 Power

Some power standards have been under development for various connector types and wave guides in wide frequency range from 10MHz to 110GHz. A power standard is prepared as a signal power accurately evaluated by a calorie-meter. Fig.1 shows the structure of the power standard system

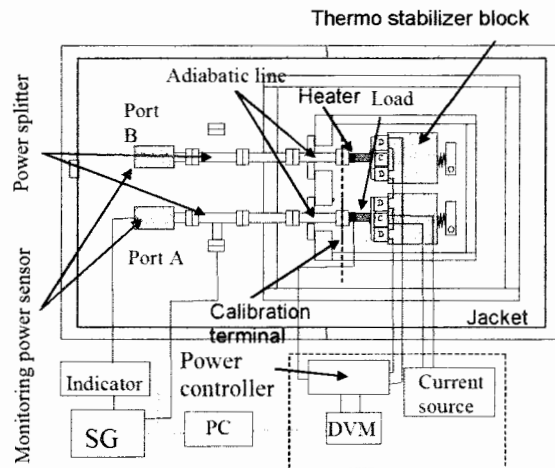


Fig. 1 Structure of RF and Microwave Calorimeter for Power Standard

prepared for the calibration of power sensors with PC-7 connector at the power levels of 1mW and 10mW from 10MHz to 18GHz [1]. The system will be registered to the Measurement Law and used for the "jcss" calibration as a specified reference standard.

The system is composed of a pair of sensor systems. One of the pair includes a stabilized signal source, a power divider, a power monitor, an adiabatic transmission line and a calorie-meter, which is the main part of the system. A power monitor is used for the stabilization of signal power. The principle of the power standard is DC power substitution calorimetry. The signal power is absorbed by the resistor in the calorie-meter and thermal balance is maintained by Peltier devices. The absolute RF power is decided substituting RF power by DC power after making the same thermal balance. The DC power is measured by the voltage and the current which are accurately measured by keeping the traceability to the national standards. The other sensor block is used for the compensation of ambient temperature change. Common temperature change on the pair block is compensated by inversely connected Peltier sensors across the blocks.

In the calibration service, the calorie-meter block is replaced to a DUT of a power sensor.

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2.2 Noise temperature

The noise standard is used as the reference in the measurement of signal-to-noise ratio. The RF noise is usually evaluated as an equivalent temperature on the basis of the Rayleigh-Jeans law which is fundamentally Planck's Black-body Radiation Law. Though the definition of noise power includes the bandwidth, the equivalent noise temperature is independently defined of the bandwidth. The equivalent temperature T_e connects to the noise power P by

$$T_e = \frac{P}{kB} \quad (1),$$

where k is the Boltzmann constant. Thermal noise sources are matched loads kept in the definite physical temperature and usually used as national standards based on the principle of the black body radiation. The noise temperature can be defined on the traceability to the physical temperature. The kind of standard is still under development in NMIJ.

Noise calibration system is composed of two noise sources having different temperatures and a radiometer as shown in Fig.2. A total power radiometer of zero-balance type having a good linearity is adopted. The sensitivity characteristic of the radiometer is fixed by these two reference noise sources and the noise temperature of a DUT can be measured by the radiometer as shown in Fig.3.

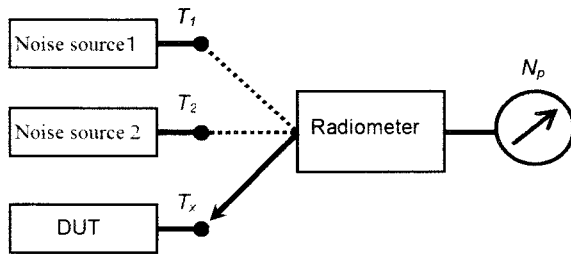


Fig.2 Configuration of calibration system of reference noise sources and radiometer

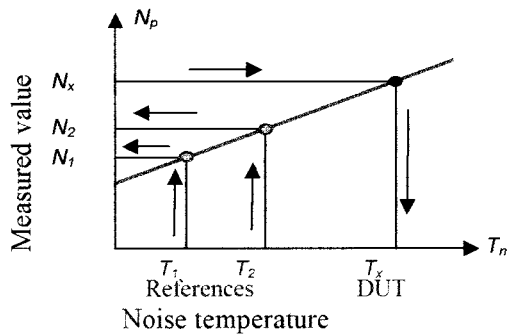


Fig.3 Method of calibration by reference noise sources and radiometer

NMIJ has prepared a noise calibration system from 2GHz to 18GHz on PC-7 connector. One reference

noise source is a room-temperature thermal noise source and the other is a diode noise source which is traceable to other NMI. The type-B uncertainty of the calibration is almost caused by those of reference noise sources (T_a , T_s), mismatching (M) of input port, and balancing attenuator(Y). The uncertainty budget is shown in Fig.4. As the temperature of DUT is decided by inter- or extrapolation between two reference temperatures, the total uncertainty is small near these two temperatures. The calibration is traceable to a JCSS physical temperature and the diode source of the higher temperature is traceable to other NMI.

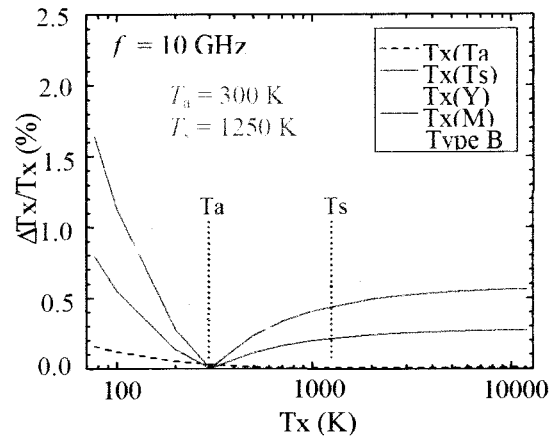


Fig.4 Type-B uncertainty budget of noise temperature calibration by two reference noise sources of a room temperature and a diode

2.3 Impedance (Reflection coefficient)

Impedance is important for the measurement of all other quantities developed as the NMIJ standards on RF metrology, because these quantities are decided by explicitly evaluating any reflection coefficient or with matching condition of important connected points in transmission lines.

The impedance of coaxial lines is accurately decided by the equation.

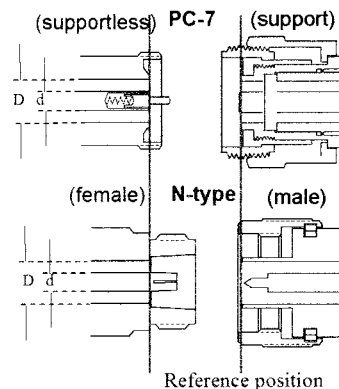


Fig.5 Structures of two common coaxial connectors of PC-7 and N. The interfaces shown by red lines are the reference positions where the impedance is evaluated.

$$Z_{0(HF)} \cong \frac{1}{2\pi} \sqrt{\frac{\mu}{\epsilon}} \ln\left(\frac{D}{d}\right) \quad (2)$$

Practical flexible coaxial lines have insulating supporter holding its center conductor separated from the outer conductor. As the permittivity of dielectric material is sensitive to temperature, the impedance of the ordinary coaxial line is also sensitive to temperature. So, air-lines without dielectrics are adopted as the impedance standards almost in all NMI's. The impedance is evaluated according to (2) by measuring the inner diameter of the outer conductor and the diameter of the center conductor.

The DUT of unknown impedance, for example, a matched load is usually measured by a vector network analyzer (VNA) using the standards airlines as the impedance reference. Fig.5 shows the procedure of the calibration by using quarter-wave standard airline. In case that the reflection coefficient Γ_m becomes Γ_{ma} after the insertion of the quarter wave line on the original VNA Z-plane, the calibrated reflection coefficient Γ_d is known on the reference plane made by the standard airline. This technique needs many different airlines in length corresponding to the wave length and is only practical in the frequency band of moderately short

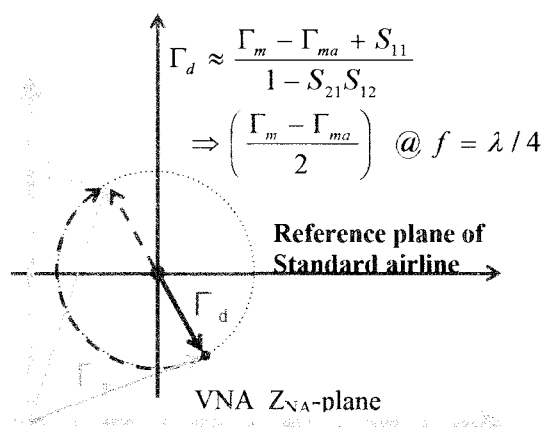


Fig.6 Procedure of calibration of coaxial impedance using quarter-wave standard airline

wave length. So the other technique must be developed for the lower frequency band.

The impedance standard is mainly traceable to the length and frequency standards in NMIJ. The other factors are the surface resistance of the airline and transmission attenuation, both of which are also traceable to the NMIJ standards.

2.4 Attenuation

RF attenuation is one of transmission characteristics both in the transmission line and respecting spatial

propagation. It is important quantity especially for antenna measurement in which the SIL needs the traceability to attenuation standards.

The attenuation is defined by the ratio of the signal powers before and after the insertion of a device. Fig.7 shows the block diagram of the standard system in NMIJ [2]. An induction voltage divider (IVD) is adopted for attenuation reference. As the IVD works at 1KHz, heterodyne frequency conversion technique is adopted for the calibration from 10MHz to 18GHz. Step attenuators up to 100dB are calibrated by the system. For such a large attenuation, the isolation between the input and output ports is major requisite. Isolation circuit utilizing optical transmission is used for coherent signal transmission line in heterodyne system instead of a metal line to reduce the leakage.

The list of the factors causing uncertainty is shown below in Table1 and the degree of contribution by each factor is shown in Fig.8 corresponding to the attenuation from 20dB to 100dB.

Source of uncertainty	Type
1 Induction voltage divider (IVD)	B
2 Source and load impedance of IVD	B
3 Amplitude instability	B
4 Linearity of mixers and amplifier	B
5 Leakage	B
6 Stability of IF output	B
7 Mismatch	B
8 Standard Uncertainty of data	A

Table1 Factors of uncertainty of ATT calibration

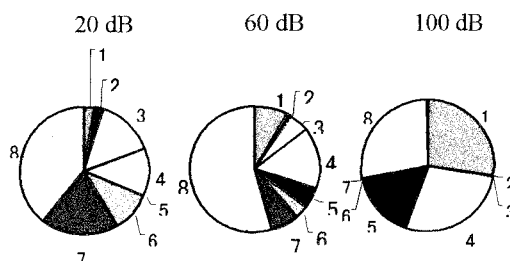


Fig.8 Contribution of major factors to the uncertainty of attenuation calibration

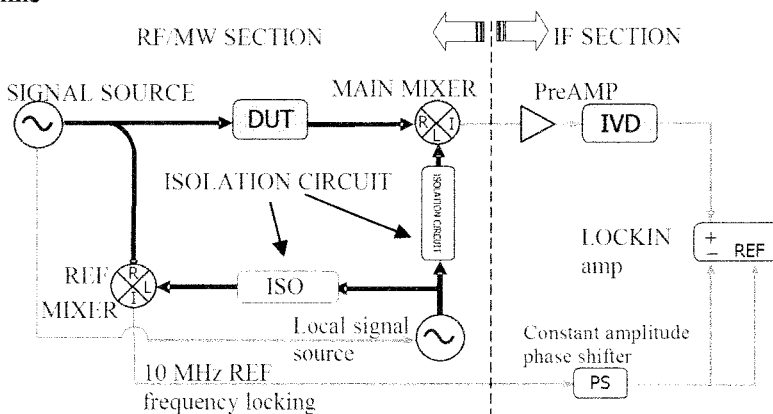


Fig.7 Block diagram of attenuation standard and calibration setup of RF attenuation measurement system based on dual channel IF substitution method (for 10MHz - 18 GHz)

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The contribution of the IVD, linearity, and leakage increases to the larger attenuation.

The attenuation standard and calibration system is traceable to the voltage ratio of low frequency induction divider which is calibrated by another electromagnetic division in NMIJ.

2.4 Dipole antenna

The service of antenna factors of dipole antennas had started in 2001 as a NMIJ calibration. Next year, the ISO17025 quality system was prepared through the accreditation by National Institute of Technology and Evaluation (NITE) with a peer review by other NMI researchers. The calibration item is the antenna factor of a definite height of 2m over a ground plane as shown in Fig.9. The antenna distance is decided not to have large sensitivity coefficient defined in the procedure of uncertainty evaluation in GUM.

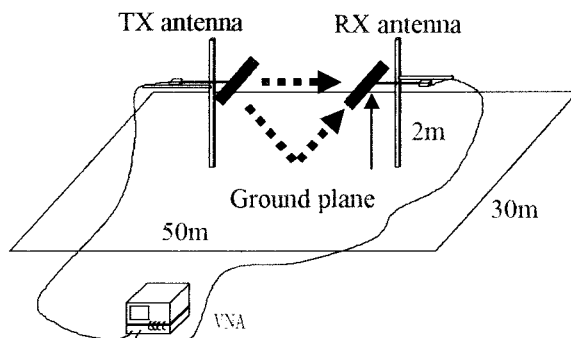


Fig.9 Antenna calibration setup in NMIJ

In 2003, the calibration was applied to the CMC (Capability of Measurement and Calibration) list which is useful for MRA in APMP and BIPM. It is still under review process.

The method of antenna calibration in NMIJ is a combination of three antenna method and substitution method [3]. The reason of using two different methods is that the three antenna method is time consuming. The three-antenna method is only used for the measurement of reference antennas and the substitution method is used for the calibration of AUT.

An example of the calibrated antenna factors of 24 half-wave dipoles and their uncertainties are shown in Fig.10. The uncertainties are the resultant values including that of the reference antenna by three-antenna method according to the procedure of GUM. The definite numbers of these uncertainties of the reference antenna and the substitution method are 0.36dB and 0.39dB, respectively, for example, at 400MHz. These values show a small increase even by 2-stage calibration procedure. The registered overall uncertainty is 0.7dB to guarantee the calibration through the whole frequency band and the number will be written in the calibration service. The traceability of the calibration is explicitly certified about length, frequency and attenuation.

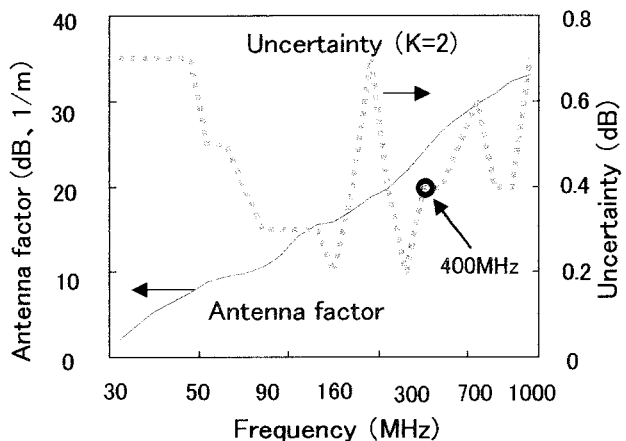


Fig.10 Antenna factors and uncertainties of NMIJ antenna calibration

The jcss calibration service is now being prepared for the registration in 2004 fiscal year based on the Measurement Law. Under the service of JCSS, some accredited calibration laboratories will start their calibration works with their expected small uncertainty increase from the NMIJ standard.

3. Conclusion

The fundamental quantities in national standards in RF band are power, voltage, noise, impedance, attenuation, electric and magnetic fields, and antennas. They are important for measurement and metrology. The NMIJ have been developing national standards on these RF quantities and preparing their calibration system. Some of them have been prepared into service with required conditions, for example, ISO17025 quality system.

The NMIJ will have the second term of the development plan for the national standards for metrology from 2005. In the term the spectrum of the calibration service will be expanded on frequency and on other parameters of connector types, line types and on other kinds of quantities.

References

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