A Substitution Method for Antenna Calibration by the Use of Broadband Antenna (30 to 1000 MHz)

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***Abstract*— ANSI C63.5-2006 [1] provides two annexes, Annex G and Annex H, for the use of antenna factors for NSA measurements.**

Annex G applies Tables G2 and G3 for Biconical dipole antennas as derived from free space antenna factors using a simulation technology to the specified geometry of Geometry-specific Correction Factor (GSCF).

Annex H describes the measurement procedure and reference site requirements in order to measure GSCF for a pair of antennas intended to be used in the normalized site attenuation (NSA) testing. Use of the Annex H assumes the user cannot apply the calculated GSCFs in Annex G. For example, calculated GSCFs have not yet been developed for hybrid broadband antennas and therefore the Annex H would be applied. This paper proposes an alternative calibration method to the Annex G and H, that is, a Broadband Antenna Substitution Method (SUB) in 10-m semi-anechoic chambers (SAC).

Keywords—antenna factor; broadband antenna; substitution; semi-anechoic chamber; calibration

I. INTRODUCTION

ANSI C63.4-2009 [2] requires that the measured normalized site attenuation for a radiated emissions test site shall be within ±4 dB of the theoretical NSA for an ideal test site, and that antenna factors of antennas to be used are determined as specified in [1]. In general, any broadband antennas are used for NSA measurements of radiated emissions test sites and the antenna factors are measured by the standard site method (SSM) in [1]. The SSM shall require a Standard Antenna Calibration Site (SACS) to calibrate antenna factors (AF) for NSA measurements. The reference [1] defines a site comprised of a flat, open-area, devoid of nearby scatters such as trees, power lines, and fences, that has a large metallic ground plane as the SACS (see ANSI C63.7-2005 [3]). Even if open-area test sites (OATS) meet physical and dimensional requirements defined in [3], many OATSs cannot always ensure to provide the stable calibration work of AF, because measurement works at OATSs are always affected by disadvantages due to such weather conditions as rain, wind, temperature, etc. Authors have repeated the study of calibration methods, which provide consistent antenna factors of broadband antennas in semi-anechoic chambers (SAC) regardless of weather conditions, through many experiments for several years. We reached a calibration method which provides approximately the same AFs compared with those measured by the SSM at an OATS, which meets requirements of [3]. The method is a substitution method which uses a broadband antenna calibrated by the SSM at the OATS meeting requirements of [3] as the reference antenna and calibrates other broadband antennas by the substitution in 10-m SACs. It is named as the Broadband Antenna Substitution Method (SUB). If the cautions described in a later section are carefully observed during the calibration setup, this method enables antenna calibrations to be repeatable, consistent and stable, and not affected by weather conditions. The SUB enables both OATSs and 10-m SACs to provide stable and accurate antenna calibration works.

The calibration of reference broadband antennas, and the OATSs and SACs used for experiments are described in section II, the calibration procedure of the SUB in section III, the comparison between AFs measured by the SSM at OATSs and SACs in section IV, the comparison between antenna factors measured by the SUB at OATSs and SACs in section V, the cautions at the setup stage of the SUB and uncertainty estimations in section VI, and advantages of the SUB in section VII.

II. MEASUREMENT CONDITIONS

All antennas used in this study were calibrated by the SSM at a reference OATS (Ref OATS) meeting the requirements of [3]. This Ref OATS has the area of a 50-m x 80-m metal ground plane in open-area and meets also CALTS requirements of CISPR 16-1-5 (2003) [4]. The AFs calibrated at the Ref OATS are written as AF_{ref} in this paper in order to discriminate from the other AFs measured in this study. Broadband antennas and test sites used are listed below:

A. *Broadband antennas*

- Biconical Antenna (Bicon): 30 to 300 MHz
  BBA9106
  - $Bicon_1$: SN# 2066
  - $Bicon_2$: SN# 2067
  - $Bicon_3$: SN# 1810
- Logperiodic Antenna (LPD): 200 to 1000 MHz
  VULP9118A
  - LPD_1: SN# 326
  - LPD_2: SN# 327
  - LPD_3: SN# 504
- Hybrid Antenna (Hybrid): 30 to 1000 MHz
  VULB9160
  - $Hybrid_1$: SN# 3123
  - $Hybrid_2$: SN# 3124
  - $Hybrid_3$: SN# 3154

- Transmitting Antenna: 30 to 1000 MHz
  VULB9160
  (The antenna is calibrated in-house)

B. Test Sites

- Reference OATS (Ref OATS):
  OATS
  Meet CALTS requirements of [4]
  Ground Plane (GP): 50 m × 80 m without weather protection enclosure
- OATS1:
  OATS
  GP: 20 m × 40 m without weather protection enclosure
- SAC1:
  10-m SAC
  Size: 24 m × 15 m × height =10 m
- SAC2:
  10-m SAC
  Size: 23 m × 14 m × height = 9.2 m
- SAC3:
  10-m SAC
  Size: 18.4 m × 9.9 m × height = 7.7 m
- SAC4:
  10-m SAC
  Size: 24.16 m × 14.6 m × height = 9.5 m

C. Correction factors to free space (ΔAF) and correction factors for NSA(GSCF) in [1]

- ΔAF and GSCF are not applied in this paper.

III. MEASUREMENT PROCEDURES

A. Broadband Antenna Substitution Method (SUB)

1) Set a Hybrid at the transmitting (Tx) side and the reference broadband antenna in 2-m height at the receiving (Rx) side separated 10-m from the transmitting antenna as shown in Fig. 1.
2) At the first, allow the measurement system to make zero-calibration by shorting cables including attenuators, and then connect both cables to Tx and Rx antennas.
3) Set the Network Analyzer (NA) to intended frequency coverage and measure receiving levels using max-hold function of NA during scanning the transmitting antenna height from 1 to 4 meters. Record the Rx level as Lref.
4) Replace the reference broadband antenna at the Rx side to a DUT antenna, repeat the step 3) and record the Rx level as Lx.
The antenna factor, AF_x, of the DUT antenna is calculated as follows;

$$AF_x = AF_{ref} + L_{ref} - L_x \text{ (dB)} \quad (1)$$

where, AF_{ref} are antenna factors of reference broadband antenna calibrated by the SSM at the Ref OATS.

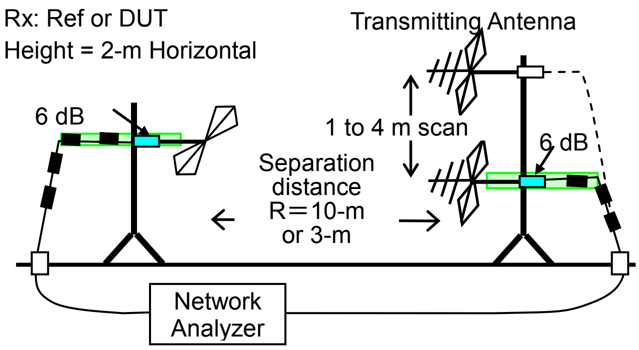

Fig. 1. Antenna arrangement of SUB

B. Standard Site Method (SSM)

According to [1], the SSM requires three site attenuation measurements under identical geometries (h_1, h_2, R) using three different antennas taken in pairs, as shown in Figure 2. The three equations associated with the three site attenuation measurements are (2), (3), and (4).

$$AF_1 + AF_2 = A_1 + 20 \log f_M - 48.92 + E_D^{max} \quad (2)$$
$$AF_1 + AF_3 = A_2 + 20 \log f_M - 48.92 + E_D^{max} \quad (3)$$
$$AF_2 + AF_3 = A_3 + 20 \log f_M - 48.92 + E_D^{max} \quad (4)$$

(All equations in dB)
where
E_D^{max} is the maximum received field at separation distance R from the transmitting antenna, shown in Table 2 and Table 3, in dB (μV/m) of [1].
AF_1, AF_2, AF_3 are the antenna factors of antennas 1, 2, and 3 in dB (1/m).
A_1, A_2, A_3 are the measured site attenuation in dB. (See Figure 3 and Section 5.3 of [1])
f_M is the frequency in MHz.

Solving (2), (3), and (4) simultaneously gives the desired expressions for the antenna factors in terms of the maximum total strength term, EDmax , and measured site attenuation, A_n. They are as follows:

$$AF_1 = 10 \log f_M - 24.46 + 1/2 [E_D^{max} + A_1 + A_2 - A_3] \quad (5)$$
$$AF_2 = 10 \log f_M - 24.46 + 1/2 [E_D^{max} + A_1 + A_3 - A_2] \quad (6)$$
$$AF_3 = 10 \log f_M - 24.46 + 1/2 [E_D^{max} + A_2 + A_3 - A_1] \quad (7)$$

Measurements are carried out using a network analyzer. The conditions are that h_1 is 2-m height, h_2 is 1 to 4 m scan and R is 10-m.

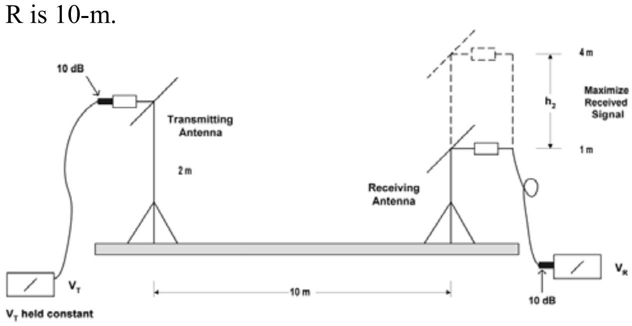

Fig. 2. Antenna arrangement of SSM

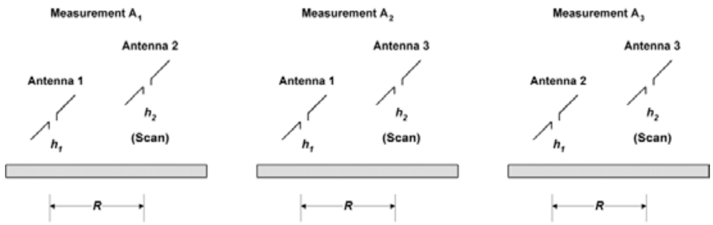

Fig. 3. Three site attenuation measurements using three different antennas in pairs

IV. Comparison between Antenna Factors of Broadband Antennas Measured at OATS and SACs by SSM

AF measurements of broadband antennas, 3 Bicons ($Bicon_1$, $Bicon_2$ and $Bicon_3$), 3 LPDs (LPD_1, LPD_2 and LPD_3) and 3 Hybrids ($Hybrid_1$, $Hybrid_2$ and $Hybrid_3$) were carried out by the SSM according to the procedure in section III-B at 5 different sites listed in section II. AF_x obtained in measurements are compared with AF_{ref}, which were calibrated by the SSM at the Ref OATS. Measurement conditions are 10-m distance, horizontal polarization and 2-m Tx height. AF differences are calculated as follows;

ΔdB1 = (AF_x measured by SSM at each test site) – (AFref by SSM at Ref OATS) (8)

Figs. 4, 6 and 8 show AF differences, ΔdB1, of $Bicon_2$, LPD_2 and $Hybrid_2$, respectively. As seen from these figures, characteristics of ΔdB1 are considerably large and irregular with frequency. Since it can be seen that the characteristics contain site attenuation characteristics of test sites as seen from SSM calculation equations, (5), (6) and (7), measurements of NSA characteristics for each test site used in this study were carried out and the differences, ΔdB2, between NSAs of each test site and the theoretical NSA are shown in Figs. 5, 7 and 9, respectively. The NSA measurement conditions are 10-m distance, 2-m Rx height and horizontal polarization using antennas of $Bicon_1$ and $Bicon_2$, LPD_1 and LPD_2, and $Hybrid_1$ and $Hybrid_2$. ΔdB2 are calculated as follows;

ΔdB2 = (NSA measured at each test site) – (Theoretical NSA) (9)

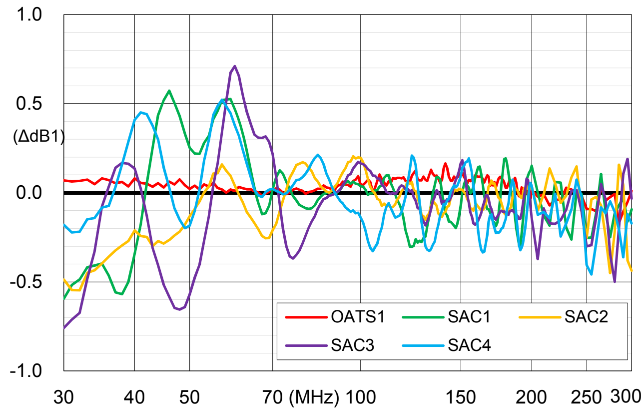

Fig. 4. ΔdB1 of $Bicon_2$ measured at each site

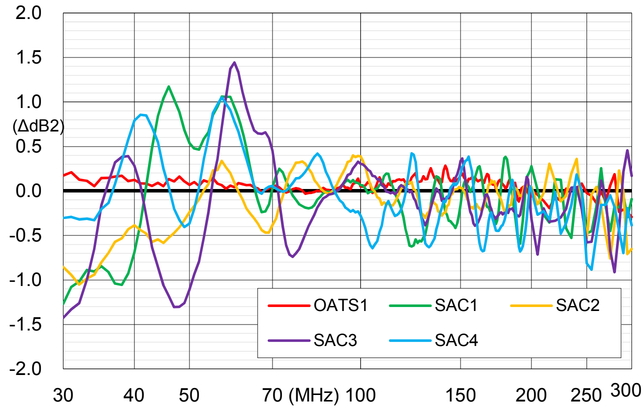

Fig. 5. ΔdB2 at each site using $Bicon_1$ and $Bicon_2$

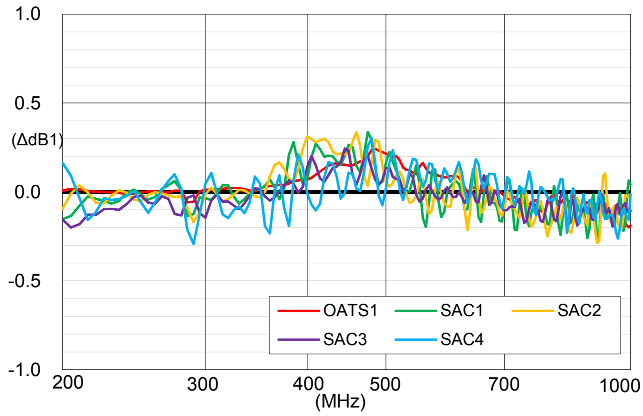

Fig. 6. ΔdB1 of LPD_2 measure at each site

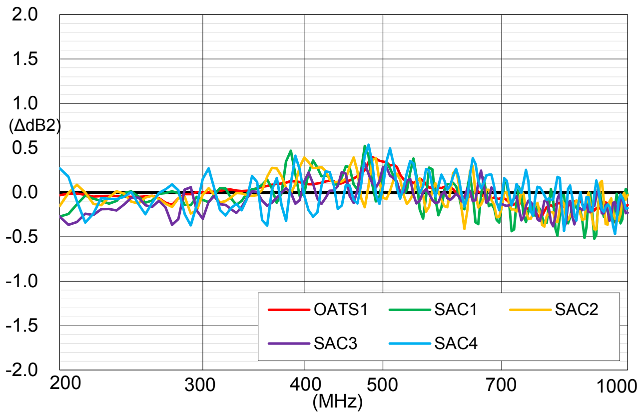

Fig. 7. ΔdB2 at each site using LPD_1 and LPD_2

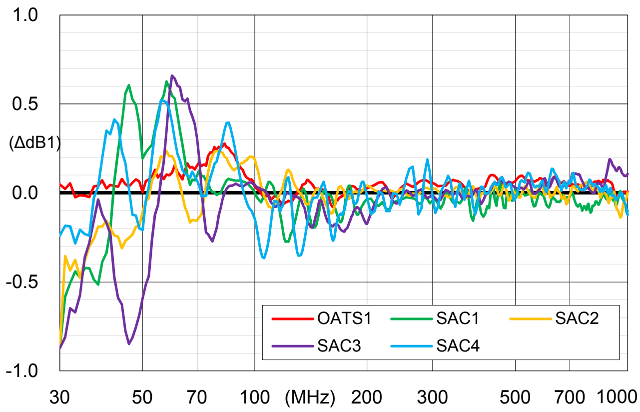

Fig. 8. ΔdB1 of $Hybrid_2$ measured at each site

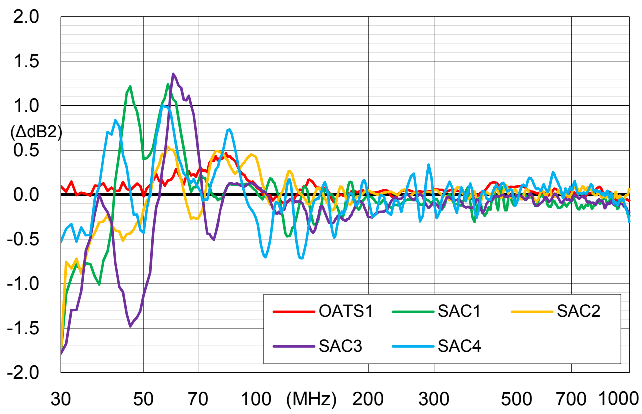

Fig. 9. ΔdB2 at each site using $Hybrid_1$ and $Hybrid_2$

As can be seen from comparisons of Figs. 4 and 5, Figs. 6 and 7, and Figs. 8 and 9, ΔdB1 characteristics are similar to ΔdB2 characteristics, and deviations of ΔdB1 are one-half of ΔdB2, approximately. From these measurement results, it can be seen that the antenna calibration by the SSM is affected by NSA characteristics of test sites used. In these test sites, the AF calibration by the SSM at OATSs shows considerably better performance because NSA deviations at the OATS are smaller than those at SACs.

V. Comparison between AFs Measured at Both OATS and SACs by SUB

Since NSA deviations from the theoretical NSA at 10-m SACs are larger than those of OATSs and the half value of NSA deviations become measurement errors as described in the previous section, AF calibrations by the SSM at 10-m SACs are not suitable for broadband antennas. Therefore, the SUB using a broadband antenna calibrated by the SSM at the Ref OATS as the reference antenna was studied and the result is reported.

The distance between antennas is 10 meters, the polarization is horizontal and the height of the reference and DUT antennas is 2-m. The differences between AFs measured by the SUB at each test site and AF_{ref} (which was calibrated by the SSM at the Ref OATS described in section II) are shown in Figs. 10 to 12 for each antenna of Bicon, LPD and Hybrid as ΔdB3, respectively.

$$\Delta \text{dB3} = (AF_x \text{ measured by SUB at each test site}) - (AF_{ref} \text{ by SSM at Ref OATS}) \qquad (10)$$

Reference antennas used are $Bicon_1$, LPD_1 and Hybrid1 and DUT antennas are $Bicon_2$, LPD_2 and $Hybrid_2$.

As can be seen from Figs. 10 to 12, AFs by this SUB coincide well with the AF_{ref} within 0.4 dB. AFs by the SUB at the OATS are worst and AFs by SUB at 10-m SACs show consistent accuracy within + 0.2/ - 0.3 dB. Those AFs measured by the SUB at SACs are affected little by NSA characteristics of test sites. Causes showing a little bit large deviations at the OATS seem to be due to changes of the measurement condition such as wind and temperature changes.

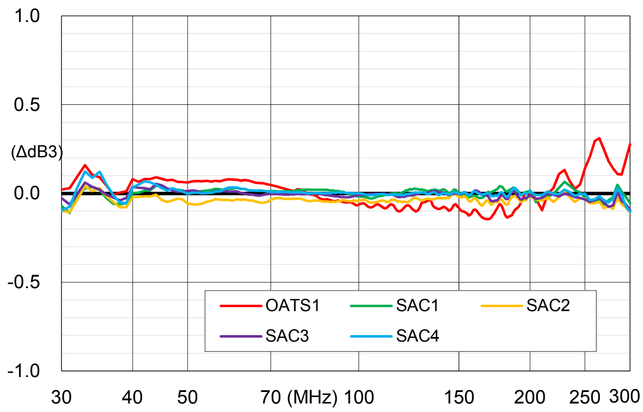

Fig. 10. Differences AFs (ΔdB3) for $Bicon_2$ at each site and AF_{ref}

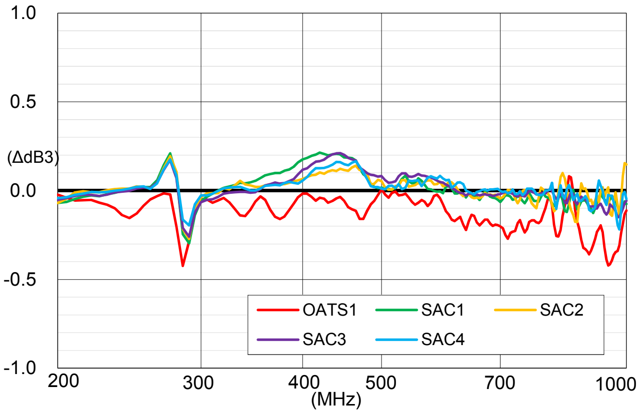

Fig. 11. Differences AFs (ΔdB3) for LPD_2 at each site and AF_{ref}

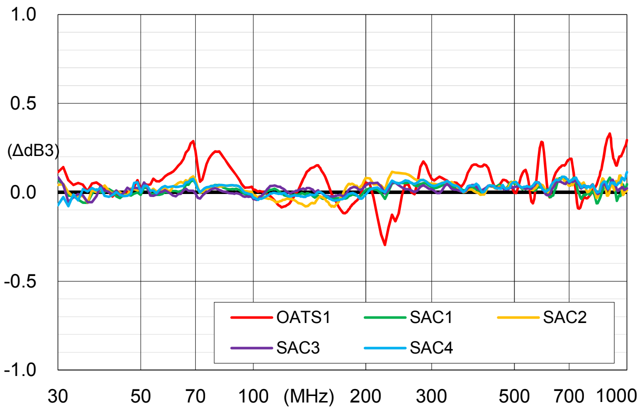

Fig. 12. Differences AFs (ΔdB3) for $Hybrid_2$ at each site and AF_{ref}

VI. Cautions of Setup and Measurement Uncertainty for SUB at SACs

A. Precautions

The following cautions must be carefully observed;

- Heat-up time for equipment and components must be sufficient to maintain a stable condition during measurements.
- AF calibration of reference antennas at the Ref OATS must be carried out in stable weather conditions.
- Distance between antennas and height of reference and DUT antennas must be accurate by using special measurement tools.
- Cables used at transmitting and receiving sides must be loaded by appropriate ferrite cores and must be sufficiently separated from antennas.

B. Uncertainty Estimation for Broadband Antenna Calibration by SUB

TABLE 1. Uncertainty Estimation for SUB

No	Source of error	Value (dB)	Probability Distribution	k	Ui (y)
1	Uncertainty of ref antenna: 30-300MHz	0.96	Normal	2.00	0.48
2	Uncertainty of ref antenna: 200-1000MHz	0.68	Normal	2.00	0.34
3	NA Linearity	0.05	√3	1.73	0.03
4	NA Stability / Reading fluctuation	0.05	√3	1.73	0.03
5	Cable loss fluctuation	0.05	√3	1.73	0.03
6	Uniformity in calibration area: 30-300MHz	0.25	√3	1.73	0.14
7	Uniformity in calibration area: 200-1000MHz	0.15	√3	1.73	0.09
8	Antenna distance: ±2cm Δ=20log(9.98/10)	0.02	√3	1.73	0.01
9	Antenna height: ±1cm	0.15	√3	1.73	0.09
10	Radiation pattern levelness / facing setting: ±1°	0.12	√3	1.73	0.07
11	ANT mast influence	0.15	√3	1.73	0.09
12	Measurement repeatability / ANT swing: 30-300MHz	0.15	Normal	1.00	0.15
13	Measurement repeatability / ANT swing: 200-1000MHz	0.20	Normal	1.00	0.20
14	Rx mismatch:30-300MHz	0.15	√2	1.41	0.11
15	Rx mismatch:200-1000MHz	0.10	√2	1.41	0.07
	Extended uncertainty (Bicon/Hybrid : 30-300MHz)			**k=2**	**1.13**
	Extended uncertainty (LPD/Hybrid : 200-1000MHz)			**k=2**	**0.88**

C. Considerations to Measurement Uncertainty(MU) on Antenna Calibration

- No. 1 & 2: Measurement Uncertainty of Calibration factor of Reference antennas for SUB;

  MU for AF_{ref} for SUB;
  Bicon: 0.96 dB
  LPD: 0.6 dB
  Hybrid: 0.68 dB
- No. 3 & 4: Amplitude resolution and Dynamic Accuracy of Network Analyzer's Specification
- No. 5: Cables characteristics: Measurement data before each calibration. After error of cable loss fluctuation is obtained, the calibration is started. The use of ferrite core mounted cables and cable guides provides stable cable sets within +/- 0.05 dB for the vertical NSA measurements.
- No. 6 & 7: Half of Receiving level is influenced by Electrical Uniformity maximum anomaly in calibration area of antenna size 1.5 m × 0.6 m × 0.6 m: 30 to 200 MHz: 0.5 dB, 200 to 1000 MHz: 0.3 dB
- No. 8: Distance setting errors: +/- 2 cm will make error +/- 0.02 dB to 10 m measurements.

- No. 9: The height setting errors to DUT antenna: +/- 1 cm height deference will make +/- 0.15 dB error at 10 meter measurements.
- No. 10: Vertical face alignment errors of both antennas of Bicon and LPA. The angle directivity of each antenna at the calibration: +/- 0.12 dB deviation every 1 degree angle of antenna direction. Antenna stay slope: ±1°, Facing: within 0.2°. Minimum 3 dB one side beam range 3 dB/25 = 0.12 dB from Hybrid: 25 °/ Bicon: 35 °/ LPD: 26°.
- No. 11: Error of setting distance between antenna end and antenna mast: The distances at 0.7 meters will make +/- 0.15 dB error in +/- 10 cm setting distance as the MU components.
- No. 12&13: This error is estimated from 5 times measurements
- No. 14 & 15: Mismatch loss Tx side has no influence by SUB.
  $\Delta = 20\log(1-\Gamma1\Gamma2)$ under Bicon/Hybrid 30 to 200 MHz SWRmax =14/$\Gamma1$ = 0.87 and 6 dB Pad SWR = 1.05/$\Gamma2$ = 0.02 = 0.15 dB
  $\Delta = 20\log(1-\Gamma1\Gamma2)$ under SWRmax with antenna 6 dB = 1.6/$\Gamma1$ = 0.23 and NA with 3dB SWR = 1.16/$\Gamma2$ = 0.07 = 0.14 dB
  Take Δ = 0.15 dB (bigger value)
  $\Delta = 20\log(1-\Gamma s\Gamma x)$ = 0.05 dB under LPD/Hybrid 0.2 to 1 GHz SWRmax = 2.0/$\Gamma1$=0.33 and 6dB: $\Gamma2$ = 0.02 = 0.05 dB
  $\Delta = 20\log(1-\Gamma s\Gamma x)$ under SWRmax with antenna 6 dB = 1.4/$\Gamma1$ = 0.17 and NA: $\Gamma2$ = 0.07 = 0.10 dB
  Take Δ = 0.10 dB (bigger value)

VII. CONCLUSION

The SUB provides stable, consistent and accurate calibrations with AF of broadband antennas calibrated by the SSM at the ref OATS. Therefore, this will provide a proper method for the antenna calibration of broadband antenna used for the compliance testing of EUT in accordance with [2].

The authors would like to propose this SUB as an AF calibration method of broadband antennas used for NSA measurements in Annex D of [2]. The SUB for the AF calibration of broadband antennas uses the broadband antenna calibrated in accordance with the SSM in [1] as the reference antenna and calibrated for each recommended geometry in Tables G.2 and G.3 of [1] at the OATS meeting requirements specified in [3]. The measurement uncertainty is ±1.13 dB for 30 to 300 MHz and ±0.88 dB for 200 to 1000 MHz at the coverage factor k = 2.

This SUB can be carried out in SACs, and this will create a time advantage. Our experience showed that AF measurements by the SUB in SACs take about two-third less time than that by the SSM at OATS. The reason is calibration works in SACs are not affected by the environment, for example surrounding noise and weather conditions. Because of the constant conditions, one set of measurements will suffice for the SUB at SACs, whereas 3 sets of measurements are required for the SSM at OATSs. Further, calibration works at the OATSs were always affected by the environment, such as winds swinging the cables, temperature changes affecting the flatness of the metal ground plane, rain changing the ground condition, etc. These conditions created larger uncertainties and more time was required for considering these uncertainties.

REFERENCES

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[4] CISPR 16-1-5(2003-11): Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-5: Radio disturbance and immunity measuring apparatus – Antenna calibration test sites for 30 MHz to 1 000 MHz