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

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ABSTRACT

Calibration of Broadband antennas

• ANSI C63.5-2006 [1] provides calibration method with the Standard Site Method (SSM) at a Standard Antenna Calibration Site (SACS) and two annexes, Annex G and Annex H, for the use of antenna factors for NSA measurements. (47CFR FCC Part 15 Sec. 31)

• 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).
I. INTRODUCTION

- Antenna calibration method in ANSI C63.5-2006:
  - Antenna calibration with SSM shall be performed at SACS
  - SACS: The site shall be void of buildings, electric lines, fences, trees, underground cable, pipelines, etc. as specified in ANSI C63.7 -2005
  - Characteristics of SACS: Ideal site for the Antenna calibration as specified in CISPR 16-1-5 2012-06 Ed.1.1 CALTS
  - SSM: Most common Calibration Method for antenna calibration specified in ANSI C63.5 -2006 Paragraph 5, Detail procedures are provided in Annex G and Annex H.
  - GSCF: Correction factors (in dB) that are calculated or measured for each frequency at a specific geometry.
I. INTRODUCTION

- Substitution method (SUB) for the broadband antenna calibration in this paper.
  - Use Reference antennas that are calibrated at the Reference OATS
  - Reference OATS shall be SACS to calibrate Reference antenna
  - Substitute the DUT with Reference antenna to obtain Antenna Factors.
  - SUB can be performed in the 10 meter Semi Anechoic Chamber or OATS for EMI measurements.
  - Measurement Uncertainty degrades at the worst value of only 0.2 dB
II. MEASUREMENT CONDITIONs

A. Using Broadband antennas

Each antenna used in this study is calibrated by the SSM at the reference OATS meeting the requirements of [3] and [4]

- Biconical Antenna (Bicon): 30 to 300 MHz
  - BBA9106 Bicon₁, Bicon₂ and Bicon₃
- Logperiodic Antenna (LPD): 200 to 1000 MHz
  - VULP9118A LPD₁, LPD₂ and LPD₃
- Hybrid Antenna (Hybrid): 30 to 1000 MHz
  - VULB9160 Hybrid₁, Hybrid₂ and Hybrid₃
- Transmitting Antenna: 30 to 1000 MHz
  - VULB9160 Hybridₜx (The antenna is validated in-house)
- Network Analyzer: Advantest R3770
II. MEASUREMENT CONDITIONS

A. Using Broadband antennas

Each antenna used in this study was calibrated by the SSM at the reference OATS (Ref OATS) meeting the requirements of [3], [4]

<table>
<thead>
<tr>
<th></th>
<th>Ant1 Bicon₁, LPD₁, Hybrid₁</th>
<th>Ant2 Bicon₂, LPD₂, Hybrid₂</th>
<th>Ant3 Bicon₃, LPD₃, Hybrid₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSA</td>
<td>✔</td>
<td>✔</td>
<td></td>
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<tr>
<td>SSM</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>SUB</td>
<td>✔ Reference Antenna</td>
<td>✔ DUT Antenna</td>
<td></td>
</tr>
</tbody>
</table>
II. MEASUREMENT CONDITIONs

B. Test sites

- **Reference OATS (Ref OATS):**
  - OATS: Meet CALTS requirements of CISPR 16-1-5 (2003) [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

Correction factors to free space (ΔAF) and correction factors for NSA (GSCF) in ANSI C63.5-2006 Annex G are not applied in this paper.
III. MEASUREMENT PROCEDEURES

A. Broadband Antenna Substitution Method (SUB)

Fig. 1. Antenna arrangement of SUB

- The antenna factor, $AF_x$, of the DUT antenna is calculated as follows;
- Set a Hybrid at the transmitting (Tx) side and the reference broadband antenna at the receiving (Rx) side as shown in Fig. 1. Record the Rx level as $L_{ref}$.
- Replace the reference broadband antenna at the Rx side to a DUT and record the Rx level as $L_x$.
- $AF_x = AF_{ref} + L_{ref} - L_x$ (dB) (1)
- where, $AF_{ref}$ are antenna factors of reference broadband antenna calibrated by the SSM at the Ref OATS.

$$AF_x = AF_{ref} + L_{ref} - L_x$$ (1)
III. MEASUREMENT PROCEDUREs

B. Standard Site Method (SSM)

According to ANSI C63.5-2006 Section 5.2, the SSM requires three site attenuation measurements under identical geometries (h1, h2, 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).

\[
\begin{align*}
\text{AF}_1 + \text{AF}_2 &= \text{A}_1 + 20 \log f_M - 48.92 + E_{D_{\max}} \\
\text{AF}_1 + \text{AF}_3 &= \text{A}_2 + 20 \log f_M - 48.92 + E_{D_{\max}} \\
\text{AF}_2 + \text{AF}_3 &= \text{A}_3 + 20 \log f_M - 48.92 + E_{D_{\max}} 
\end{align*}
\]

(All equations in dB)

AF, AF, and AF are the antenna factors of antennas 1, 2, and 3 in dB (1/m).

A, A, and A are the measured site attenuation in dB. (See Figure 3 and Section 5.3 of [1])
IV. COMPARISON BETWEEN ANTENNA FACTORS OF BROADBAND ANTENNAS MEASURED AT OATS AND SACs BY SSM

SSM measurement studies in OATS and SAC

$A_{F_x}$ at the Ref OATS for 10-m distance, horizontal polarization and 2-m Tx height.
AF differences at each site is calculated as follows and shown in Figs. 4, 6 and 8.

$$\Delta dB_1 = (A_{F_x} \text{ measured by SSM at each test site}) - (A_{F_{ref}} \text{ by SSM at Ref OATS}) \quad (8)$$

The NSA at each site for 10-m distance, 2-m Tx height and horizontal polarization using antennas of $\text{Bicon}_1$ and $\text{Bicon}_2$, $\text{LPD}_1$ and $\text{LPD}_2$, and $\text{Hybrid}_1$ and $\text{Hybrid}_2$.
$\Delta dB_2$ are calculated as follows and shown Figs. 5, 7 and 9.

$$\Delta dB_2 = (\text{NSA measured at each test site}) - (\text{Theoretical NSA}) \quad (9)$$
IV. COMPARISON BETWEEN ANTENNA FACTORs OF BROADBAND ANTENNAS MEASURED AT OATS AND SACs BY SSM (Bicon)

Fig. 4. AF Deviation: D10H2
\[ \Delta dB_1 \text{ of Bicon}_2 \text{ measured at each site} \]

Fig. 5. NSA Deviation: D10H2
\[ \Delta dB_2: \text{Pair of Bicon}_1 \text{ and Bicon}_2 \]

Fig. 4 shows AF differences of \( \Delta dB_1 \) for Bicon\(_2\). Fig. 5 shows the differences of \( \Delta dB_2 \) each test site.
IV. COMPARISON BETWEEN ANTENNA FACTORS OF BROADBAND ANTENNAS MEASURED AT OATS AND SACs BY SSM (LPD)

Fig. 6. AF Deviation: $\Delta dB_1$ of LPD$_2$ measured at each site

Fig. 7. NSA Deviation: $\Delta dB_2$: Pair of LPD$_1$ and LPD$_2$

Fig. 6 shows AF differences of $\Delta dB_1$ for LPD$_2$. Fig. 7 shows the differences of $\Delta dB_2$ at each test site.
IV. COMPARISON BETWEEN ANTENNA FACTORS OF BROADBAND ANTENNAS MEASURED AT OATS AND SACs BY SSM (Hybrid)

Fig. 8. AF Deviation: D10H2
ΔdB1 of Hybrid2 measured at each site

Fig. 9. NSA Deviation: D10H2
ΔdB2: Pair of Hybrid1 and Hybrid2

Fig. 8 shows AF differences of ΔdB1 for Hybrid2.
Fig. 9 shows the differences of ΔdB2 at each test site.
IV. COMPARISON BETWEEN ANTENNA FACTORS OF BROADBAND ANTENNAS MEASURED AT OATS AND SACs BY SSM

As can be seen from comparisons of Figs. 4 and 5, Figs. 6 and 7, and Figs. 8 and 9, $\Delta dB_1$ characteristics are similar to $\Delta dB_2$ characteristics, and deviations of $\Delta dB_1$ are one-half of $\Delta dB_2$, approximately.

From these measurement results, it can be seen that the antenna calibration with SSM in SAC is significantly affected by NSA characteristics of the SAC used.
V. COMPARISON BETWEEN AFs MEASURED AT BOTH OATS AND SACs BY SUB

The SUB using a broadband antenna calibrated by the SSM at the Ref OATS as the reference antenna was studied and the specific results are reported (Supplemental data of D10V1 referred)

- Conditions:
  - Distance of antennas: 10 meters
  - Polarization: Horizontal
  - Height of antennas: 2-m.
  - Reference antennas: Bicon$_1$, LPD$_1$ and Hybrid$_1$
  - DUT antennas: Bicon$_2$, LPD$_2$ and Hybrid$_2$
V. COMPARISON BETWEEN AFs MEASURED AT BOTH OATS AND SACs BY SUB

The differences between AFs measured by the SUB at each test site and $AF_{ref}$ are shown in Figs. 10 to 12 for each antenna of Bicon, LPD and Hybrid as $\Delta dB3$.

$$\Delta dB3 = (AFx \text{ measured by SUB at each test site}) - (AF_{ref} \text{ by SSM at Ref OATS})$$  \hspace{1cm} (10)

As can be seen from Figs. 10 to 12, AFs by this SUB coincide within 0.4 dB to the $AF_{ref}$. AFs by the SUB at the OATS are worse than at SAC showing consistent accuracy within + 0.2 / - 0.3 dB. Those AFs measured by the SUB at SACs would not be affected by NSA characteristics of test sites. The large deviations at the OATS are caused by changes of the measurement condition such as wind breezing and temperature changes.
V. COMPARISON BETWEEN AFs MEASURED AT BOTH OATS AND SACs BY SUB (Bicon)

Fig. 10. Differences of AFs ($\Delta dB3$) for Bicon$_2$ at each site and AF$_{ref}$

Fig. 5. NSA Deviation: D10H2
$\Delta dB2$: Pair of Bicon$_1$ and Bicon$_2$

Fluctuations of AFs from the OATS may be caused by wind breezing.
V. COMPARISON BETWEEN AFs MEASURED AT BOTH OATS AND SACs BY SUB (LPD)

Fig. 11. Differences of AFs ($\Delta dB3$) for LPD$_2$ at each site and AF$_{ref}$

Fig. 7. NSA Deviation: D10H2
$\Delta dB2$: Pair of LPD$_1$ and LPD$_2$

Fluctuations of AFs from the OATS may be caused by wind breezing.
V. COMPARISON BETWEEN AFs MEASURED AT BOTH OATS AND SACs BY SUB (Hybrid)

Fig. 12. Differences of AFs (ΔdB3) for Hybrid₂ at each site and AFₚₑᵣₑ

Fig. 9. NSA Deviation: D10H2
ΔdB2: Pair of Hybrid₁ and Hybrid₂

Fluctuations of AFs from the OATS may be caused by wind breezing.
VI. CAUTIONs OF SETUP AND MEASUREMENT UNCERTAINTY FOR SUB AT SACs

A. Precautions

The following cautions must be carefully kept by procedures’ instructions;

- Heat-up time
- Consistent reference antenna calibration
- Distance and height of antennas
- Cable treatment

B. Uncertainty Estimation for Broadband Antenna Calibration by SUB

<table>
<thead>
<tr>
<th>No.</th>
<th>Source of error</th>
<th>Value (dB)</th>
<th>Probability Distribution</th>
<th>k</th>
<th>U (v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Uncertainty of ref antenna: 30-300MHz</td>
<td>0.06</td>
<td>Normal</td>
<td>2.0</td>
<td>0.48</td>
</tr>
<tr>
<td>2</td>
<td>Uncertainty of ref antenna: 200-1000MHz</td>
<td>0.68</td>
<td>Normal</td>
<td>2.0</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>NA Linearity</td>
<td>0.05</td>
<td>V3</td>
<td>1.73</td>
<td>0.06</td>
</tr>
<tr>
<td>4</td>
<td>NA Stability / leadin fluctuation</td>
<td>0.05</td>
<td>V3</td>
<td>1.73</td>
<td>0.03</td>
</tr>
<tr>
<td>5</td>
<td>Cable loss/fluctuation</td>
<td>0.05</td>
<td>V3</td>
<td>1.73</td>
<td>0.03</td>
</tr>
<tr>
<td>6</td>
<td>Uniformity in calibration area: 30-300MHz</td>
<td>0.25</td>
<td>V3</td>
<td>1.73</td>
<td>0.14</td>
</tr>
<tr>
<td>7</td>
<td>Uniformity in calibration area: 200-1000MHz</td>
<td>0.15</td>
<td>V3</td>
<td>1.73</td>
<td>0.09</td>
</tr>
<tr>
<td>8</td>
<td>Antenna distance ±2cm / Δ=20log(9.98/10)</td>
<td>0.02</td>
<td>V3</td>
<td>1.73</td>
<td>0.01</td>
</tr>
<tr>
<td>9</td>
<td>Antenna height ±1cm</td>
<td>0.15</td>
<td>V3</td>
<td>1.73</td>
<td>0.09</td>
</tr>
<tr>
<td>10</td>
<td>Radiation pattern levelness/facing setting: ±1°</td>
<td>0.12</td>
<td>V3</td>
<td>1.73</td>
<td>0.07</td>
</tr>
<tr>
<td>11</td>
<td>ANT mast influence</td>
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<td>13</td>
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<tr>
<td>14</td>
<td>Rx mismatch: 30-300MHz</td>
<td>0.15</td>
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<td>1.41</td>
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Extended uncertainty (BioC/0.300MHz) = k=2 1.13

Extended uncertainty (LPD/0.200-1000MHz) = k=2 0.88
VI. CAUTIONs OF SETUP AND MEASUREMENT UNCERTAINTY FOR SUB AT SACs

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

No. 6 & 7: Influence by Electrical Uniformity

No. 8: Distance setting errors.

No. 9: The height setting errors to DUT antenna.

No. 10: Vertical face alignment errors of both antennas of Bicon and LPA.

No. 11: Error of setting distance between antenna end and antenna mast.

No. 12 & 13: This error is estimated from 5 times measurements

No. 14 & 15: Mismatch loss Tx side has no influence by SUB.
VII. CONCLUSION

- Antenna calibration with SSM shall use a Standard Antenna Calibration Site (SACS)/ ANSI C63.5-2006_5.2 and should not be applied in the 10-m semi-anechoic chambers (SAC) especially for Bicon and Bilog antennas.

- Advantage on antenna calibration with SUB:
  - Consistent Calibration: less affects from ambient conditions of wind, rain, radio noises and NSA characteristics.
  - Time saving: AF measurements by the SUB take about two-third less than that of SSM.

- Disadvantage on antenna calibration with SUB:
  - Measurement Uncertainty will be degraded around 0.2dB to that of Ref OATS at the worst case.

◆ **SUB will be acceptable for the broadband antenna calibration method.**
REFERENCES


Thank you
Meet CALTS requirements of CISPR 16-1-5 (2003) [4].

Ground Plane (GP):
50 m × 80 m without weather protection enclosure
Test sites: OATS1

OATS GP:
20 m × 40 m without weather protection enclosure
Test sites: SAC1

10-m SAC Size:
24 m × 15 m × height = 10 m
Supplemental data - 4

Test sites: SAC2

10-m SAC Size:

23 m × 14 m × height = 9.2 m
Test sites: SAC3

10-m SAC Size:
18.4 m × 9.9 m × height = 7.7 m
Supplemental data - 6

Test sites: SAC4

10-m SAC Size:
24.16 m × 14.6 m × height = 9.5 m
## Supplemental data - 7

### Uncertainty Estimation for Broadband Antenna Calibration by SUB

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### Extended uncertainty

- **Bicon/Hybrid : 30-300MHz**
  
  \[k=2 \quad 1.13\]

- **LPD/Hybrid : 200-1000MHz**
  
  \[k=2 \quad 0.88\]
Fig. 13. SSM AF Deviation: D10V1
ΔdB1 of Bicon₂ measured at each site

Fig. 14. NSA Deviation
ΔdB2: Pair of Bicon₁ and Bicon₂
Fig. 15. SSM AF Deviation: D10V1
$\Delta\text{dB}_1$ of LPD$_2$ measured at each site

Fig. 16. NSA Deviation: D10V1
$\Delta\text{dB}_2$: Pair of LPD$_1$ and LPD$_2$
Fig. 17. SSM AF Deviation: D10V1
$\Delta dB_1$ of Hybrid$_2$ measured at each site

Fig. 18. NSA Deviation: D10V1
$\Delta dB_2$: Pair of Hybrid$_1$ and Hybrid$_2$
Fig. 19. SUB Differences AFs ($\Delta$dB3) for Bicon2 at each site and AFref

Fig. 14. NSA Deviation $\Delta$dB2: Pair of Bicon$_1$ and Bicon$_2$
Fig. 20. SUB
Differences AFs (ΔdB3) for LPD₂ at each site and AF_{ref}

Fig. 16. NSA Deviation: D10V1
ΔdB2: Pair of LPD₁ and LPD₂
Fig. 21. SUB Differences AFs ($\Delta dB_3$) for Hybrid$_2$ at each site and AF$_{ref}$

Fig. 18. NSA Deviation: D10V1
$\Delta dB_2$: Pair of Hybrid$_1$ and Hybrid$_2$