Influence of antenna half-power beam width on equipment under test volume in radiation disturbance measurement

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Abstract: Through the study of the latest radiation disturbance measurement standards, the difference between test volume and equipment under test volume was compared and analyzed. Different types of antennas will be used in the radiated disturbance measurement in terms of the different frequency range. Various antennas have kinds of directional characteristics. This article analyzes the influence of antenna half-power beam width on the equipment under test volume, especially on the height, from three frequency ranges. Furthermore, taking the typical horn antenna as the starting point, as well as the formula of volume with antenna half-power beamwidth, the relationship between equipment volume and frequency is calculated. Finally, the influence of antenna half-power beam width on the equipment under test volume is obtained.

1. Introduction
The latest version of CISPR 16-2-3 standard adds the specification of influencing factors about the equipment under test (EUT) volume. According to the standard, the EUT volume depends on the test distance and frequency range in the radiation disturbance measurement. That means the EUT volume suffers the restrictions of field strength underestimation effect, near-field effect, test antenna half-power beam width (HPBW) and site validation results [1]. For radiation disturbance measurement, different types of test antennas are used for different frequency bands. Thus test antennas has the different directivity. The half-power beam width or 3dB beam width is an important technical index of antenna directivity. The narrower the half-power beam width, the better the directivity and the stronger the anti-interference ability [2-3], and the smaller the volume of EUT is required. Matching degree between EUT volume and antenna HPBW determines the accuracy of the measurement, which has the impact on the evaluation of uncertainty. Therefore, it is necessary to study the influence of half-power beam width of receiving antenna on EUT volume.

2. Methods and Materials

2.1 Comparison of test volume and EUT volume
In radiation disturbance test, test volume and EUT volume are two different concepts. Test volume refers to the effective volume to place EUT in a set of test system. The test volume is the volume...
containing EUT volume. Before the radiation measurement, the test site needs to be validated. The results of site validation determine the size of test volume, which is maximum range meeting the site requirements in the anechoic chamber [4].

EUT volume is a cylindrical space defined by EUT diameter and height. The EUT volume consists of a cylinder formed by the rotation of the EUT around its geometric center. The cylinder includes every EUT part, even the cables and cable racks. The length of included cable is related to test frequency. When the frequency range is from 30MHz to 1GHz, the EUT volume includes 1.6m long cable. When the frequency range is above 1GHz, the EUT volume includes 0.3m long cable. The diagram of test volume and EUT volume is shown in Figure 1.

![Figure 1. Diagram of test volume and EUT volume](image)

Generally, to find the maximum field strength generated by EUT, the receiving antenna needs height scanning during the measurement [5]. If the half-power beam width of the antenna cannot completely cover the EUT at each scanning height, the test data might be inaccurate, which will increase the uncertainty. Therefore, testers should know whether the HPBW of the antenna can fully cover the EUT before testing. When the HPBW cannot completely cover the EUT, step scanning is required. The height scanning is like a field strength probe, which sniff the radiation disturbance by approaching the EUT. This method can effectively judge whether there is radiation or not, but it can not precisely measure the field strength of radiation.

2.2 9kHz - 30MHz measurement method

In the range of 9 kHz – 30 MHz, radiation disturbance measurement can be carried out with large loop antenna system (LLAS) or in semi anechoic chamber. The LLAS system uses three loop antennas to measure the magnetic field components in three directions perpendicular to each other. Due to the weak directivity of the loop antenna, the HPBW of the antenna is not the main limiting factor of the EUT volume in this frequency range. As the EUT shall be placed in the center of the LLAS system during measurement, the EUT size is mainly limited by the diameter of the LLAS system. When the test is conducted in a semi anechoic chamber or open site, the separating distance will be a major limitation on the EUT volume.

2.3 30MHz - 1GHz measurement method

EUT volume mainly includes two parameters: diameter and height. In the frequency range of 30 MHz – 1 GHz, log periodic antenna is generally used. The directivity of this kind of antenna has an important impact on the uncertainty of radiation disturbance test. Take the log periodic dipole array antenna (LPDA) as an example [6], the antenna has strong directivity above the 200MHz. The typical value of antenna HPBW is 60°, according to the trigonometric function, the diameter of EUT volume can reach 6m when the separating distance is 3m as shown in Figure 2. The EUT volume is large enough. It can also be said that the diameter limit of the antenna HPBW on the EUT volume is relatively loose.
Figure 2. Calculation of typical EUT volume diameter (30MHz - 1GHz)

However, the parameters of EUT volume include not only the diameter of the cylinder, but also the height. When the HPBW $\theta_{3dB}$ is 60 ° and the test distance $d$ is 3m, it can be calculated that the volume height $w$ of EUT is 1.73m according to the trigonometric function formula $w = d \tan 0.5\theta$ as shown in Figure 3.

![Figure 3. Calculation of typical EUT volume height (30MHz - 1GHz)](image)

Figure 3. Calculation of typical EUT volume height (30MHz - 1GHz)

When measured in a semi anechoic chamber, the HPBW of the receiving antenna shall completely cover the EUT and the EUT image in the floor. If the HPBW is 60 °, the antenna can achieve full coverage of EUT and its image only at the position of O point on the ground. Generally, the radiation disturbance is measured by non-pitch antenna, which means the receiving antenna always remains parallel to the reference plane at each scanning height. Thus there is a problem. It is impossible for the antenna to reach point O in Figure 3, because the receiving antenna has a certain size. So, the HPBW of the antenna cannot completely cover the EUT and its image. The bore-sight test method may be adopted to ensure that the axis of the test antenna always points to the center of EUT and mirror image with the change of antenna height. Therefore, it can be seen that the height of EUT volume is a more important parameter than the diameter in the radiation disturbance measurement. In the frequency range of 30MHz - 1GHz, the HPBW of the antenna limits the height of EUT more than the diameter.

2.4 1GHz - 18GHz measurement method

The radiation measurement above 1GHz is generally carried out in the full anechoic chamber with horn antenna. The directivity of horn antenna is very strong, and the beam width is much narrower than that below 1GHz [7]. Taking one horn antenna as an example, under different distances, Table 1 shows the limit of antenna half-power beam width on EUT volume.
Table 1. Requirements of HPBW for EUT volume (1GHz - 18GHz)

| distance /m | 3     | 5     | 10    |
|-------------|-------|-------|-------|
| EUT volume  | 1.5×1.5 | 2×2 | 5×3   |
| $D\times h$ /m |       |       |       |
| HPBW $\theta_{3dB}$/° | 28    | 22.6  | 22.6  |

$D$ is the diameter of EUT volume, $h$ is the height of EUT volume, $\theta_{3dB}$ is the half-power beam width of antenna.

Figure 4. Height scanning requirements for EUT

As shown in the Figure 4, if the test distance $d$ and the antenna HPBW $\theta_{3dB}$ are known, $w$ is set the width of the antenna beam on the EUT, then the corresponding EUT size can be calculated by Formula 1 below.

\[
    w = 2d\tan(0.5\theta_{3dB})
\]

It can be seen from Table 1 that the smaller the separating distance, the smaller the half-power beam width of the antenna, and the smaller the EUT volume. The larger the measurement distance, the larger the HPBW of the antenna, which means the larger EUT volume. In the radiation disturbance test, the distance and antenna type must be reasonably selected. That means the antenna beam width irradiated on EUT can completely cover the height of EUT volume, or to increase the separating distance or replace the antenna with larger beam width.

3. Results & Discussion

In the radiation disturbance measurement, the separating distance and antenna type must be selected in advance to ensure that EUT is within the coverage of antenna pattern. When the EUT size is larger than the HPBW, the receiving antenna needs to height scan to obtain the accurate field strength.

According to the formula (1), the size $w$ of EUT is decided by the separating distance $d$ and the half-power beam width $\theta_{3dB}$. In order to study the relation between EUT size and antenna HPBW, we select the measuring distance of 3m and the frequency range of 1 GHz – 18 GHz by means of the double ridged horn antenna.

According to the antenna pattern provided by the manufacturer, we can obtain the relation between HPBW, EUT volume and frequency as shown in the Table 2.
Table 2. Relation between HPBW, EUT volume and frequency

| Frequency f/GHz | HPBW θ<sub>3dB</sub> (E plane) /° | Width w<sub>E</sub> /m | HPBW θ<sub>3dB</sub> (H plane) /° | Width w<sub>H</sub> /m |
|----------------|-----------------------------------|----------------------|-----------------------------------|----------------------|
| 1              | 96.4                              | 6.71                 | 57.9                              | 3.32                 |
| 2              | 52.9                              | 2.98                 | 41.3                              | 2.26                 |
| 3              | 37.6                              | 2.04                 | 32.1                              | 1.73                 |
| 4              | 32.4                              | 1.74                 | 37.3                              | 2.03                 |
| 5              | 51.7                              | 2.91                 | 35.8                              | 1.94                 |
| 6              | 46.2                              | 2.56                 | 37.3                              | 2.03                 |
| 7              | 51.7                              | 2.91                 | 37.5                              | 2.04                 |
| 8              | 49.2                              | 2.75                 | 35.3                              | 1.91                 |
| 9              | 46.5                              | 2.58                 | 35.3                              | 1.91                 |
| 10             | 48.7                              | 2.72                 | 36.9                              | 2.00                 |
| 11             | 49.5                              | 2.77                 | 33.3                              | 1.79                 |
| 12             | 45.7                              | 2.53                 | 35.9                              | 1.94                 |
| 13             | 45.8                              | 2.53                 | 36.1                              | 1.96                 |
| 14             | 46.9                              | 2.60                 | 34.1                              | 1.84                 |
| 15             | 45                                | 0.79                 | 9.0                               | 0.47                 |
| 16             | 13                                | 0.68                 | 9.0                               | 0.47                 |
| 17             | 43                                | 2.36                 | 16.1                              | 0.85                 |
| 18             | 12                                | 0.63                 | 11.1                              | 0.58                 |

Antenna pattern refers to the pattern in which the field strength of the radiation changes with the direction at a certain distance from the antenna. Due to the spatial complexity of the pattern, the antenna pattern is usually represented by two mutually perpendicular plane patterns in the maximum radiation direction of the antenna. Therefore, w<sub>E</sub> and w<sub>H</sub> in Table 2 represent the corresponding widths on the E plane and H plane perpendicular to each other, respectively.

Figure 5. Relation between HPBW and frequency

As illustrated in the Figure 5, for E-plane and H-plane, at 1 GHz - 4GHz, the HPBW of the antenna is large and varies sharply with the frequency, and the antenna pattern angle is large. With the increase of frequency, the HPBW decreases rapidly. In the frequency range of 4GHz – 14GHz, the beam width is relatively stable with no significant change. When the frequency reaches above 14GHz, the HPBW in the H plane decreases gradually, following the decline in the E plane.

Using the data in Table 2 and Formula 1, the relation between EUT volume and antenna HPBW can be calculated. It is shown in the Figure 6 and Figure 7.
Figure 6. Relation between EUT volume and antenna HPBW

As shown in the Figure 6, whether in E or H plane, the higher the half-power beam width of the antenna, the larger the EUT volume, which is consistent with the actual situation. The difference is about the range and rate of change. For E plane, the variation range of HPBW is large. The difference between the maximum and the minimum is 84.4 °. The difference between the maximum and minimum of EUT volume is up to 6.08m. In the whole frequency range, the situation in E plane changes more largely. The situation in the H plane is much more relaxed. The antenna HPBW varies from 0 to 48.9 °, while the maximum and minimum of EUT volume is only 2.85m.

Figure 7. Relation between EUT volume and frequency

As shown in the Figure 7, the relation between EUT volume and frequency is similar to that between HPBW and the frequency. The situation in the high-frequency band and low-frequency band all changes sharply and it remains relatively stable in the middle part. This is because, according to Formula 1, the EUT volume is positively correlated with the antenna half-power beam width. When the antenna HPBW is large, the EUT volume should be large and vice versa.

4. Conclusions

The differences between test volume and EUT volume are analyzed and compared. In different frequency bands, antennas with certain patterns will be used in radiation disturbance measurement. So the influence of antenna HPBW on EUT volume is deeply analyzed from frequency ranges. Finally, taking the typical horn antenna as the starting point, in terms of the relation between antenna HPBW
and frequency, and the formula between EUT volume and HPBW, the relation between EUT volume and frequency is calculated, and the influence of antenna HPBW on EUT volume is obtained eventually.

It is concluded that the antenna half-power beam width has little effect on the volume of EUT in the range of 9 kHz – 30 MHz. The EUT volume is mainly limited by the diameter of LLAS antenna system in this band. In the frequency range of 30MHz-1GHz, especially above 200MHz, the antenna HPBW has a great impact on the height of EUT volume. If the HPBW cannot completely cover the EUT, the bore-sight method may be used. Above 1GHz, the horn antenna with stronger directivity is usually used. Basically, as the antenna HPBW increases, the applicable EUT volume also increases. In the 1 GHz - 4 GHz band and the 14 GHz - 18 GHz band, due to the large fluctuation of HPBW, the EUT volume also changes sharply. At middle part of 4 GHz - 14 GHz, the volume changes relatively stable. In conclusion, the half-power beam width of antenna is an important factor for the volume size of EUT in radiation disturbance measurement. You can use the bore-sight method or increase the separating distance to overcome the limitation of the HPBW of the antenna on the EUT volume.

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