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# SENSITIVITY AND UNCERTAINTY ANALYSIS FOR CALCULABLE ANTENNA FACTOR OF THE DIRECT-FEED BICONICAL ANTENNA

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## ABSTRACT

Antennas calibrations are required for EMC measurements that determine the radiated disturbance of a communications product, as well as household electronics and automotive equipment. Usually, the EMC test laboratory employs equipment calibrated by calibration laboratories. The important parameter during the antenna calibration is the Antenna Factor (AF). Basically, AF was determined and calibrated by measurement techniques. Measurement methods to determine the AF require a great deal of time and expensive facilities, such as an anechoic chamber, network analysers and high precision cables. Any measurement can lead to uncertainty and worsen the calibration results. To overcome this difficulties, a calculable wideband biconical antenna has been introduced. Therefore, in this paper, the sensitivity analysis for calculable AF has been done to ensure which parameter give the most sensitive changes to the AF results. Based on the analysis, it is show that the directivity (D) is the highest contributor to the sensitivity analysis. In addition, uncertainties in the calculable AF are on average ±0.56 dB which is smaller than ±4.1 dB obtained using the measurement method. Therefore, any factors that contribute to the change in directivity must be taken into consideration and can be references to other researcher for AF determination in future.

**Keywords:** biconical antenna, antenna factor, sensitivity analysis, uncertainty, antenna calibration.

## INTRODUCTION

Antenna factor (AF) is one of the most important antenna characteristics used to determine the electric field from antenna radiation or reception. Since the early 1980s, various techniques and methods have been employed to calibrate the AF in response to the requirements of electromagnetic compatibility (EMC) measurements. Calibration techniques are mainly based on measurements method due to the complexity of calculable or analytical methods. Unfortunately, measurements require exhaustive time and expensive facilities such as anechoic chambers, network analysers and high precision cables. Until now, only linear dipole antennae could be calibrated using calculable methods since they have a closed-form calculable radiation characteristic. However, this type of antenna is a single band antenna, which is not practical for wideband radiated emission EMC measurements between 200 MHz to 2 GHz. Therefore to overcome this limitation, an optimised 50 Ω wideband biconical antenna is developed as a novel standard-reference antenna with calculable AF.

## CALCULABLE ANTENNA FACTOR

### Introduction of calculable antenna factor

A calculable antenna means the AF, gain and other related antenna parameter can be calculated or determined by an analytical or numerical method. This calculable antenna can be used as a reference for antenna calibration, validation test sites and EMC measurement. Owing to the fact that the high uncertainty of the test site is related to the attainable uncertainty of the antenna gain and the AF, non-uniformity of electromagnetic fields in the test site will occur. This factor forces the antenna to be used as calibration should have low uncertainty and good accuracy.

The standard site method (SSM) of antenna calibration requires a standard site, while the standard antenna method (SAM) of antenna calibration requires a standard antenna. This interdependence means that either the AF must be known precisely for antenna calibration, or the testing site must be near-field accurate for the AF determination. Therefore, a calculable antenna as a reference antenna is an alternative method to improve the accuracy of the antenna calibration.

The calculable antenna as a reference antenna for antenna calibration was first published in 1991, by Salter *et al*. (1991). The calculable antenna is more accurate compared to the measurement method, because the coupling effect between two antennas, the ground plane effect and far field assumptions during the measurement can increase the uncertainty during the measurement. Therefore, repeated measurement is required, and eventually will increase the time consumption, and any

single measurement is less accurate than the calculated value.

A half wavelength dipole has well-known calculable radiation characteristics, and can be used as a calculable standard for antenna calibration and EMC measurements, with low uncertainty level (Kawalko *et al.*, 1997). Knowing that the radiating characteristics, including the current distribution for dipole antenna is well established, the AF analytical model of the dipole is easy to construct, and the derivation of the antenna characteristic can be simplified. In order to determine the AF, the input impedance and effective length of the element are used, and can be calculated either by assuming a simple new current distribution along the dipole (Kazemipour, A. *et al.*, 2005), or by using a numerical method NEC (Alexander, M., *et al*. (1996), Alexander, M., et al. (2002), Garn, H. (2002), Alexander, M. (2010)).

Kawalko, S. F. *et al.*'s (1997) study on the effective length of the dipole and this technique could be applied as a reference antenna for EMC antenna calibration. However, 24 resonant dipoles were used to cover the frequency range 30 MHz-1 GHz, and eventually increased the calibration time during the measurement (Kawalko, S. F. *et al.*'s, 1997). As a result of this fact, a dipole antenna is not practical for antenna calibration because time consumption and cost-effectiveness are the main issues.

Numerous researchers have tried to improve the use of dipole as a reference antenna because of the single frequency criterion. Martin Alexander proposed the use of a broadband calculable dipole with low uncertainty for certain frequencies (Alexander *et al*., 2002). The author achieved the broad frequency dipole owing to the construction of a very large and flat ground plane and a validation of numerical versus analytical calculations of impedance and effective length of resonant dipoles. The results obtained by the researchers show excellent agreement between measurements and method-of-moment calculations of the coupling between resonant dipoles. Careful design of antennas and support with precision measurements indicate good agreement over a broad bandwidth. However, the antenna proposed by this author is not wide enough to support broad frequency because for certain frequency ranges, it still needs to adjust the antenna length for resonance. A broadband antenna is important because most of the electronic products produced nowadays mostly occupy this frequency band and its usage will increase in the future. Therefore, because of high demand on wideband antennas, some researchers focus on calculable wideband antennas.

## Direct feed wideband calculable biconical antenna

Wideband calculable antenna with low uncertainty is required in order to achieve high accuracy antenna calibration. The feed point of the existing biconical antenna is positioned at the centre of the antenna as shown in Figure-1. This existing design used a BALUN to match the unbalanced coaxial cable and the balanced biconical antenna. BALUN usage will affect AF accuracy because according to the literature (Alexander, M., *et al.*, 2002), BALUN cannot be determined using mathematical equations but it must be included in the AF determination by using a S-parameter measurement. In addition, bandwidth limitations and difficulty in fabricating the BALUN will reduce the ability. Some modification has therefore been proposed to reduce uncertainty during AF evaluation (Sapuan, S. Z, *et al*. (2011).


**Figure-1.** Existing biconical antenna with BALUN.

The modification has been made where the new feed points are directly connected, as shown in Figure 2 (Sapuan, S. Z, *et al*. (2011). The inner conductor of the coaxial cable will connect directly to the first cones; (A) and the outer conductor of the coaxial cable is connected to the second cone; (B).

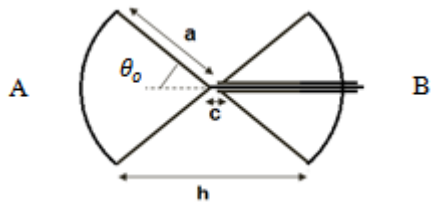


**Figure-2.** Direct feed biconical antenna.

## Calculable antenna factor

AF has been derived, and Equation (1) will be used to determine the AF and become the main parameter in this research.

$$AF = \frac{2\pi}{\lambda}\sqrt{\frac{120(1-|\Gamma^2|)}{DR_a}} \quad (1)$$

where,

$D$ = directivity
$\Gamma$ = reflection coefficient = $Z_{in}$-$Z_o$ / $Z_{in}$ + $Z_o$
$Z_{in} = R_{in} + jX_{in}$
$R_a$= Real antenna resistance = 50 Ω

Based on Equation (1), AF is determined by depending on D and Γ. Therefore, by using mathematical

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method (Sapuan, S. Z, *et al.* (2011), directivity for biconical antenna has been evaluated. Figure 3 shows the results of the directivity from analytical method and were compared with simulation CST Microwave Studio and give a good agreement. In addition, the reflection coefficient can be determined by using input impedance results of the biconical antenna.

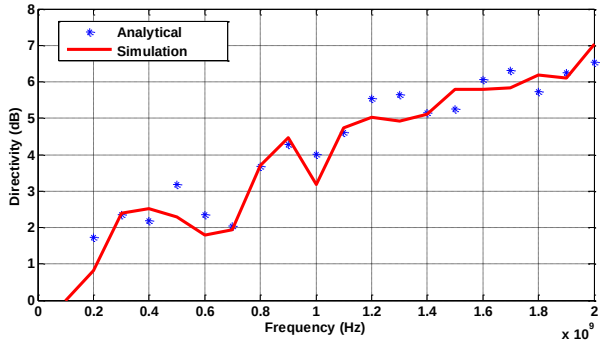



**Figure-3.** Directivity vs frequency for analytical and simulation.

In relation to that, accuracy of the AF is important to ensure the proposed calculable antenna have better performance in terms of the uncertainty compared to the measurement method. It is important to determine variable in the AF parameter (D or Γ) that gives significant impact to the equation. An analysis of sensitivity and uncertainty has undertaken done for future references.

## SENSITIVITY AND UNCERTAINTY CONTRIBUTION

### Sensitivity analysis for analytical AF

Sensitivity analysis is concerned with the propagation of uncertainties in mathematical models (Ostermann, A., (2004)). The main task of sensitivity analysis is to identify critical parameter dependences. A sensitivity coefficient is basically the ratio change in output to the change in input while all other parameter remains constant. This different is the 'sensitivity' of the equation to uncertainty.

A partial derivative method has been used if more than one variable parameter for sensitivity analysis. Therefore, a partial derivative technique has been used to solve each parameter of the Equation (1).

Partial derivative for D respect to AF is:

$$\frac{\partial AF}{\partial D} = -\frac{\pi}{\lambda}\left[\frac{120\,(1-|\Gamma^2|)}{R_a}\right]^{1/2} D^{-1.5} \qquad (2)$$

and the partial derivative for Γ respect to AF is

$$\frac{\partial AF}{\partial \Gamma} = -\frac{2\pi\Gamma}{\lambda}\left[\frac{120}{DR_a}\right]^{1/2}[1-\Gamma^2]^{-0.5}. \qquad (3)$$

All calculations are in linear form to simplify the derivation.

Therefore, for example, at f = 300MHz,

$$\frac{\partial AF}{\partial D} = -3.1122 \qquad (4)$$

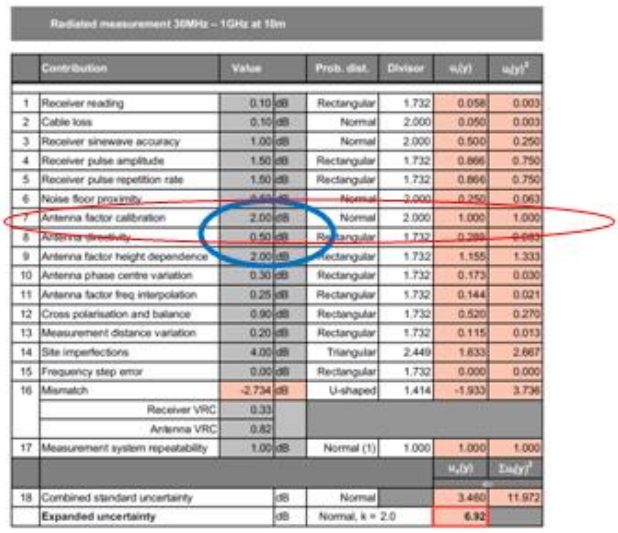
and

$$\frac{\partial AF}{\partial \Gamma} = -1.2435. \qquad (5)$$

By checking the value of two derivatives, the magnitude of $\frac{\partial AF}{\partial D}$ is greater than magnitude of $\frac{\partial AF}{\partial \Gamma}$. Therefore, the function of the AF is most sensitive to unit errors of Directivity (D).

### Uncertainty contribution

The sensitivity analysis of D and Γ with respect to AF will lead to uncertainty of the AF. Uncertainty for the calculable AF is important during the antenna calibration or radiated emission (RE) measurement (EMC testing). Each measurement result either from antenna calibration or RE measurement should has uncertainty data. Figure-4. Shows an example of the uncertainty for RE measurement (EMC measurement) obtained by EMC engineer.



Radiated measurement 30MHz – 1GHz at 10m

| | Contribution | Value | | Prob. dist. | Divisor | $u_i(y)$ | $u_i(y)^2$ |
|---|---|---|---|---|---|---|---|
| 1 | Receiver reading | 0.10 | dB | Rectangular | 1.732 | 0.058 | 0.003 |
| 2 | Cable loss | 0.10 | dB | Normal | 2.000 | 0.050 | 0.003 |
| 3 | Receiver sinewave accuracy | 1.00 | dB | Normal | 2.000 | 0.500 | 0.250 |
| 4 | Receiver pulse amplitude | 1.50 | dB | Rectangular | 1.732 | 0.866 | 0.750 |
| 5 | Receiver pulse repetition rate | 1.50 | dB | Rectangular | 1.732 | 0.866 | 0.750 |
| 6 | Noise floor proximity | 0.50 | dB | Normal | 2.000 | 0.250 | 0.063 |
| 7 | Antenna factor calibration | 2.00 | dB | Normal | 2.000 | 1.000 | 1.000 |
| 8 | Antenna directivity | 0.50 | dB | Rectangular | 1.732 | 0.289 | 0.083 |
| 9 | Antenna factor height dependence | 2.00 | dB | Rectangular | 1.732 | 1.155 | 1.333 |
| 10 | Antenna phase centre variation | 0.30 | dB | Rectangular | 1.732 | 0.173 | 0.030 |
| 11 | Antenna factor freq interpolation | 0.25 | dB | Rectangular | 1.732 | 0.144 | 0.021 |
| 12 | Cross polarisation and balance | 0.90 | dB | Rectangular | 1.732 | 0.520 | 0.270 |
| 13 | Measurement distance variation | 0.20 | dB | Rectangular | 1.732 | 0.115 | 0.013 |
| 14 | Site imperfections | 4.00 | dB | Triangular | 2.449 | 1.633 | 2.667 |
| 15 | Frequency step error | 0.00 | dB | Rectangular | 1.732 | 0.000 | 0.000 |
| 16 | Mismatch | -2.734 | dB | U-shaped | 1.414 | -1.933 | 3.736 |
| | Receiver VRC | 0.33 | | | | | |
| | Antenna VRC | 0.82 | | | | | |
| 17 | Measurement system repeatability | 1.00 | dB | Normal (1) | 1.000 | 1.000 | 1.000 |
| | | | | | | $u_c(y)$ | $\Sigma u_i(y)^2$ |
| 18 | Combined standard uncertainty | | dB | Normal | | 3.460 | 11.972 |
| | Expanded uncertainty | | dB | Normal, k = 2.0 | | 6.92 | |

**Figure-4.** Uncertainty for radiated emission (EMC measurement).

According to Figure-4, one of the uncertainty contributions in EMC measurement is 'AF calibration' with 2.0 dB value. This value was provided in the antenna

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manufacturer datasheet and has been determined depends on the antenna type by the manufacturer. For typical incalculable antenna; the AF has been determined using measurement antenna calibration method (SSM, SAM or SFM) (Sapuan, S. Z. *et al*. (2013)). In relation to that, Figure-5 shows an example of the SSM measurements

| Source of uncertainty | Value dB | Probability distribution | Divisor | Contribution dB |
|---|---|---|---|---|
| Common uncertainty component in SIL measurement (see Table 1) | 0,26 | Normal | 2 | 0,11 |
| Repeatability of SIL value (N3) | 0,10 | Normal | 2 | 0,04 |
| Transmit antenna mismatch (N5) | 0,16 | U-shaped | $\sqrt{2}$ | 0,10 |
| Receive antenna mismatch (N5) | 0,16 | U-shaped | $\sqrt{2}$ | 0,10 |
| Insertion loss of the adaptor used in SIL measurement (N6) | 0,06 | Rectangular | $\sqrt{3}$ | 0,03 |
| Effects of site and masts (N7) | 1,0 | Rectangular | $\sqrt{3}$ | 0,50 |
| Antenna separation error (N8) | 0,04 | Rectangular | $\sqrt{3}$ | 0,02 |
| Antenna height error (N9) | 0,01 | Rectangular | $\sqrt{3}$ | 0,01 |
| Antenna orientation error | - | Rectangular | $\sqrt{3}$ | - |
| Effects of phase centre position | - | Rectangular | $\sqrt{3}$ | - |
| Polarization mismatch | - | Rectangular | $\sqrt{3}$ | - |
| Near-field effects and antenna mutual coupling (N10) | 0,1 | Rectangular | $\sqrt{3}$ | 0,06 |
| Combined standard uncertainty | | | | 0,54 |
| **Expanded uncertainty ($k$ = 2)** | | | | **1,07** |

**Figure-5.** Uncertainty example for SSM measurements.

However, for calculable antenna, the uncertainty contribution should be determined by consideration of:

- Mechanical failure during the fabrication process of the direct feed biconical antenna. Two main components which contribute to the analytical uncertainties are:

a. Antenna length
b. Cone angle

Mechanical failure during the fabrication process is the failure made by an antenna manufacturer during a fabrication process. Proposed antenna height in this research is $h$ = 0.4 m. However, by considering an uncertain failure during a fabrication, the antenna size may divert from an actual parameter either smaller or greater than 0.4 m as shown in Figure-6. Based on the previous fabrication process, 1 cm is the largest prediction uncertain value during the antenna development. Therefore, the uncertainty for antenna height is:

Nominal value: 0.4 m
Uncertainty contribution: 0.01 m
Therefore, antenna height with uncertainty = 0.4 ± 0.01 m

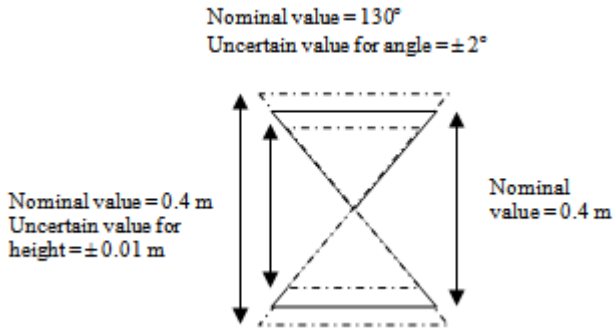


**Figure**-Error! No text of specified style in document.**.** Uncertainty for manufacturing failure during a fabrication process.

Cone angle (θ) for wideband biconical antenna in this research has been calculated equal to 65° x 2 = 130° (Sapuan, S. Z, *et al*. (2011). However, uncertain will occur during the fabrication process with maximum 2° deviation. Therefore,

Nominal value = 130°
Uncertainty contribution = 2°
Therefore, cone angle with uncertainty = 130° ± 2°

Directivity (D) and reflection coefficient coefficient (Γ) are depends on antenna length, $h$ and cones angle, $\theta$. Any deviation from both physical parameters ($h$ or $\theta$) could affect both D and Γ and eventually contributed to the total AF uncertainty (δAF). Figure-7 shows the summary of uncertain physical parameter that could affect both directivity uncertainty (δD) and reflection co-efficient coefficient uncertainty (δΓ) and eventually contribute to the total of δAF.

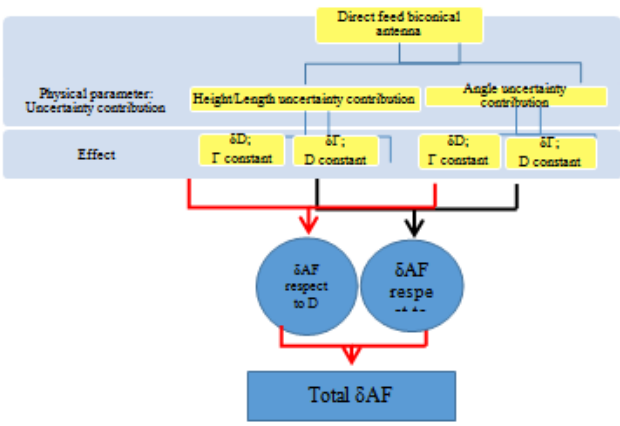


**Figure-7.** Summary for uncertainty from analytical AF.

**Uncertainty due to a cone angle**

Deviation from $\theta$ will contribute to the $D$ and $\Gamma$ uncertainty. By taking the 2 degrees deviated from

nominal value, directivity has been plotted as shown in Figure-8. It is indicated that the uncertainty for D due to the uncertainty of the cones angle are;

at 300 MHz;
Angle = 132°
Directivity = 1.874 dB
= 1.5396 (linear)

Angle = 130°
Directivity = 2.394 dB
= 1.735 (linear)

Therefore, δD due to cones angle;
= 1.5396 – 1.735 = ±0.1954 (linear)

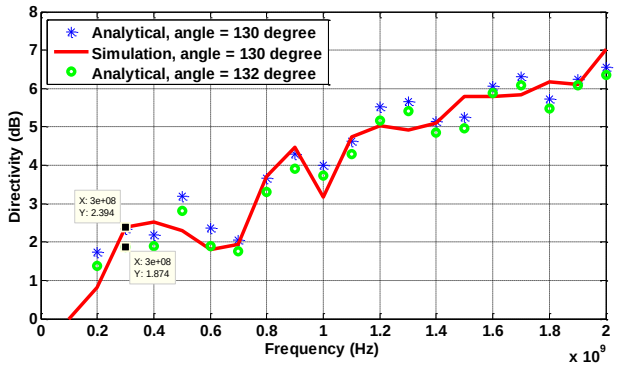


**Figure-8.** Directivity vs frequency for $\theta$ = 130 degree and $\theta$ = 132 degree.

Uncertainty of the Γ due to the cone angle can be described by analysing the input impedance as shown in Figure-9. It is indicates that the input impedance for biconical antenna has been deviated from 50.28 Ω to 47.75 Ω.

where;
For angle = 130°
Input impedance = 50.28 Ω
Reflection co-efficient = |zin-50 / zin+50|
= 0.0028 (linear)

And for angle = 132°;
Input impedance = 47.75 Ω
Reflection co-efficient = 0.023 (linear)

Therefore, uncertainty for reflection co-efficient due to the uncertainty of $\theta$
= 0.023-0.0028
= ±0.0202 (linear)

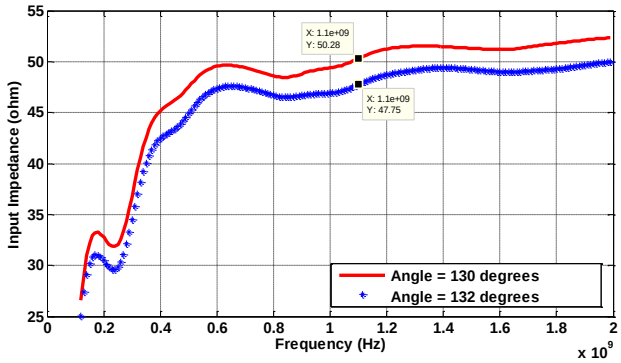


**Figure-9.** Uncertainty for input impedance due to cones angle.

**Uncertainty due to antenna height, h**

Uncertainty contribution for directivity due to the antenna height as shown in Figure 10 has been calculated as below:
Height = 0.4 m
Directivity = 2.359 dB
= 1.7215 (linear)
Height = 0.41 m
Directivity = 2.044 dB
=1.6 (linear)
Uncertainty for directivity due to antenna height, *h*:
|1.7215 – 1.6| = ±0.1215 (linear)

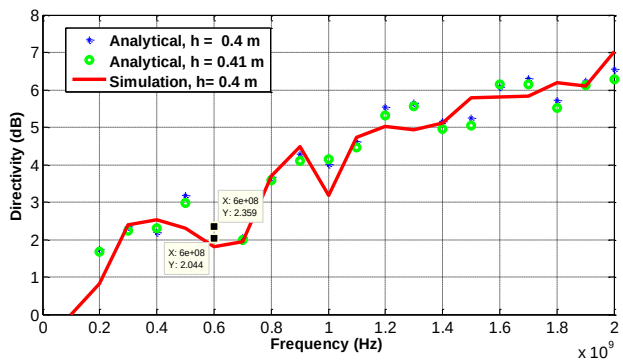


**Figure-10.** Uncertainty of the directivity due to antenna height.

Uncertainty for Γ; due to antenna height, *h* as shown in Figure-11 has been calculated as below:
For h = 0.4 m
Input impedance = 44.89 Ω
Reflection co-efficient = |zin-50 / zin+50|
= 0.0539 (linear)
And for h=0.41 m;
Input impedance = 51.89 Ω
Reflection co-efficient = 0.019 (linear)

Therefore, uncertainty for reflection co-efficient due to the antenna height
= |0.0539 - 0.019|
= ±0.035 (linear)

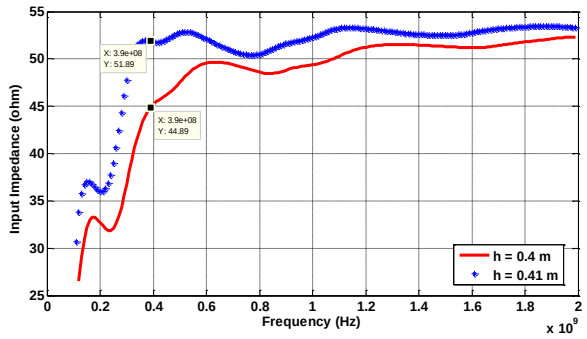


**Figure-11.** Uncertainty for reflection co-efficient due to antenna height.

Table-1 shows a summary for both uncertainty of the D and Γ due to the cone angle, θ and antenna height, *h*. Therefore, total uncertainty for directivity is,

$$\delta D = \sqrt{\delta D_{\theta}^2 + \delta D_{h}^2}$$

$$\delta D = \sqrt{0.1954^2 + 0.1215^2}$$
$$= \pm\, 0.23 \text{ (linear)}$$

and total uncertainty for reflection co-efficient;

$$\delta\Gamma = \sqrt{\delta\Gamma_{\theta}^2 + \delta\Gamma_{h}^2}$$
$$\delta\Gamma = \sqrt{0.0202^2 + 0.0350^2}$$
$$= \pm\, 0.0404 \text{ (linear)}$$

**Table-1**. Summary for δD and δΓ contribution.

| **Contribution factor** / **Uncertainty** | **Cone angle** (linear) | **Antenna height** (linear) |
|---|---|---|
| Directivity; δD | ±0.1954 | ±0.1215 |
| Reflection Coefficient; δΓ | ±0.0202 | ±0.0350 |

Uncertainty of AF ($\partial AF_D$) respect to directivity (D) and uncertainty of AF ($\partial AF_\Gamma$) respect to reflection co-efficient coefficient (Γ) has been evaluated based on partial derivative function as in sensitivity analysis part.

For example;
At 300 MHz with $\partial D = 0.23$ ; therefore $\partial AF_D$ is;

$$\frac{\partial AF_D}{\partial D} = |-3.1122|$$
$$\partial AF_D = |-3.1122[\partial D]|$$
$$\partial AF_D = |0.7158|$$
$$\partial AF_D = \pm 0.7$$

Uncertainty for AF respect to the reflection coefficient at f = 300 MHz and $\delta\Gamma = 0.0404$ is

$$\frac{\partial AF_\Gamma}{\partial \Gamma} = |-1.2435|$$
$$\partial AF_\Gamma = |-1.2435\,[\partial\Gamma]|$$
$$\partial AF_\Gamma = |0.05|$$

$$\partial AF_\Gamma = \pm 0.05$$

Therefore, Total uncertainty for AF at f = 300MHz is:

$$\delta AF = \sqrt{\partial AF_D^2 + \partial AF_\Gamma^2}$$
$$\delta AF = \sqrt{0.7158^2 + 0.05^2}$$
$$= \pm\, 0.7175 \text{ (linear)}$$

Table-2 shows the results of the δAF for the AF equation (calculable AF) from 200 MHz to 2 GHz. Uncertainty for AF due to the directivity is higher than reflection co-efficient. However, uncertainty for AF due to the reflection coefficient is insignificant and gradually increased especially at higher frequency. Therefore, the highest total uncertainty value for both D and *Γ* is at 700 MHz and has been calculated as below:

$$\delta AF = \sqrt{\partial AF_D^2 + \partial AF_\Gamma^2}$$
$$\delta AF = \sqrt{1.057^2 + 0.0002^2}$$

$$\delta AF = \pm 1.0570 \text{ (linear)}$$

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**Table-2.** Analytical uncertainty analysis for various frequencies.

| F (MHz) | $\partial AF/\partial D$ | $\partial D$ | $\lvert\partial AF_D\rvert$ | $\partial AF/\partial \Gamma$ | $\partial \Gamma$ | $\lvert\partial AF_\Gamma\rvert$ | $\partial AF$ |
|---|---|---|---|---|---|---|---|
| 200 | -1.0676 | 0.23 | 0.2455 | 1.009 | 0.0404 | 0.0408 | 0.2489 |
| 300 | -3.1122 | 0.23 | 0.7158 | 1.2435 | 0.0404 | 0.0502 | 0.7176 |
| 400 | -2.6119 | 0.23 | 0.6007 | 0.4393 | 0.0404 | 0.0177 | 0.6010 |
| 500 | -2.3113 | 0.23 | 0.5316 | 0.2222 | 0.0404 | 0.0090 | 0.5317 |
| 600 | -3.6488 | 0.23 | 0.8392 | 0.000014 | 0.0404 | 0.0000 | 0.8392 |
| 700 | -4.5957 | 0.23 | 1.0570 | 0.0046 | 0.0404 | 0.0002 | 1.0570 |
| 800 | -3.7898 | 0.23 | 0.8717 | 0.1353 | 0.0404 | 0.0055 | 0.8717 |
| 900 | -4.3638 | 0.23 | 1.0037 | 0.093 | 0.0404 | 0.0038 | 1.0037 |
| 1000 | -3.9423 | 0.23 | 0.9067 | 0.0484 | 0.0404 | 0.0020 | 0.9067 |
| 1100 | -3.2920 | 0.23 | 0.7572 | 0.2598 | 0.0404 | 0.0105 | 0.7572 |
| 1200 | -3.8558 | 0.23 | 0.8868 | 0.5423 | 0.0404 | 0.0219 | 0.8871 |
| 1300 | -4.1307 | 0.23 | 0.9501 | 0.6748 | 0.0404 | 0.0273 | 0.9505 |
| 1400 | -4.0891 | 0.23 | 0.9405 | 0.7219 | 0.0404 | 0.0292 | 0.9409 |
| 1500 | -4.5308 | 0.23 | 1.0421 | 0.7868 | 0.0404 | 0.0318 | 1.0426 |
| 1600 | -4.4545 | 0.23 | 1.0245 | 0.8212 | 0.0404 | 0.0332 | 1.0251 |
| 1700 | -3.9900 | 0.23 | 0.9177 | 0.8654 | 0.0404 | 0.0350 | 0.9184 |
| 1800 | -4.3488 | 0.23 | 1.0002 | 0.9774 | 0.0404 | 0.0395 | 1.0010 |
| 1900 | -4.5281 | 0.23 | 1.0415 | 1.0655 | 0.0404 | 0.0430 | 1.0424 |
| 2000 | -4.4350 | 0.23 | 1.0200 | 1.0625 | 0.0404 | 0.0429 | 1.0014 |

**Table-3.** Uncertainty calculation/budget for measurement AF.

| NO | Source of uncertainty | Value (dB) | Probability distribution | Divisor | ui(y) | ui(y)2 |
|---|---|---|---|---|---|---|
| **1** | Uncertainty in AF (RA) | 1.80 | Normal | 2 | 0.9 | 0.81 |
| **2** | AUC height error (Antenna Mast affecting AF) | 0.30 | Rectangular | 1.732 | 0.17321 | 0.030 |
| **3** | Repeatability of AF in SAM | 0.80 | Normal | 2 | 0.4 | 0.160 |
| **4** | Distance error between RA and AUC | 1.30 | Rectangular | 1.732 | 0.75058 | 0.563 |
| **5** | Site imperfection | 4.0 | Triangular | 2.449 | 1.63332 | 2.668 |
| **6** | Attenuation: Antenna-Receiver (cable loss) | 0.1 | Normal | 2 | 0.05 | 0.003 |
| | Summation of ui(y)2 | | | | | 4.234 |
| | Combined standard uncertainty ; $u_c(y)$ | | Normal | | | 2.058 |
| | Expanded uncertainty | | Normal, k=2 | | | 4.115 |

Based on Table-2, the uncertainty for analytical AF is at 700 MHz. Total uncertainty of the AF ($\delta AF$) = ±1.0570 (linear) at 700 MHz should be converted to unit in dB. Therefore, the $\delta AF$ for analytical AF in dB is equal to ±0.56 dB. This is the uncertainty for calculable wideband biconical antenna.

Uncertainty for measurement AF has been evaluated and has been simplified in Table-3. It can be seen that the total uncertainty for measurement AF is ±4.1 dB which is higher than calculable AF. Therefore the calculable AF is better in terms of uncertainty and will contribute to the high accuracy results in antenna calibration.

## CONCLUSIONS

In conclusion, directivity (D) is the highest contributor in uncertainty to determine the AF. In other word, any small change in directivity will give large effect to the AF value. Therefore, any factors that contribute to the change in directivity must be taken into consideration

Both uncertainty for the analytical method and the SAM measurement were evaluated and the comparison showed that the proposed calculable wideband antenna is better in terms of uncertainty. Uncertainties in the calculable AF are on average ±0.56 dB which is smaller than ±4.1 dB obtained using the measurement method

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