On De-Embedding Antenna Baluns from Site Attenuation Measurements

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Abstract—Previous studies have concentrated on improving the theoretical site attenuation (SA) models for broadband antennas, such as for bicones or log periodic antennas. However, it has not been emphasized that even if a perfect model is obtained, the antennas used in the tests cannot be readily “normalized” from the site attenuation measurements. Specifically, the antenna baluns have nonlinear effects on the site attenuation measurements, and the balun effects do not cancel exactly in the $\Delta SA$ ($SA$ from the site-under-test as compared to $SA$ from an ideal site). This implies in practice that the performance of a test site can be altered ostensibly by a simple change of antenna baluns.

Keywords—Normalized Site Attenuation, site attenuation, antenna factor, balun, site qualification test.

I. INTRODUCTION

The adoption of Normalized Site Attenuation (NSA) in the ANSI C63.4/63.5 standards made it possible to perform site qualification tests with a wide range of antennas. Various investigations have been carried out to improve the model, including a set of correction factors for bicones, which are proposed by the author and have been incorporated in the draft version of the ANSI C63.5 [1]. With these correction factors applied, an ideal site will have much smaller $\Delta NSA$ using biconical antennas [2]. The question posed in this paper is not whether the improved $SA$ or $NSA$ can predict the correct behavior of an ideal site, but of a non-ideal site. It has been eloquently pointed out [3] that $SA$ depends on the effective impedances seen at the antenna driving points looking toward the baluns. Thus the $SA$ can be different even if the antenna elements have identical structures. Unfortunately, this fact has not been widely publicized and emphasized, that is, even with the correction factors applied, effects from the antenna baluns do not cancel between the site-under-test and an ideal site. The antenna balun effects are not linear. The nonlinearity exists in both the NSA method (comparing the $SA$ with the theoretical data) and the site-to-site comparison method (comparing the $SA$ with another near ideal site). In other words, regardless the methods used to obtain the deviation for the site-under-test, the resulting $\Delta SA$ or $\Delta NSA$ is not devoid of influences from the antennas and their baluns used for the measurements.

Here, we define $\Delta SA$ as the site response differences between the site-under-test and an ideal site (with an infinite perfectly conducting, and perfectly flat ground plane). Note that $\Delta SA$ and $\Delta NSA$ are the same because antenna factors cancel in the division process. The expression is

$$\Delta SA = \Delta NSA = \frac{S_{21}}{S_{21}^{\text{Ideal}}}, \quad (1)$$

whereas $S_{21}$ is the magnitude of the forward scattering parameter from the site-under-test, and $S_{21}^{\text{Ideal}}$ is from the ideal site. Each $S_{21}$ can be represented by three cascading two-port networks:

- transmitting antenna balun,
- antenna elements in the test environment,
- and receiving antenna balun.

The baluns can be regarded as constants that are not influenced by the sites. If the $SA$ were a simple multiplicative quantity from the three networks, the baluns would cancel between the site-under-test and the ideal site in (1). In that case, the $\Delta SA$ would only include the terms involving the sites and the antenna elements. However, $S$-parameters do not multiply in a cascaded network in a straightforward manner.
II. THEORY

Consider that the site attenuation measurement consists of three two-port networks cascaded, as shown in Figure 1. \([l]\) matrix is the S-parameters of balun 1 (transmitting antenna), \([m]\) is the S-parameters of the antenna elements and the site, and \([n]\) is for balun 2 (receiving antenna). The \(S_{21}\) of this system is the total site attenuation \((SA)\), and is given by [4]

\[
SA = S_{21} = \frac{l_{21} m_{21} n_{21}}{1 - (l_{22} m_{11} + m_{22} n_{11}) + l_{22} m_{21} n_{21}} \cdot (2)
\]

Let us assume a site under test is non-ideal, and its actual \(SA\) is

\[
SA = \tilde{S}_{21} = \frac{l_{21} \tilde{m}_{21} n_{21}}{1 - (l_{22} \tilde{m}_{11} + \tilde{m}_{22} n_{11}) + l_{22} \tilde{m}_{21} n_{21}} \cdot (3)
\]

The tildes (~) signify the parameters from a non-ideal site. Note that the \(S\)-parameters of the baluns \([l]\) and \([n]\) are assumed to be unaffected by the site, so the only perturbations are on the \([m]\) matrix. \(\Delta SA\) is obtained from a division of (2) by (3),

\[
\Delta SA = \frac{\tilde{S}_{21}}{S_{21}} = \frac{\tilde{m}_{21}}{m_{21}} \times \frac{1 - (l_{22} \tilde{m}_{11} + \tilde{m}_{22} n_{11}) + l_{22} \tilde{m}_{21} n_{21}}{1 - (l_{22} m_{11} + m_{22} n_{11}) + l_{22} m_{21} n_{21}} \cdot (4)
\]

The forward transmission terms in the balun \((l_{21} \text{ and } n_{21})\) cancel in (4), but not the reflection terms \((l_{22} \text{ and } n_{11})\). The reflection terms correspond to the impedances seen into the baluns by the antenna elements. For ideal 50 Ω baluns,

\[
l_{50\Omega} = n_{50\Omega} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}.
\]

The second term \(([\cdots])\) in (4) reduces to unity for the 50 Ω baluns, and

\[
\Delta SA = \frac{\tilde{m}_{21}}{m_{21}} \cdot (5)
\]

For antennas with other than non-ideal 50 Ω baluns, such as those with impedance transformations (using balun transformers), the second term in (4) does not reduce to 1. For example, ideal 100 Ω baluns (2:1 impedance ratio) have the following \(S\) matrices (in a 50 Ω system):

\[
l_{100\Omega} = \begin{bmatrix} -1/3 & 2\sqrt{2}/3 \\ 2\sqrt{2}/3 & 1/3 \end{bmatrix}
\]

and \(n_{100\Omega} = \begin{bmatrix} 1/3 & 2\sqrt{2}/3 \\ 2\sqrt{2}/3 & -1/3 \end{bmatrix} \).

For ideal 200 Ω baluns (4:1 impedance ratio), their ideal \(S\)-parameters are

\[
l_{200\Omega} = \begin{bmatrix} -0.6 & 0.8 \\ 0.8 & 0.6 \end{bmatrix}
\]

and \(n_{200\Omega} = \begin{bmatrix} 0.6 & 0.8 \\ 0.8 & -0.6 \end{bmatrix} \).

and for ideal 450 Ω baluns (9:1 impedance ratio), their ideal \(S\)-parameters are

\[
l_{450\Omega} = \begin{bmatrix} -0.8 & 0.6 \\ 0.6 & 0.8 \end{bmatrix}
\]

and \(n_{450\Omega} = \begin{bmatrix} 0.8 & 0.6 \\ 0.6 & -0.8 \end{bmatrix} \).

As an example, Equation (4) for the 100 Ω baluns takes on the form:

\[
\Delta SA_{100\Omega} = \frac{\tilde{m}_{21}}{m_{21}} \left\{ \frac{1 - (1 + m_{11} + \frac{1}{2} m_{22} + \frac{1}{2} m_{21} m_{21}) + \frac{1}{2} m_{21} m_{22}}{1 - (1 + \frac{1}{2} m_{11} + \frac{1}{2} m_{12} + \frac{1}{2} m_{22} m_{22}) + \frac{1}{2} m_{21} m_{22}} \right\} \cdot (6)
\]

The first term in (4) or (6) contains solely the information on the site and antenna elements. The second term \(([\cdots])\) can be considered as a scaling
factor for $\Delta SA$. Its value depends on the site deviation from the ideal, as well as the baluns used in the measurement ([7] and [9]). Obviously, if the site-under-test is identical to the ideal site, the second term in (4) also reduces to 1 (for that matter, so does the whole expression). It is easily seen that (4) works out for an ideal site. However, for non-ideal sites, the amount of deviation ($\Delta SA$) is modified by the balun $S$-parameters. Conceivably, a set of baluns can be selected to modify the $\Delta SA$ value, and thus the apparent performance of the site.

III. A Case Study

We consider one of the geometries in the ANSI C63.4/63.5 – the transmit antenna height $h_1$ is 2 m; the receive antenna height $h_2$ is varied from 1 m to 4 m; the separation distance $d$ is 3 m; and the antenna is horizontally polarized. NEC-2 [5] is used for simulating two identical biconical antennas in the above geometry. The bicones are the typical skeletal wire designs with a width of 1.34 m. The validity of NEC-2 has been widely qualified for this type of antenna, such as reported in [2] and [4].

![Fig. 2. A scatterer directly above the receiving antenna is introduced in the SA setup to simulate a non-ideal site.](image)

To simulate a non-ideal test site, we intentionally introduce a scatterer, which is a wire-grid plate. It is located at a height of 5 m, and is parallel with the infinite PEC ground plane. The size of the plate is 1 m wide by 2 m long. It is located directly above the height-scanning antenna, as shown in Figures 2 and 3. The scatterer is made lossy with resistive loading elements.

Figure 4 shows the site attenuation deviations of this non-ideal site. Note that in the $\Delta SA$ calculation, the baluns are the same for both the ideal and

![Fig. 3. A side view of the scatterer above the receiving antenna.](image)

![Fig. 4. By using 50 Ω, 100 Ω and 200 Ω baluns (in transmitting and receiving pairs), the site attenuation deviations are different.](image)

![Fig. 5. The differences between two $\Delta SA$'s by using different balun sets.](image)
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the non-ideal sites. For example, $\Delta S_A_{100\Omega}$ is obtained by comparing the $S_A$ for the pair of 100 $\Omega$ baluns on the non-ideal site with the $S_A$ for the same pair of 100 $\Omega$ baluns on the ideal one. As shown in Figure 4, the $\Delta S_A$'s for the same exact site are different depending on which set of baluns are used for the evaluations. Obviously, a general conclusion of which balun sets yield the smallest $\Delta S_A$ cannot be drawn from this simple example. The conditions of the site-under-test and the frequencies of interest are all factors. Nonetheless, it can be concluded that the selection of baluns can impact the $S_A$ and $\Delta S_A$. In this case, for a site that has relatively small variations from the ideal (a maximum $\Delta S_A$ of 0.8 dB), the maximum difference in the $\Delta S_A$ for the same site due to using two separate pairs of baluns is more than 0.5 dB, which may not be negligible in many practical applications. Figure 5 shows the direct $\Delta S_A$ differences when using different balun pairs.

IV. SUMMARY AND CONCLUSION

We have proven that the selection of antenna baluns can influence the $\Delta S_A$ or $\Delta N S A$. In addition, the antenna patterns can influence the $\Delta S_A$ in a non-ideal site, but that is a different subject beyond the scope of this study. The baluns used in a site attenuation measurement have nonlinear effects on the $\Delta S_A$, and their influences do not cancel in the comparison to an ideal site. The variations in the evaluation of a site performance due to using different baluns is not insignificant, but neglected in the current standards and in practices.

One approach the standards can take to address this issue is to specify standard antennas with well-defined baluns for site attenuation measurements. In the ANSI C63.4/63.5, Roberts' dipoles are referred as the ultimate antennas in case of a dispute. However for Roberts' dipoles, their balun impedances vary significantly with frequency. The Roberts' dipoles thus do not seem to be appropriate for these broadband metrology grade measurements. Calculable dipoles [6] or calculable biconical antennas [4], which are designed to have stable and predictable balun parameters, are the ideal fit for unbiased EMC site evaluation measurements.

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REFERENCES


