# Calibration to facilitate comparison of numerical and experimental data for antenna

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A simple procedure to calibrate numerical data in a manner which allows for accurate comparison to experimental data is presented. A simple dipole is used to demonstrate the procedure. The numerical calibration procedure is essentially the same as the experimental calibration procedure which makes it possible to make good comparisons. The antenna, along with three calibration standards, are numerically modelled and experimentally measured. Standard *S*-parameter calibration procedures are used for both. The calibrated numerical data and the measured data are compared in terms of reflected voltage in the feed line. Agreement is shown to be improved significantly with the calibration technique.

*Introduction:* To build an accurate numerical model for an antenna, the antenna structure must be accurately represented in the model. However, some parts of the structure are difficult to represent in the numerical model. Those parts of the structure are approximated. For example, in the experimental model, the antenna is driven by a wave incident in a transmission line, where the incident wave has multimodes near the drive point as it interacts both with the antenna and the transmission line. However, in the numerical model, the source is predefined, such as delta-gap voltage sources and wave ports, which only approximate the source. Most of the time, the antenna model with a predefined source located at the end of a short transmission line produces relatively accurate radiated fields. However, the input impedance calculated from the model often differs significantly from the experimental data. The difference may be corrected by appropriately tuning the numerical results if the antenna operates over a narrow band. However, the correction by a tuning is limited if the antenna operates over a wide band. Thus, a calibration technique over a wide band is required to allow fair comparison between the numerical and the experimental data and reduce the difference observed in the input impedance.

In this Letter we present a technique to correct the input impedance of an antenna driven from a transmission line. The technique is demonstrated on a dipole antenna, when it is driven by a balanced transmission line and the source is a delta-gap voltage source. The numerical model has been built based on the EIGER software suite, which is based on the method of moments [1].

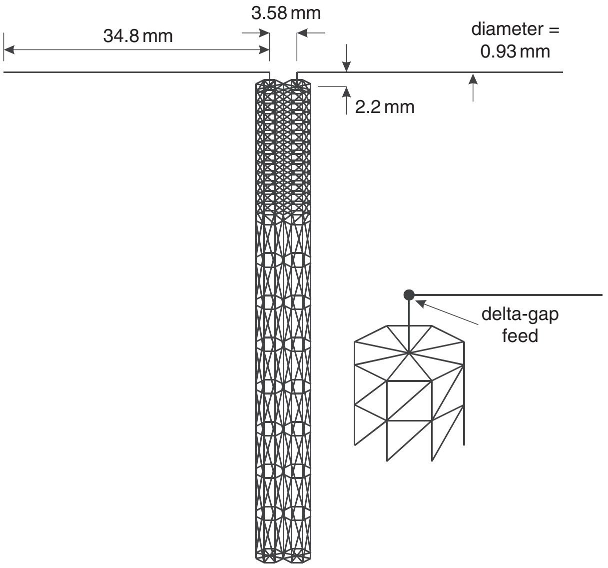

**Fig. 1** *Mesh for numerical model for dipole sensor*

*Numerical model:* Fig. 1 shows the mesh for the numerical dipole model, which closely approximates the experimental model. In the experimental model the two arms of the dipole are attached to the centre conductors of two 50 Ω coaxial cables which are driven differentially. The external conductors of the two coaxial cables are connected electrically and grounded. Thus, the two coaxial cables form a 100 Ω balanced transmission line. In the numerical model, the antenna is driven at the terminals of the centre conductor as shown in Fig. 1. The numerical model contains part of the coaxial cables to model the interactions between the antenna and the feed cables. The feed cables that are close to the antenna are discretised more densely because the interactions are thought to be stronger around the drive point. Triangular cells are used to discretise the outer conductors of the feed cables and linear wire elements are used to discretise the antenna arms. The cables and the wire elements are modelled as perfect electric conductors, and the electric field integral equations with linear basis functions are associated with the cell elements.

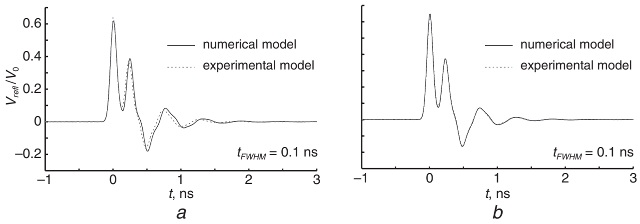

**Fig. 2** *Comparisons of result from experimental model with raw result from numerical model and calibrated result from numerical model*

*a* Comparison of result from experimental model with raw result from numerical model
*b* Comparison of result from experimental model with calibrated result from numerical model

Fig. 2*a* shows the reflected wave from the antenna when a Gaussian pulse is incident in the feed line. The Figure shows the result from the numerical model on top of the result from the experimental model to show the accuracy of the numerical data. Here, the Gaussian pulse is defined as [2]

$$V(t) = V_0 \exp\left\{-\ln 16 (t/t_{FWHM})^2\right\} \qquad (1)$$

where $V_0$ is the peak of the incident pulse, and $t_{FWHM}$ is the full-width at half-maximum. For the results in Fig. 2, $t_{FWHM} = 0.1$ ns is used. The frequency content of the Gaussian pulse is spread over a wide bandwidth that includes DC. Thus, the Gaussian pulse input is useful to observe the responses of an antenna over a wide bandwidth. In addition, the time domain representation of the result is useful, especially when the dipole is developed for pulse applications.

The measured result in Fig. 2 is obtained using a vector network analyser. The result is calibrated according to the standard one-port reflection calibration technique. First, the antenna is removed and the three known loads, i.e. short, open, and matched load, are connected across the feed line terminals. The reflections measured from the known loads are used to calibrate the reflection from the antenna. In this Letter, the open load is obtained by leaving the terminals open, the short load is obtained by connecting the two terminals with a wire, and the matched load is obtained by attaching a 100 Ω chip resistor across the two terminals.

The results shown in Fig. 2 are obtained by transforming the frequency domain data into the time domain. The input impedance obtained from the numerical model is transformed to the reflection coefficient by [3]

$$\Gamma = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} \qquad (2)$$

where $Z_{\text{in}}$ is the input impedance obtained from the numerical model and $Z_0 = 100\,\Omega$ is the characteristic impedance of the balanced feed line. The reflection coefficient is multiplied by the frequency spectrum of the Gaussian pulse and then transformed into the time domain. The same technique is used to transform the reflection coefficient from the experimental model into the time domain.

As shown in Fig. 2*a*, the results from the experimental model and the numerical model agree well, thus showing that the accuracy of the numerical data is good. However, there are slight discrepancies, e.g. the numerical result shows slightly lower peak around $t = 0$ ns than the experimental result; in addition, the responses are slightly delayed in the numerical result at later times. These discrepancies are due to differences of the drive point representation. In the experimental model the antenna is driven by the wave incident in the feed line. The effects experienced by the wave in the feed line are removed by the *S*-parameter calibration. However, in the numerical model, the antenna is driven by a pair of delta-gap voltage sources, which have opposite polarities. The differences between the drive point representations must be removed to allow fair comparison between the experimental data and the numerical data. In the following Section a numerical calibration technique is presented which facilitates fair comparison of the experimental and the numerical data.

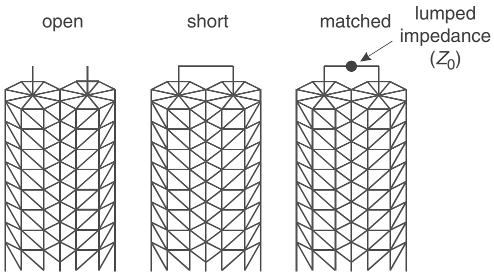

**Fig. 3** *Meshes for open, short, matched loads*

*Numerical data calibration:* Calibration of the numerical result is carried out in a way similar to the standard reflection calibration for the experimental model. Fig. 3 shows the three numerical models, i.e. open, short, matched, for the calibration procedure, where all the structures are identical to the previous numerical model for the dipole antenna, except the dipole arms. In the calibration models the two terminals of the feed line are left open for open model, connected with wire elements for short model, and connected with wire elements with lumped impedance $Z_0$ at the centre for matched load model. The impedances obtained from the calibration models are each transformed into the reflection coefficients using (2). The reflection coefficients from the calibration models are then used to calibrate the response from the antenna according to the following:

$$\Gamma = \frac{\Gamma_{dip} - S_{11}}{(\Gamma_{dip} - S_{11})S_{22} + S_{12}S_{21}} \qquad (3)$$

where $\Gamma_{dip}$ is the reflection coefficient when the dipole is connected to the feed line terminals, and $S_{ij}$, $i, j = 1, 2$, are the scattering parameters obtained as follows:

$$S_{11} = \Gamma_{\text{match}}, \quad S_{22} = \frac{2S_{11} - \Gamma_{\text{short}} - \Gamma_{\text{open}}}{\Gamma_{\text{short}} - \Gamma_{\text{open}}}, \qquad (4)$$
$$S_{12}S_{21} = (\Gamma_{\text{open}} - S_{11})(1 - S_{22})$$

where $\Gamma_{\text{open}}$, $\Gamma_{\text{short}}$ and $\Gamma_{\text{match}}$ are the reflection coefficients obtained from the calibration models. Fig. 2*b* shows the calibrated result on top of the experimental result. It is clearly shown that improvement is significant.

*Conclusion:* A procedure to calibrate a numerical data for a dipole antenna is presented when the antenna is driven from a balanced feed line and the results are compared with the result from the experimental model. The results are compared in the time domain in terms of the reflected voltage in the feed line when a Gaussian pulse is incident in the feed line. The calibrated result is shown to be improved significantly. The technique presented may be applied not only to the dipole antennas but also to other types of antennas fed by a balanced feed line. The technique is to be further studied for other types of feed line structures.

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