Analysis on Balanced and Unbalanced Modes for Dipole Antennas Using Characteristic Modes

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Abstract – **Modal analysis on dipole antenna using method of moments and characteristic modes is used to evaluate the amount of the excitation for balanced and unbalanced modes. To separate the current on the antenna into the balanced and unbalanced modes, the current distribution is decomposed into even- and odd-symmetrical distribution with respect to reference plane. As a result, the power ratio of the unbalanced to balanced modes can be numerically computed without setting both balanced and unbalanced feed ports on the analytical model.**

Index Terms — **Balanced and unbalanced modes, dipole antenna, characteristic modes, method of moments.**

I. INTRODUCTION

If antenna geometry including feed structure is asymmetric, it is known that the unbalanced current flows on the antenna and feeding lines and affects input impedance and radiation pattern. Baluns can be used to prevent unbalanced current from flowing on the line, and antenna geometry is often designed to be symmetrical. Therefore, it is required to evaluate the amount of generating the unbalanced current on the antenna or antenna system. For example, power ratio of the unbalanced to balanced modes can be evaluated by introducing mixed-mode S parameters [1].

In this paper, it is proven that the power ratio related to the balanced and unbalanced modes can be numerically evaluated by using method of moments (MoM) [2] and characteristic modes [3]. In experiment, balanced and unbalanced feeds for the antenna under test can be realized by using two semi-rigid cables. However, it is difficult to model the unbalanced feed unless feeding cable is modeled. Conversely, the balanced feed can be easily modeled in MoM, however, it is difficult to separate the power generated on the antenna into balanced and unbalanced modes. For this reason, characteristic mode is introduced to evaluate the power ratio by numerically analyzing the antenna geometry without the feeding lines using the method of moments. For the analysis using the characteristic modes, the generalized eigenvalue problem for the generalized impedance matrix in MoM should be solved and actual current distribution on the antenna can be expanded by the characteristic current modes. The coefficients of the modes can denote the amount of generating the modes.

In this paper, a technique for decomposing the characteristic modes into odd and even modes, which are correspondent to balanced and unbalanced modes, is proposed to estimate the power ratio of unbalanced to balanced modes.

II. EVEN-ODD ANALYSIS FOR METHOD OF MOMENTS

If generalized impedance matrix in MoM is expressed as $[Z] = [R] + j[X]$, characteristic modes is given by solving the following eigenvalue problem

$$[X][I_n] = \lambda_n[R][I_n], \tag{1}$$

where, λ_n denotes eigenvalue. $[I_n]$ denotes eigenvector or normalized current distribution for the characteristic mode. Actual current distribution $[I]$, which can be determined by giving feed information, can be expanded by using the modal current vector $[I_n]$ as

$$[I] = \sum_n c_n[I_n]. \tag{2}$$

Using the orthonormality of $[I_n]$s, power on the antenna, P, can be expanded as

$$P = \sum_n |c_n|^2 . \tag{3}$$

This means that power for mode $\#n$, $|c_n|^2$ is non-correlated with powers for the other modes or total power is obtained by summing the powers for all modes if the current on the antenna is expanded by the characteristic modes. Also, the modes can be classified in two categories, which have even- and odd-symmetrical current distribution. By summing $|c_n|^2$s in each category, it is possible to calculate the power which belongs to each category.

For simplicity, let us consider a dipole antenna which is modeled by sinusoidal expansion bases and has a symmetrical plane T as shown in Fig. 1. If bases $\#i$ and $\#j$ are symmetrical with respect to the plane T, let us express this relationship as $i = M(j)$ or $j = M(i)$. Also, let us express a row vector as $[A] = (A_i)$ whose element denotes A_i. Then, the current modal vector $[I_n]$ can be separated into even- and odd-symmetrical vectors $[I_n^e]$ and $[I_n^o]$ as

$$[I_n] = (I_{n,i}) = \frac{(I_{n,i})+(I_{n,M(i)})}{2} + \frac{(I_{n,i})-(I_{n,M(i)})}{2} = [I_n^e] + [I_n^o]. \tag{4}$$

By considering the orthogonality between $[I_n^e]$ and $[I_n^o]$, the modal power $|c_n|^2$ for the mode $\#n$ can be also separated into the powers $|c_n|^2_{\text{even}}$ and $|c_n|^2_{\text{odd}}$ which correspond to the even- and odd-symmetrical vectors, respectively. Therefore, the total powers for even- and odd-symmetrical current distributions, P_{even} and P_{odd} can be given as

$$P_{\mathrm{even}} = \sum_n |c_n|^2_{\mathrm{even}},\ \ P_{\mathrm{odd}} = \sum_n |c_n|^2_{\mathrm{odd}}. \qquad (5)$$

The power ratio of the unbalanced to balanced modes can be given as $P_{\mathrm{odd}}/P_{\mathrm{even}}$ if the even- and odd-symmetrical current distributions are correspond to the balanced and unbalanced modes.

III. POWER RATIO OF UNBALANCED TO BALANCED MODES FOR DIPOLE ANTENNAS

In this paper, a dipole antenna which has a length of $l = 86\mathrm{mm}$ is numerically analyzed at a frequency of 1.75GHz. In our analysis, the radius and conductivity of wire segment are assumed to be 0.5 mm and 5.8×10^7 S/m. And the dipole antenna is modeled by five sinusoidal bases. As shown in Fig. 1, modal current distribution $I_n(s)$, which can be constructed from eigenvector $[I_n]$, is expressed as a function of the distance s from the end point of the dipole antenna. The dipole antenna is fed at the points A, B, and C using delta gap model. A plane which includes the point A, T is selected as the symmetrical plane.

As a result of modal analysis, current distributions for the modes #1 and #2 are approximated as $\sin(\pi s/l)$ and $\sin(2\pi s/l)$ and so on. Namely, the modes #1 and #2 are even and odd with respect to the symmetric plane T. The magnitudes of modal coefficients for the even- and odd-symmetrical current distributions, $|c_n|^2_{\mathrm{even}}$ and $|c_n|^2_{\mathrm{odd}}$, are shown in Fig. 2(a) and (b), respectively. For the feed points A, B, and C, the mode #1, which is even-symmetrical, is most excited. For the feed point A, odd-symmetrical modes are not excited at all. Conversely, for the feed points B and C, $|c_2|^2$ and $|c_4|^2$, which correspond to the magnitude of the odd-symmetrical modes, are not zero. This fact quantitatively explains that the balanced modes are only excited for the center-fed dipole antenna whereas the unbalanced modes as well as the balanced modes are excited for the offset-fed dipole antenna, where the balanced modes are superior to the unbalanced modes.

Power ratio of the odd- to even-symmetrical modes is shown in Fig. 3 as a function of the frequency. In this figure, the ratio for the feed point A is not depicted because the level of the ratio is from -288dB to -245dB in the frequency range of 1.0GHz to 2.0GHz. The reason why the ratio is extremely small is that the power for the unbalanced modes are hardly excited or odd-symmetrical current components is impossible to distribute on the center-fed dipole antenna. Conversely, the level of the power ratio is ranged from -34.9dB to -21.2dB for the feed point B, and from -28.6dB to -14.7dB for the feed point C. If the feed point is offset, the unbalanced current can flow on the antenna and the ratio is larger as the amount of the offset is larger. This corresponds to the fact that the unbalanced current is caused by the asymmetry of the antenna geometry including the feed point. Moreover, the reason why the ratio is locally minimized at the frequency of 1.6 GHz is that the magnitude of the coefficient for mode #1 is locally maximized because the mode #1 is resonant.

IV. CONCLUSION

To analyze power ratio of unbalanced to balanced modes on the dipole antenna, the combination of the method of moments and characteristic modes can be used by decomposing actual current distribution into even- and odd-symmetrical current distributions. The numerical results suggests that the unbalanced mode be more excited as the antenna geometry including the feed structure is less symmetrical.

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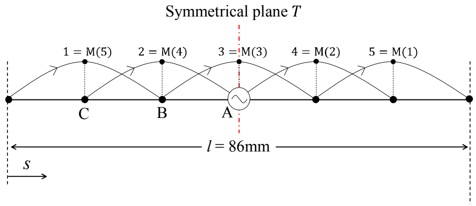
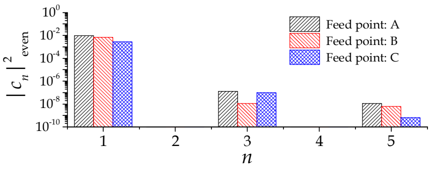
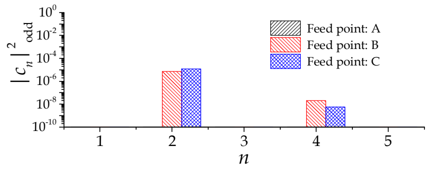


Fig. 1. Dipole antenna with various feeding points and symmetrical plane T.



(a) Even-symmetrical distribution



(b) Odd-symmetrical distribution

Fig. 2. Modal coefficients for characteristic modes.

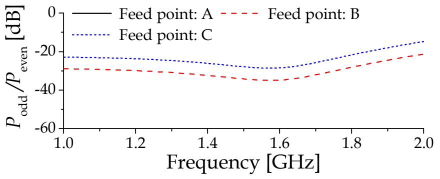


Fig. 3. Power ratio of odd- to even symmetrical modes