Forced ·Resonant Type EMI Dipole Antennas for Frequencies Below 80 MHz

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Abstract

This paper presents the basic characteristics of a forced resonant type EMI dipole antennas for frequencies below 80 MHz in which two reactance elements are used for the impedance matching at the feed point. The input impedance of the short dipole less than half-wavelength is controlled by the properly determined loading position and the value of loading reactance. The numerical results show that the small-sized EMI dipole antenna with lower antenna factors for frequencies below 80 MHz can be realized by the reactance loading. In case the proposed center driven forced resonant type EMI dipole antenna with 0.3 λ length is loaded from the center, the input impedance is matched at feed line with 50 Ω, and hence the antenna has lower factors in the frequency range of 30 to 80 MHz.

Key words : EMI antennas, forced resonance, EMI measurement.

Ⅰ. Introduction

EMI antennas for measuring electromagnetic interference are necessary to measure radiated emission from electronic equipments and systems or site attenuations of an open area test site. The various kinds of antennas have been already developed and used for the EMI antennas, but half-wavelength (half-wavelength resonance) dipole antenna is most basic [1]~[4]. Since a half-wavelength dipole antenna becomes longer in lower frequencies, a horizontally polarized antenna bends down to a cantilever and a vertically polarized antenna buckles. The long length of half-wavelength dipoles at the lower frequencies results in undesirable mutual coupling effects and limitations on the antenna height-scan range for vertical polarization. In addition, space restrictions preclude the use of half-wavelength dipoles in many indoor sites and anechoic chambers at the lower frequencies. In order to avoid these limitations and undesirable effects, some standards bodies recommend that for frequencies below 80 MHz, the antenna length should be fixed at the 80-MHz resonant length[1],[2]. The measured antenna factors in the range of 30 to 80 MHz of some tunable dipoles fixed at 80-MHz tuned length is also reported[4].

In this paper, in order to avoid space limitations and undesirable effects, we proposed a forced resonant type EMI dipole antenna with improved characteristics[5], such as higher sensitive characteristic (lower antenna factors), less buckling and bending. The method of loading reactance is applied to shorten the antenna. And Roberts balun[6] is attached to the input port of the antenna. In theoretical analysis, the integral equation for unknown current distribution is solved by applying Galerkin's method of moments[7] with piecewise sinusoidal expansion functions. The determining equation for reactance value giving the forced resonance is derived by regarding the antenna as a three-port network. From the result of theoretical analysis, if the forced-resonant loading reactance is appropriately loaded on the dipole length of 0.3 λ (dipole length of 3 m at 30 MHz), we can realize a small EMI dipole antenna with the input resistance 50 Ω and lower antenna factors in the frequency range of 30 to 80 MHz. To check the validity of the theoretical analysis, the frequency characteristics of the input impedance and antenna factors were compared with those of experiments.

Ⅱ. Theoretical Analysis

Figure 1 shows the structure and coordinate system of a forced resonant type EMI dipole antenna with loaded reactance. The dipole antenna of length L, radius a is placed along the z-axis. The reactance elements are loaded at $z=c$ and $z=-c$. The method of constuction of the loading reactance is shown in Fig. 1(b). And Roberts balun [6] is connected to the antenna terminal. Assuming the radius of the antenna is much smaller than wavelength and the antenna is fed by a delta-gap generator as the voltage source, the integral equation for the current distribution can be written as

$$\frac{1}{j\pi\omega\varepsilon_0}\int\left(\frac{\partial^2}{\partial z_2}+k_0^2\right)\frac{e^{jk_0R}}{R}I(z')dz' = -V\delta(z)+jXI(c)\delta(z-c)+jXi(-c)\delta(z+c) \quad (1)$$

where $R=\sqrt{(z-z')^2+a^2}$, k_0 is the wave number in free space, ω is the angle frequency, ε_0 is free space permittivity, $\delta(*)$ is the Dirac delta function, $I(c)$ and $I(-c)$ are currents at the loading point, and X is a loaded-reactance.

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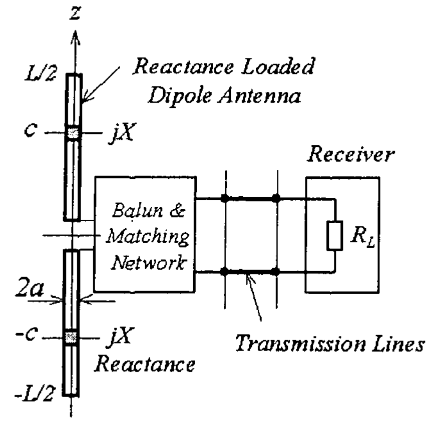
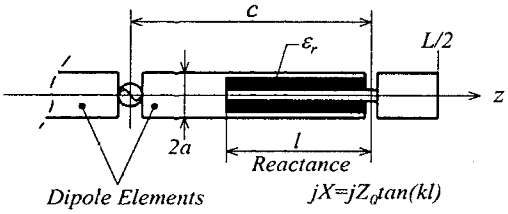


(a) Schematic diagram



(b) Construction of loading reactance

Fig. 1. Forced resonant type EMI dipole antennas with Roberts balun.

To solve the integral equation for the unknown, the current distribution $I(z)$ in Eq. (1) can be expanded as[7]

$$I(z) = \sum_{n=1}^{N} I_n F_n(z) \tag{2}$$

where I_n is the unknown current coefficients, and the basis function F_n on the segmented wire is defined by

$$F_n(z) = \begin{cases} \dfrac{\sin k_0(z - z_{n-1})}{\sin k_0 \Delta z_n}, & z_{n-1} \le z \le z_n \\ \dfrac{\sin k_0(z_{n+1} - z)}{\sin k_0 \Delta z_n}, & z_n \le z \le z_{n+1} \end{cases} \tag{3}$$

where $\Delta z_n = z_n - z_{n-1} = z_{n+1} - z_n$.

Substituting the assumed basis function into the integral equation (1) and employing Galerkin's method of moments, we obtain a set of linear equations for the unknown expansion coefficients.

$$\sum_{n=1}^{N} I_n Z_{n'n} = V_{n'} \tag{4}$$

There are generally two different methods to obtain the forced resonance of antenna. One is the perfect matching which is totally matched with transmission line. The other is the partial matching which is partially matched with transmission line. We just used the partial matching because a loaded-reactance can achieve the similar characteristic of perfect matching according as the location of reactance element is controlled [8]. The resonant condition for the partial matching of the reactance-loaded antenna in Fig. 1 is given by

$$\mathrm{Im}\{Z_{in}(y_{ij}, jX)\} = 0 \tag{5}$$

where the symbol Im{*} taking the imaginary part of {*}.

We can obtain forced resonant characteristics by treating the antenna as a three-port network with the applied voltage at port 1 and the reactance element at port 2 and port 3 [7]. The relations between terminal currents (i_1, i_2, i_3) and terminal voltages (v_1, v_2, v_3) at each port can be expressed as

$$\begin{pmatrix} i_1 \\ i_2 \\ i_3 \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} & y_{13} \\ y_{21} & y_{22} & y_{23} \\ y_{31} & y_{32} & y_{33} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} \tag{6}$$

using admittance parameters y_{ij} (i, $j = 1, 2, 3$). The terminal currents at port 2 and port 3 can be expressed as $i_2 = i_3 = -(1/jX)v_2 = -Yv_2$ since a reactance elements are connected at port 2 and port 3. Substituting the above relation into Eq. (6), we can obtain the input impedance at the driving point in the following form.

$$Z_{in} = \frac{y_{22} + y_{23} + (jX)^{-1}}{y_{11}\{y_{22} + y_{23} + (jX)^{-1}\} - 2y_{12}^2} \tag{7}$$

Substituting Eq. (7) into Eq. (5), the value of reactance to satisfy the resonant condition is expressed as

$$X = \left(\frac{2y_{11}^I}{-H \pm \sqrt{H^2 + 4y_{11}^I Q}} \right) \tag{8}$$

where

$$H = 2(y_{12}^I y_{21}^I - y_{11}^I y_{22}^I - y_{11}^I y_{23}^I - y_{12}^R y_{21}^R) \tag{9}$$

$$\begin{aligned} Q = {} & 2(y_{22}^I y_{12}^I y_{21}^I + y_{23}^I y_{12}^I y_{21}^I + y_{22}^R y_{12}^R y_{21}^I \\ & + y_{23}^R y_{12}^R y_{21}^I + y_{22}^R y_{12}^I y_{21}^R + y_{23}^R y_{12}^I y_{21}^R \\ & - y_{22}^I y_{11}^I y_{23}^I - y_{22}^R y_{23}^R y_{11}^I - y_{22}^I y_{12}^R y_{21}^R \\ & - y_{23}^I y_{12}^R y_{21}^R) \\ & - y_{11}^I \{(y_{22}^I)^2 + (y_{23}^I)^2 + (y_{22}^R)^2 + (y_{23}^R)^2\} \end{aligned} \tag{10}$$

y_{ij}^R and y_{ij}^I denote the real part and the imaginary part of y_{ij}, respectively. The reactance X which satisfies the resonant condition (Eq. (5)) is called the forced-resonant loading reactance. The plus sign in Eq. (8) corresponds to the series resonance and the minus sign to the parallel resonance.

The antenna factor of EMI antennas is defined by

$$K = \frac{E_i}{V_L} \tag{11}$$

where E_i is the incident electric field and V_L is the input voltage of the receiver. The antenna factor of the forced resonant type EMI dipole antenna with Roberts balun in Fig. 1 is obtained, neglecting the conduction loss in B/M (Balun and Matching) circuit and cable, as the following form (Bennett [9], Kim et. al.,[3]).

$$K = \frac{2}{h_e}\sqrt{\frac{R_a}{R_L}}K_B = K_0 K_B \tag{12}$$

where h_e is the effective length, R_a is the input resistance of the antenna, R_L is the input resistance of the receiver, K_0 is the antenna factor in case the ideal B/M circuit is used, and K_B is the variation of the antenna factor caused by the impedance mismatch due to insertion of the B/M circuit. If the B/M circuit is lossless, K_B is given by

$$K_B = \sqrt{\frac{|Z_{bl} + Z_a|^2}{4R_a R_{bl}}} \tag{13}$$

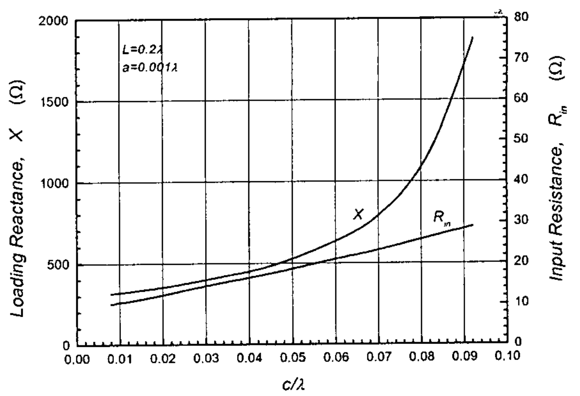
where $Z_{b1}(= R_{b1} + jX_{b1})$ is the input impedance of the antenna seen from the input terminal of the B/M circuit into the receiver. We assumed an ideal case of no reflection from the receiver terminal in this paper.

Ⅲ. Numerical Results and Discussion

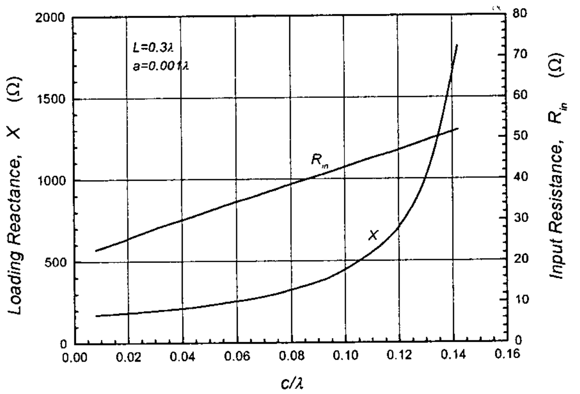
In the numerical calculation, the method of moments model for dipoles used standard thin wire kernel approximation and used 35 segments/basis functions per dipole length of 0.3 λ.

Figure 2 shows the value of forced-resonant reactance dependent on the loading position as the case of series resonance. And the input resistance in such a case is also represented. As shown in Fig. 2, if the antenna length is shorter than 0.3 λ, the real part of the input impedance becomes smaller and the matching with balun would be difficult. Therefore it is found that the antenna of length 0.3 λ is effective. In this paper, only the series resonance is investigated since the input resistance is much larger in parallel resonance. As can be seen from Fig. 2, it can be found that the loading position with the input resistance 50Ω exists from Fig. 2(b) when the antenna length of 0.3 λ (dipole length of 3 m at 30 MHz) is used. If the reactance is loaded at 0.133 λ, the forced-resonant loading reactance of X= 1151.01Ω and the input impedance of 49.96Ω are obtained, and hence the perfect impedance matching can be obtained since the resonance is occurred near the input resistance of 50Ω.

Table 1 represents the loaded reactance and antenna factors in the range of 30 to 80 MHz of the forced resonant type EMI dipole antennas with loaded reactance when the dipole length of and the diameter of 6.350 mm. When the reactances are loaded at c=0.133 λ, the perfect impedance matching can be obtained since the resonance is occurred near the input resistance of 50 Ω.



(a) 0.2 λ



(b) 0.3 λ

Fig. 2. Loading reactance and input resistance vs. loading position (series resonance).

Table 1. Loading reactance and antenna factors of forced resonant type EMI dipole antennas with Roberts balun.

Frequency (MHz)	$L = 0.3\lambda$, $2a = 6.350$mm, $c = 0.133\lambda$			
	Antenna length (m)	Loading position (m)	Loading reactance (Ω)	Antenna factor (dB)
30	3.000	1.333	1732.89	−0.86
35	2.571	1.143	1654.26	−0.32
40	2.250	1.000	1586.20	0.42
45	2.000	0.889	1526.24	1.32
50	1.800	0.800	1472.66	2.36
60	1.500	0.667	1380.12	5.16
70	1.286	0.571	1302.09	7.36
80	1.125	0.500	1234.70	7.65

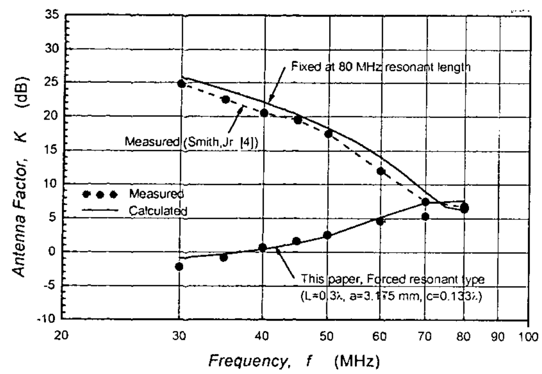


Fig. 3. Measured and calculated antenna factors.

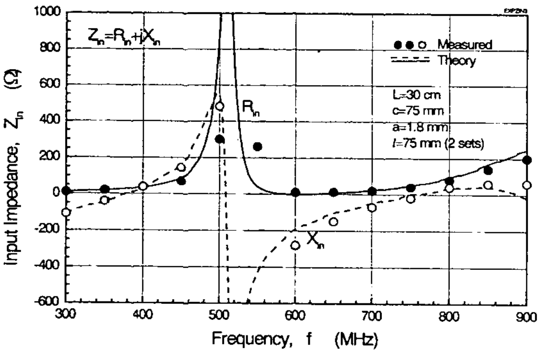


Fig. 4. Frequency characteristics of input impedance.

Figure 3 shows the antenna factors of the forced resonant type EMI dipole antenna when the dipole length of 0.3λ and of the fixed short dipole adjusted to their 80-MHz resonant length. It is shown that the calculated antenna factors of the forced resonant type EMI dipole antenna are almost equal to those measured by the standard site method and standard antenna methods, in case of the half-wavelength resonant dipole antenna[3]. As can be seen from the Fig. 3, the conventional antenna factors in the range of 30 to 80 MHz fixed short dipole adjusted to their 80-MHz length have higher factors (higher than 6.8 dB)[4], but the antenna factors of the forced resonant type EMI dipole antenna presented in this paper have lower antenna factors (lower than 7.65 dB) as shown in Fig. 3. As the results, it is found that the antenna factors of the forced resonant type EMI dipole antenna presented in this paper are almost equal to those of half-wavelength resonant dipole antenna.

In this paper, we are experimented on the input impedance because the input impedance of the loaded dipole is primary parameters on the actual antenna design. To check the validity of the numerical calculations, the input impedance of the reactance loaded dipole antenna was compared with those of experiments. The EMI dipole antenna with forced resonance by reactance loading is made by hollow aluminum pipe with radius of 1.8 mm. Loading reactances are made by the semi-ridged coaxial cable with diameter of 3.6 mm and these are inserted into the hollow pipe (see Fig. 1(b)).

Figure 4 shows the measured and calculated frequency characteristics of the input impedance. In this case the frequency range of 300 to 900 MHz is selected for easy experiments. It is shown that the calculated input impedance is good agreement with experimental results.

Ⅳ. Conclusions

In this paper a EMI dipole antenna with forced resonant by reactance loading for frequencies below 80 MHz is proposed and its basic characteristics are analyzed. Roberts balun is connected to the antenna terminal, and the loading reactance is used for downsizing of the antenna. The integral equation for unknown current distribution is solved by the Galerkin's method of moments with piecewise sinusoidal functions. As the results, if the forced-resonant loading reactance is appropriately loaded on the dipole length of , we can realize a small EMI dipole antenna with the input resistance 50 Ω and lower antenna factors in the frequency range of 30 to 80 MHz.

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