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Antenna Systems with Inductive Loading

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1. Introduction

Linear antennas, shorter than self-resonant length, are tuned to resonance by the two methods. One is inductive loading at the driving point in series with the generator; the other is inductive loading in the antenna elements in series with the antenna. The former tuning is ordinarily used and the theory is simple. The latter leads to an improvement in antenna efficiency. A theoretical treatment of single inductive loaded monopole with infinite groundplane has been given by C.W. Harrison(1). But he did not obtain the comparison between the experimental results and the calculated results and did not refer to the frequency characteristic. In this paper, the inductive loaded dipole and the asymmetrically driven dipole are considered. The experimental results agree quite well with theory.

2. Driving point admittance of the loaded dipole

A loaded dipole is equivalent to the superposition of three dipoles; one symmetrically and the other two asymmetrically driven as shown in Fig. 1. The terminals of the dipoles are located at z=0, and the conductor of radius ρ_0 extends over the range $-L/2 \leq z \leq L/2$ At $z=D_1$, D_2, lumped loading admittance Y_1, Y_2 are connected respectively in series with the wire. The driving point admittance Y_i of the loaded dipole is

$$Y_i = h(0) - F \cdot f(0) - G \cdot g(0)$$

where f(x) and g(x) are current distribution on aymmetrically driven dipole shownin Fig. 1 (a), (b), and h(x) is on symmetrically driven dipole shown in Fig. 1 (c) when unit voltage is applied, and F, G are

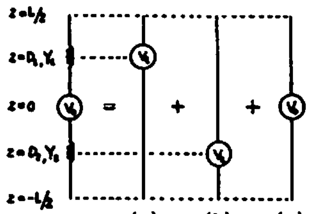


Fig.1 (a) (b) (c)

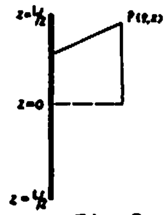


Fig.2

$$F = \frac{h(D_1)(Y_2+g(-D_2)) - h(-D_2)g(D_1)}{(Y_1+f(D_1))(Y_2+g(-D_2))-f(-D_2)g(D_1)}$$

$$G = \frac{h(-D_2)(Y_1+F(D_1)) - h(D_1)f(-D_2)}{(Y_1+f(D_1))(Y_2+g(-D_2))-f(-D_2)g(D_1)}$$

where $k_n=n\pi/L$ and $\alpha_n=n\pi/2$ from the boundary condition $I(\pm L/2)=0$. Let's consider the driving point is located at z=D and unit voltage is applied. Using the admittance matrix $(Y)=(Z)^{-1}$, Fourier components of the current I_n may be easily computed and can be written in the form

$$I_n = \sum_{m=1}^{\infty} Y_{mn} \sin(k_m D + \alpha_m)$$

3. Summary of Nomura's theory for an asymmetrically driven dipole

Let's consider an asymmetrically driven dipole of length L and radius ρ_0 as shown in Fig. 2 where $\rho_0 \ll L$. Harrison used the method of R.King(2). However, in this paper, a different method given by Y.Nomura and T. Hatta(3) is adopted. Since this method is generally applicable to the arbitrary distribution of driving points, it is powerful for the study of the loaded dipole.

The impedance matrix (Z) is introduced to connect Fourier components of the current with the field intensity. The total current at $z=\xi$, $I(\xi)$ can be expanded into Fourier Seris

$$I(\xi) = \sum_{n=1}^{\infty} I_n \sin(k_n \xi + \alpha_n)$$

Impedance matrix element Z_{mn} is non-vanishing, only when both n and m are even or odd and may be written

$$Z_{mn} = -\frac{k_m}{4\pi\varepsilon_0\omega}\,\frac{k^2-k_n^2}{k_n^2-k_m^2}\left\{E_i(k-k_n)-E_i(k+k_n)\right\}+$$

$$\frac{k_n}{4\pi\varepsilon_0\omega}\,\frac{k^2-k_m^2}{k_n^2-k_m^2}\left\{E_i(k-k_m)-E_i(k+k_m)\right\}$$

$$Z_{mm} = \frac{1}{8\pi\varepsilon_0\omega}\,\frac{k^2+k_n^2}{k_n}\left\{E_i(k-k_n)-E_i(k+k_n)\right\}+$$

$$\frac{1}{8\pi\varepsilon_0\omega}\Big[(k+k_n)\left\{e^{j(k-k_n)L}-e^{j(k-k_n)\frac{\rho_0}{2}}\right\}+$$

$$(k-k_n)\left\{e^{j(k+k_n)L}-e^{j(k+k_n)\frac{\rho_0}{2}}\right\}\Big]-$$

$$\frac{j}{8\pi\varepsilon_0\omega}(k^2-k_n^2)L\left\{E_i(k-k_n)+E_i(k+k_n)\right\}$$

where $E_i(x)$ is exponential integral, defined as

$$E_i(x) = \int_{\frac{\rho_0}{2}}^{L}\frac{e^{jxt}}{t}\,dt$$

It is important in this theory to decide the number of the terms that approximate the infinite order matrix. It is found by numerical calculation that good approximation is obtained if the order of the square matrix is 15.

4. Numerical results and comparison with experiment

Asymmetrically driven dipole

The line is excited by a 500MHz. A set of asymmetrically driven dipoles are prepared. They are made of brass pipe and its diameter $2\rho_0$ is 0.005λ and the length L is 0.5λ. The length D between the driving point and the center of the pipe is changed between 0 to 0.35L. The variation of the driving point impedance Z_i due to D/L is shown in Fig. 3. The ratio D/L is changed from 0 to 0.35 but no significant change in the radiation patterns is observed.

Loaded dipole

Measurments are made on 0.4λ-length symmetrically loaded dipoles ($D=D_1=D_2$; the length between the driving point and the loaded point). The variation of reactance X_L of two coils (the number of turns N is 3 and 6, respectively) due to frequency (460MHz to 540MHz) is shown in Fig. 4. The driving point impedance of three antennas that values of D/L are 0.1417, 0.2708, 0.4375 are measured in the range f=460-500MHz. Calculated and measured driving point reactance of the three dipoles (unloaded and loaded with coils of N=3,6) are shown in Fig. 5 (a), (b), respectively. The driving point resistance is not significantly changed with the variation of the loading impedance.

References

(1) C.W. Harrison; IEEE Trans., vol. AP-11, No.4, pp. 394-400, 1963

(2) R. King; Proc. I.R.E., vol. 38, pp. 1154-1164, 1950

(3) Y. Nomura and T. Hatta; Tech. Reports Tohoku Univ., vol. 17 pp. 1-18, 1952

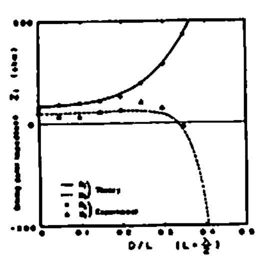


Fig.3

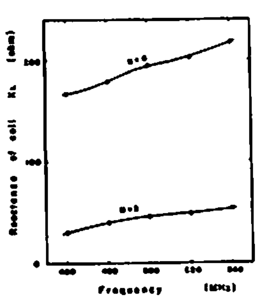
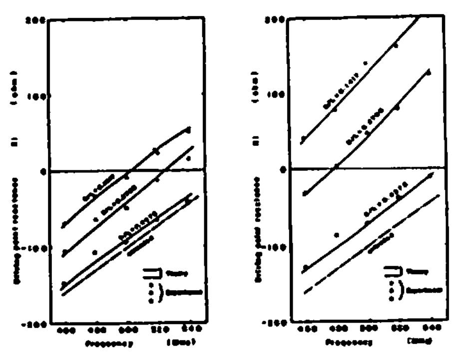


Fig.4



(a) (b)

Fig.5