§15. Recurrence Formulas of Combline Antenna

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A combline antenna is under investigation to be installed in LHD at the sixth experimental campaign. This antenna has some advantages; 1) use of mutual coupling of a traveling wave, 2) vacuum feed-throughs required only for end straps, 3) easiness to obtain an impedance matching, 4) wide bandwidth, 5) controllability of parallel wave number with frequency. In this paper, the radio frequency (RF) characteristics of the combline antenna is described.

The equivalent circuit of the combline antenna is shown in Fig.1. Two antenna elements on both sides are an inlet antenna and an outlet antenna. The real combline antenna consists of the 2 antennas and the 8 antennas, which are the same as the middle antenna as shown in Fig.1. There are two resonance frequency referred to as an even mode and an odd mode, i.e., ω_e and ω_o. These frequencies are calculated as $\omega_e=1/\sqrt{LC}$ and $\omega_o=1/\sqrt{(L+2L_C)C}$ using the inductance, L and the capacitance, C of the antenna element, and the inductance of the support of the antenna L_c.

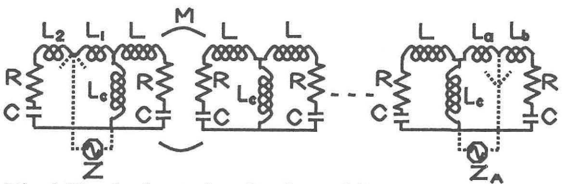

Fig.1 Equivalent circuit of combline antenna

Now, we consider the combline antenna with N antenna elements. In the N-4 antenna elements among N elements, the characteristic equations are calculated taking account a mutual coupling from the two adjacent antenna elements; the mutual inductances for the even mode and the odd mode are expressed as M_{ee} and M_{oo}. Two recurrence formulas are solved for the even mode and the odd modes in the following equations,

$$M_{ee}I_{e,k+1}+tI_{e,k}+M_{ee}I_{e,k-1}=0$$

$$M_{oo}I_{o,k+1}+(t+2i\omega L_c)I_{o,k}+M_{oo}I_{o,k-1}=0$$

Here t is a complex, and expressed as

$$t=R+i\omega L+\frac{1}{i\omega C}$$

By solving the recurrence formulas the current at the k^th element can be known using the current at the 3^rd antenna element, I_3, and the current at the 2^nd, I_2, for both modes in the following formulas.

$$I_{e,N-1}=d_{11}^{(e)}I_{e,3}+d_{12}^{(e)}I_{e,2}$$

$$I_{o,N-1}=d_{11}^{(o)}I_{o,3}+d_{12}^{(o)}I_{0,2}$$

where, $d^{(e)}$ and $d^{(o)}$ are 2x2 matrixes shown as

$$d^{(e)}=\begin{pmatrix} \dfrac{\beta_e^{N-3}-\alpha_e^{N-3}}{\beta_e-\alpha_e} & \dfrac{-\alpha_e\beta_e^{N-3}+\beta_e\alpha_e^{N-3}}{\beta_e-\alpha_e} \\ \dfrac{\beta_e^{N-4}-\alpha_e^{N-4}}{\beta_e-\alpha_e} & \dfrac{-\alpha_e\beta_e^{N-4}+\beta_e\alpha_e^{N-4}}{\beta_e-\alpha_e} \end{pmatrix}$$

$$d^{(o)}=\begin{pmatrix} \dfrac{\beta_o^{N-3}-\alpha_o^{N-3}}{\beta_o-\alpha_o} & \dfrac{-\alpha_o\beta_o^{N-3}+\beta_o\alpha_o^{N-3}}{\beta_o-\alpha_o} \\ \dfrac{\beta_o^{N-4}-\alpha_o^{N-4}}{\beta_o-\alpha_o} & \dfrac{-\alpha_o\beta_o^{N-4}+\beta_o\alpha_o^{N-4}}{\beta_o-\alpha_o} \end{pmatrix}$$

α_e and β_e are solutions of the recurrence formula of the even mode, α_o and β_o are those of the odd mode.

$$\alpha_e=\frac{-t+\sqrt{t^2-4(i\omega M_{ee})^2}}{2i\omega M_{ee}}$$

$$\beta_e=\frac{-t-\sqrt{t^2-4(i\omega M_{ee})^2}}{2i\omega M_{ee}}$$

$$\alpha_o=\frac{-(t+2i\omega L_c)+\sqrt{(t+2i\omega L_c)^2-4(i\omega M_{oo})^2}}{2i\omega M_{oo}}$$

$$\beta_o=\frac{-(t+2i\omega L_c)-\sqrt{(t+2i\omega L_c)^2-4(i\omega M_{oo})^2}}{2i\omega M_{oo}}$$

The currents at the outlet antenna element are obtained similarly as the procedure in the previous method,

$$0=2tI_{e,1}-i\omega L_aI_A+2i\omega M_{ee}I_{e,2}$$

$$0=2tI_{o,1}+4i\omega L_cI_{o,1}+i\omega(2L_c+L_a)I_A+2i\omega M_{oo}I_{o,2}$$

Here I_A is a current at the output transmission line and the output impedance Z_A is expressed as

$$Z_AI_A+(R+i\omega L_b+\frac{1}{i\omega C})(I_{e,1}-I_{o,1})=0$$

At the 2^nd antenna element the recurrence formulas are similarly formulated using the currents at the outlet and the 3^rd antenna elements;

$$0=2tI_{e,2}+2i\omega M_{ee}(I_{e,3}+I_{e,1})-i\omega M_AI_A$$

$$0=2tI_{o,2}+4i\omega L_cI_{o,2}+2i\omega M_{oo}(I_{o,3}+I_{o,1})+i\omega M_AI_A$$

Here M_A is a mutual impedance at the RF power output connected to the dummy load. At the (N-1)^th element recurrence formula are obtained using I_z at the N^th antenna element, which is a current at the RF power supply.

$$0=2tI_{e,N-1}+2i\omega M_{ee}(I_{e,N}+I_{e,N-2})-i\omega M_ZI_Z$$

$$0=2tI_{o,N-1}+4i\omega L_cI_{o,N-1}+2i\omega M_{oo}(I_{o,N}+I_{o,N-2})+i\omega M_ZI_Z$$

Here M_Z is a mutual impedance at the RF power supply. At the N^th antenna element,

$$0=2tI_{e,N}+i\omega L_1I_Z+2i\omega M_{ee}I_{e,N-1}$$

$$0=2tI_{o,N}+4i\omega L_CI_{o,N}+i\omega(L_1+2L_C)I_Z+2i\omega M_{oo}I_{o,N-1}$$

Reference

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[2] Takase, Y. et al. : TCM-Steady state Oparation, Kyushu (1999).