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ON THE IMPEDANCES OF TWIN LOOP ANTENNAS

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INTRODUCTION

The Twin Loop Antenna (TLA) created by K.Endo[1] is widely used for TV broadcast in Japan and in China because of their broadband and simple feeding,but an exact theory of TLA has not been completed.

The radiating elements of TLA are a pair of excited loops (L_1 & L_2) and a pair of image loops (L_4 & L_3) located symmetrically with respect to the reflector of screen-type (Fig.1). In early researches the input impedance Z_{in} of TLA was computed based on the mutual impedances such as $Z_{12}=Z_{21}$, $Z_{14}=Z_{23}$, $Z_{13}=Z_{24}$ between two isolated loops and the self impedance $Z_{11}=Z_{22}$ of an isolated loop in free space, and on the impedance transformation from the excited point of loop to the feeding point of TLA.

The measured curves of mutual impedances by Endo[2] only suit the loops with one wavelength circumference, they are insufficient for computing the frequency response of Z_{in}. Iizuka[3], Bhattacharyya[4], Abul-Kassem[5] et al. solved the simultaneous integral equations of currents along two identical parallel circular-loops using the method of Fourier expansion, and gave the impedances for different arrangements, but the arrangement which suits the computation of Z_{12} and Z_{13} has not been given. Authors computed the mutual impedances for all the cases which are encountered in the structures of TLA using the electromagnetic force method (e.m.f.)[6,7] and the moment method (MM)[8,9] respectively.

Nevertheless, all of the privous methods have an intrinsic disadvantage, that the mutual impedance between two loops in the practical TLA is different from that in free space because of the effects of multicoupling among all loops. Endo and Sato[10,11] analized the whole structure including both the radiating and the irradiating elements of TLA with the reflector of grid-type using the MM , and computed the input impedance of TLA directly. This can be regarded as a rational idea for analizing TLA rather then designing it.

In this paper the excitation impedance Z_1 is analized and computed with consideration the multicoupling among all four loops using the MM . There are several main differences between this work and reference[9] :

(a) The analysis of MM excludes the irradiating elements of TLA such as the parallel transmission lines and the loading or tuning stubs .

(b) The ideal image loops are used to substitute the reflector of screen-type which is equivalent to the reflector of grid-type in practice[10].

(c) The improvements on the singularities of integral kernel in equations and on the selection of basis functions of currents are made .

(d) The point excitation with infinitesimal gap at the excited point of loop is considerd .

MOMENT METHOD SOLUTION

The simultaneous operator equations of four parallel loops have been derived by analogy to the equations of two loops[7]

$$\begin{cases} \sum_{\nu=1}^{4} \mathcal{L}_{\mu\nu}[I_\nu(\phi'_\nu)] = V_\mu\, \delta(\phi_\mu) \\ \mu = 1,2,3,4 \end{cases} \quad , \tag{1}$$

the integro-differential operators (μ,ν=1,2,3,4) are

$$\mathcal{L}_{\mu\nu} = \frac{j\eta}{ka}\int_0^{2\pi} d\phi'_\nu \left[\hat{\phi}_\mu \cdot \hat{\phi}'_\nu (ka)^2 G(\phi_\mu|\phi'_\nu) + \frac{\partial}{\partial\phi_\mu} G(\phi_\mu|\phi'_\nu)\frac{d}{d\phi'_\nu}\right] \tag{2}$$

and the Green's function in free space is $G(\phi_\mu|\phi'_\nu)=\exp(-jkR_{\mu\nu})/4\pi R_{\mu\nu}$, where η is wave impedance, k is wave number, $R_{\mu\nu}$ is the distance between the field-point located at ϕ_μ of the surface of L_μ and the source-point located at ϕ'_ν of the axis of L_ν. This distance is determined by the geometric relations between these loops.

According to the symmetry of structure, the parallel feeding, the negative polarity of images, and the uniform definition of orientation of angles ϕ'_ν and ϕ_μ in the sense of counter-clockwise, the relations of current polarities $I_1=-I_2=I_3=-I_4$ and of exciting voltages $V_1=-V_2$ hold. When the unknown currents along each loop are expanded in terms of the basis functions $\{\psi_n(\phi'_\nu)\,|\,n=1,2,\cdots,N\}$ as

$$\begin{cases} I_\nu(\phi'_\nu) = \sum_{n=1}^{N} c_n\, \psi_n(\phi'_\nu) \\ \nu = 1,2,3,4 \end{cases} \quad , \tag{3}$$

the equation describing the boundary condition of electric fields on L_1 is

$$\sum_{n=1}^{N} c_n \left\{\sum_{\nu=1}^{4}(-1)^{\nu+1}\mathcal{L}_{1\nu}[\psi_n(\phi'_\nu)]\right\} = V_1\, \delta(\phi_1) \quad ,$$

thus N algebraic equations can be derived using the operation of inner-products with the weighting functions of $\{w_m(\phi_1)\,|\,m=1,2,\cdots,N\}$ respectively, and then a matrix equation can be expressed as

$$\mathbf{F}\mathbf{C} = V_1\mathbf{W} \quad , \tag{4}$$

where the unknown vector of (N × 1) order $\mathbf{C}=[c_n]$ may be computed from the known vector of (N × 1) order $\mathbf{W}=[w_m(0)]$ and the matrix of (N × N) order $\mathbf{F}=[f_{mn}]$, where the generalized impedance parameters are (m, n =1,2,···,N)

$$f_{mn} = \sum_{\nu=1}^{4}(-1)^{\nu+1} a \int_0^{2\pi} w_m(\phi_1)\, \mathcal{L}_{1\nu}[\psi_n(\phi'_\nu)]\, d\phi_1 \quad . \tag{5}$$

From the inversion of equation (4), the vector of coefficients in (3) is

$$\mathbf{C} = (\mathbf{F}^{-1}\mathbf{W})V_1 \quad ,$$

so that the excitation impedance of loop L_1 is obtained as

$$Z_1 = V_1/I_1(0) = 1/(\mathbf{\Psi}^T\mathbf{F}^{-1}\mathbf{W}) \quad , \tag{6}$$

where the known vector of (N × 1) order is $\mathbf{\Psi}=[\psi_n(0)]$.

NUMERICAL RESULTS

The numerical computation of impedances have been performed from equation (6) for the TLA with the following sizes: $(\rho/2\pi a)=0.015$; $(h/2\pi a)=0.250\sim0.300$; $(D/a)=3.8\sim7.0$. The computed data of $Z_1=R_1+jX_1$ have been processed using the fitting of a polynomial as shown in Fig.2 .

In practical computation, the number of independent parameters f_{mn} have been decreased by the symmetry of structure of TLA, the partial integration have been used to reduce the sigularity of Green's function for the purpose of improving the accuracy of solution[9]. Both the Galerkin Method with triangular pulse bases

(N=6) and the MM with the bases of B-splines of 4th-order and the weighting functions of triangular pulses (N=6) are used, the results of each method are convergent and very close, but the latter only needs about 1/6 computer time of the former[12] .

DISCUSSION

After the excitation impedance Z_i is obtained, a tuning stub constructed at this excited point as a shunt succeptance provides rational local tuning,that is beneficial to widen the frequency bandwidth of TLA. Fig.2 shows that X_i are always negative in all operation band, so a tunable inductive stub with less than a quarter of wavelength is suitable (Fig.3). This structure of TLA is used frequently in China.

In general the feed impedance Z_f can not effectively describe the matching situation of TLA, because a balun must be inserted between the coaxial feeder and antenna.Therefore an excellent design of TLA should take the balun into account, this matter will be detailed in other paper[13] .

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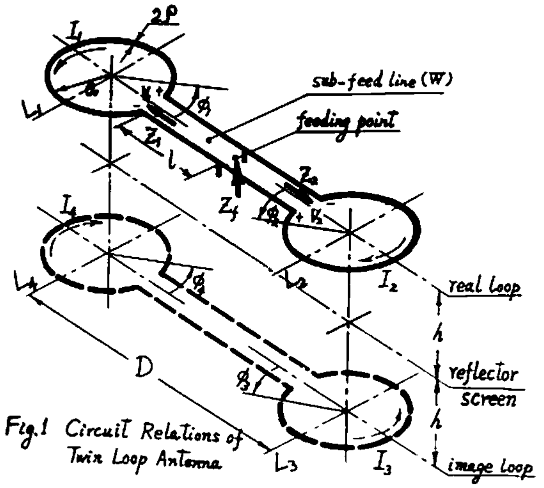

Fig.1 Circuit Relations of Twin Loop Antenna

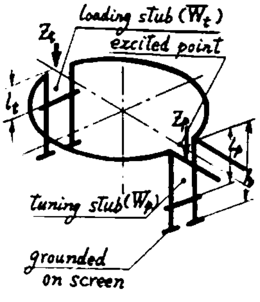

Fig.3 Loading & Tuning Loop

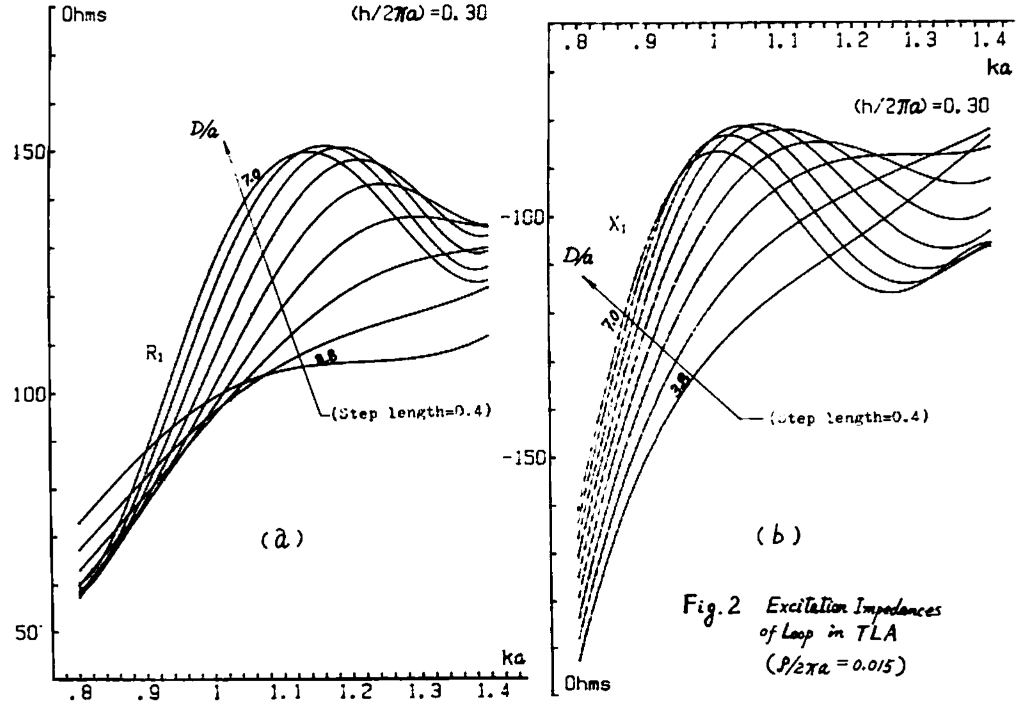

Fig.2 Excitation Impedances of Loop in TLA ($\rho/2\pi a = 0.015$)