

A Novel Design Method of Loaded Beam Tilting Antenna with Reactive Loads

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1.Introduction

For the base station antenna of cellular mobile telephone systems, a beam tilting antenna is desired[1]. Such a beam tilting is realized easily by a loaded wire antenna. We reported the determination method of the loading impedances for the antenna with 1 or 2 loads from desired tilt angle [2]. In this paper, we describe design method of the loaded beam tilting antenna with more than 3 reactive loads which realize desired tilt angle, high directive gain and low sidelobe level.

From Section 2 to Section 4, the determination method of loading impedances of the antenna with 2 loads is described. In Section 5, design method of the antenna with more than 3 reactive loads is presented. We realized antennas by using the combination of the determination method of loading impedances and determination method of the spaces of the loads we propose this time. In Section 6, examples of the antennas designed by the proposed method are shown.

2.Relation between electric field and loading impedances of antenna

Fig.1 shows a loaded antenna with 2 loads fed by the voltage V_s . The antenna is assumed divided into N equal-length segments. $I_1, I_2, \dots, I_L, \dots, I_N$ are the currents on the segments. Z_L and Z_M are loading impedances.

From [3], we have the relation between the electric field at the far zone observation point and the loading impedances as follows. The current is assumed along the z -axis. The current distribution is computed by using the Moment method (Galerkin's method). We used piecewise sinusoidal function as the basis function. By the computing, we obtain

$$[V] = [Z][I] \quad (1)$$

where $[I]$ represents currents on the antenna, $[V]$ incorporates V_s , $-Z_L I_L$ and $-Z_M I_M$. $[Z]$ is square matrix which is determined from shape of the antenna.

The electric field at the far zone observation point from the antenna is given by

$$E(\theta) = jK \sin\theta \int_0^h I(z) \exp(jkz \cos\theta) dz \quad (2)$$

where K is the constant, k is the free space wave number. $I(z)$ is current on the antenna and can be represented by

$$I(z) = \sum_{t=1}^N I_t T_t(z) \quad (3)$$

For $T_t(z)$, we used piecewise sinusoidal function. I_t ($t=1, 2, \dots, N$) are the currents on the segments of the antenna.

When the antenna has Z_L and Z_M , we have from (1), (2) and (3)

$$E(\theta) \cong A[\alpha Z_L Z_M + \beta Z_L + \gamma Z_M + \delta] \quad (4)$$

where

$$A = jK V_s \sin \theta / [1 + Y_{LL} Z_L + Y_{MM} Z_M + (Y_{LL} Y_{MM} - Y_{LM} Y_{ML}) Z_L Z_M] \quad (5)$$

and

$$D_t(z) = \int_{z_{t-1}}^{z_{t+1}} T_t(z) \exp(jkz \cos \theta) dz \quad (t = 1, 2, \dots, N) \quad (6)$$

, , and are represented using $D_t(z)$ and the elements of $[Y]$ which is inverse matrix of $[Z]$ [2].

3. Representation of tilt angle, directive gain and sidelobe

Fig. 2 shows radiation pattern. θ_{TL} represents the position of the main lobe maximum, that is, $\theta_{TL} = \theta + 90^\circ$. From Fig. 2, for the radiation intensity in the θ_{TL} direction,

$$\partial |E(\theta_{TL})|^2 / \partial \theta = 0 \quad (7)$$

$$\partial^2 |E(\theta_{TL})|^2 / \partial \theta^2 < 0 \quad (8)$$

are derived.

Next, for the straight wire antenna, directive gain (G_d) in θ_{TL} direction is represented using the following equation.

$$G_d = \frac{2 |E(\theta_{TL})|^2}{\int_0^\pi |E(\theta)|^2 \sin \theta d\theta} \quad (9)$$

Moreover, we define that radiation to the upper half-plane in Fig. 2 is sidelobe. And, we consider the following equation for representing sidelobe.

$$\frac{1}{n} \sum_{i=1}^n |E(\theta_i)|^2 = b_k |E(\theta_{TL})|^2 \quad (10)$$

In this equation, b_k is the ratio of the average of radiation intensities in n directions within sidelobe to the radiation intensity in θ_{TL} direction. We realize low sidelobe level by making the b_k small.

4. Determination method of loading impedances to realize desired tilt angle

From (4), (9) and (10), for the antenna with $Z_L (= R_L + jX_L)$ and $Z_M (= R_M + jX_M)$, following equations are obtained.

$$\partial |E(\theta_{TL})|^2 / \partial \theta = afR_M^2 + afX_M^2 + bfR_M + cfX_M + df \quad (11)$$

$$\partial^2 |E(\theta_{TL})|^2 / \partial \theta^2 = asR_M^2 + asX_M^2 + bsR_M + csX_M + ds \quad (12)$$

$$G_d = \frac{2(agR_M^2 + agX_M^2 + bgR_M + cgX_M + dg)}{aiR_M^2 + aiX_M^2 + biR_M + ciX_M + di} \quad (13)$$

$$\begin{aligned} \frac{1}{n} \sum_{i=1}^n (ar_i R_M^2 + ar_i X_M^2 + br_i R_M + cr_i X_M + dr_i) \\ = b_k (atR_M^2 + atX_M^2 + btR_M + ctX_M + dt) \end{aligned} \quad (14)$$

where each coefficient is function of Z_L and derived from (4) and (6). Then, we have the equations which represent circles by assuming (11)=0 and (12)=0

In Fig.3, determining Z_L , C_1 is derived from (11) and C_2 is derived from (12), respectively. When as in (12) > 0 , the impedances in the inside area of C_2 satisfy (8) as shown

in Fig.2. When as in (12) < 0 , the impedances in the outside area of C_2 satisfy (8). Therefore, the antennas with the impedances denoted by the arrow realize desired tilt angle. The impedance on X_M axis represents that the load is reactance. We obtain G_d and b_k , by substituting the reactance X_M into (13) and (14), respectively.

For the antenna with reactive loads only, determining $R_L=R_M=0$, X_L and X_M which realize desired tilt angle, higher G_d and smaller b_k are chosen.

5.Design method of the antenna with more than 3 loads

Next, we describe the design method of the beam tilting antenna with more than 3 reactive loads. The model antenna is shown in Fig.4. The antenna has 6 loads. h , L_I and L_E are dimensions of the antenna. The loading impedances of the antenna are $Z_F(=R_F+jX_F)$, $Z_L(=R_L+jX_L)$, and $Z_M(=R_M+jX_M)$, that is, a number of Z_F is 4. For the antenna, spaces of the loads are equal. L_I and L_E are determined as following equations.

$$\begin{aligned} L_I &= \lambda / 2 + 2D \times i \\ L_E &= \lambda / 2 + D \times i \quad \text{or} \quad \lambda / 2 + D \times i - 1 \\ &\quad (i = 0,1,2,\dots) \end{aligned} \tag{15}$$

where λ is 1 wavelength and D is length of 1 segment of the antenna. D is $\lambda/24$ for the design. The maximum length of L_I is $3\lambda/4$ and that of L_E is $3\lambda/4$. We realize current distribution as shown in Fig.4(a) by L_I and L_E of suitable length and loading impedances of suitable value. Then, the antenna realize current distribution same as dipole array as shown in Fig.4(b).

Determining the dimensions of the antenna and positions of the loads above mentioned method and adding jX_F which is impedance of reactive loads to the corresponding diagonal elements in the matrix $[Z]$, X_L and X_M are obtained from the same method applied for the antenna with two loads. For X_F , several values were used. The beam tilting antenna which realize desired tilt angle, high directive gain and small b_k were designed by using this process.

6.Example of the loaded beam tilting antenna

Table 1 shows example of the dimensions, loading impedances and characteristics of the loaded beam tilting antenna with 6 loads designed by the proposed method. In these antennas, the tilt angles agreed with the desired tilt angles. They realized comparably small b_k and high directive gain. And, their VSWR didn't exceed 2.0.

7.Conclusion

A novel design method of loaded beam tilting antenna with more than 3 loads to realize desired beam tilting, high directive gain and low sidelobe level was proposed. In this method, a number of loads isn't limited.

References

- [1]Y. Yamada, Y. Ebine and K. Tsunekawa, " Base and Mobile Station Antennas for Land Mobile Radio Systems, " IEICE Trans. Japan, Vol.E74, No.6, pp.1547-1555, 1991.
- [2]T. Tanaka, S. Egashira, A. Sakitani and M.Aikawa " A Design Method of Loaded Beam Tilting Antenna, " IEICE Trans. Japan, Vol.J82-B, No.6, pp.1229-1238, 1999.
- [3]K. Hirasawa, " Design of Arbitrary Shaped Thin Wire Antennas by Passive Impedance Loadings, " IECE Trans. Japan, Vol.J61-B, No.8, pp.713-720, 1978.

Table 1. Example of the loaded beam tilting antenna with 6 loads.
(Frequency:1465MHz, Radius of antenna: 0.015)

T (degree)	gain(dBi)	bk	h ()	LE ()	LI ()	ZF ()	ZL ()	ZM ()
5	9.4	0.06	130/24	15/24	20/24	j130	j122	j102
10	9.1	0.03	118/24	14/24	18/24	j150	j150	j144
15	8.8	0.04	113/24	14/24	17/24	j160	j152	j118
20	8.5	0.05	106/24	13/24	16/24	j160	j184	j143

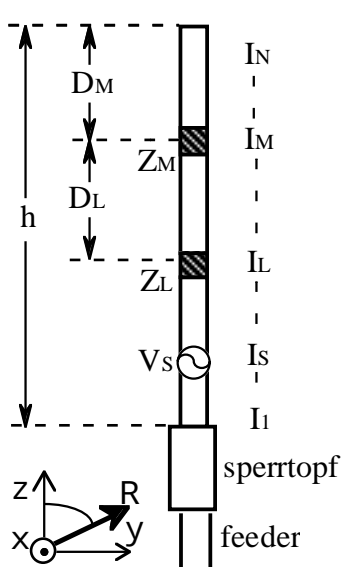


Fig.1. Loaded antenna with 2 loads.

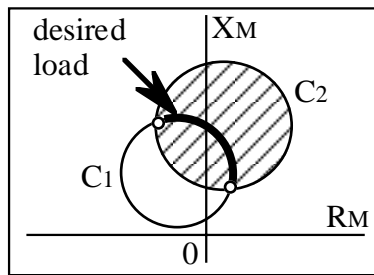


Fig.3. Loading impedance to realize desired tilt angle (when $\alpha > 0$).

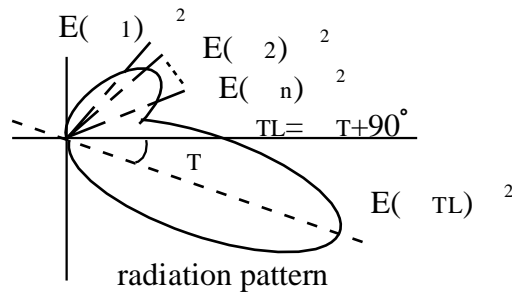


Fig.2. Expression of beam tilting and sidelobe.

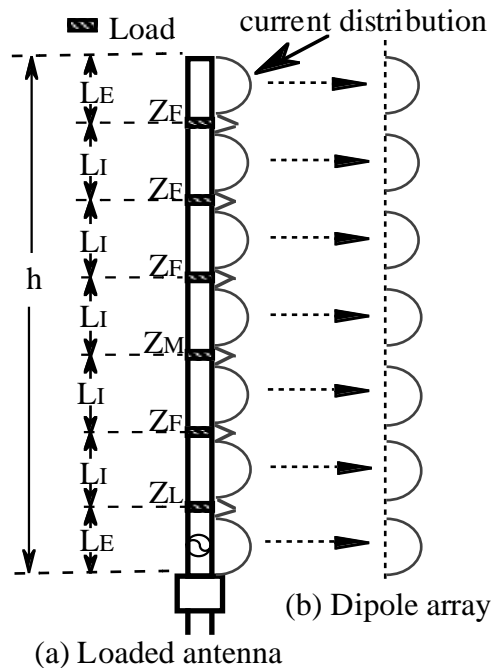


Fig.4 Loaded antenna which realize dipole array.