PROCEEDINGS OF ISAP '85

123-3

THE OPTIMIZATION OF TWIN LOOP ANTENNAS

Zhang Wen Xun
Yuan Jin Yun
Yang Xian Hua

Electromagnetics & Microwave Lab.,
Nanjing Institute of Technology,
The People's Republic of China

INTRODUCTION

The Twin Loop Antennas (TLA) have been widely used for TV broadcasting for 22 years. The radiation patterns and the impedance characteristics of TLA have been analized and computed$^{1\sim7}$, but the design always relies on the experiential data and the cut-and-try method rather than rigorous computational formulas and the performances of TLA depend mainly on the skill of adjustments. In this paper the multi-dimensional fitting of impedance data provided by the authors in another paper[8] is formulated and a computer program for optimizing TLA including a Balun is used to widen the frequency bandwidth .

For the structure of unloaded loop shown in Fig.1, the excitation impedance Z_l involves a capacitive reactance in the operation band[8]. The sub-feed line (W,l) transforms Z_l to the feed impedance Z_f, and the Balun transforms Z_f to the input impedance Z_{in} of TLA (Fig.2). For the purpose of reaching a good match with the feeder (W_f),in a tradition design an inductive loading stub (W_t,l_t) is connected to the loop at the point opposite to the excited point (Fig.3) causing real Z_l, but the current distribution along the loaded loop is different from the unloaded loop,thus the analyses of radiation pattern and impedance characteristics based on the unloaded loop are inefficient. Furthermore,the loading stub decreases the bandwidth of radiation gain[3]. In this paper an inductive tuning stub (W_p,l_p) shunted at excited point is used to widen the matching band. According to the conclusions of previous paper[7] , the bandwidth of TLA for the case of unloaded loop with tuning stub only is wider than the case of the loop with both loading and tuning stubs, so that only tuning stub is used in this paper.

The structure of TLA includes many geometric sizes and circuit parameters(such as the characteristic impedances), all of these have effect on the frequency response of Z_{in}(ka) of TLA. In practice it is impossible to optimize all of these sizes and parameters,some sizes (such as the diameters of conductors)are defined in advance,and others are determined by a two-step optimization procedure for Z_f and Z_{in} . These are detailed as follows.

OPTIMIZATION OF ANTENNA STRUCTURE

The objective function of optimization is the maximum sample value of the VSWR at feeding point in a defined frequency range (ka= 0.8~1.4), the optimization means minimizing this $(VSWR)_f$, which is determined by Z_f and the characteristic impedance of feeder W_f as

$$(VSWR)_f = \frac{|Z_f+W_f|+|Z_f-W_f|}{|Z_f+W_f|-|Z_f-W_f|} , \qquad (1)$$

where

$$Z_f = \frac{W}{2}\,\frac{Z_l'+j\,W\,tg(kl)}{W+j\,tg(kl)\cdot Z_l'} \qquad (2)$$

and
$$Z_1' = Z_p Z_1 / (Z_p + Z_1) \quad , \tag{3}$$

$$Z_p = j W_p \, tg(k l_p) \quad . \tag{4}$$

The excitation impedances Z_1 have been computed by the authors[8]. When the ratio (ρ/a) is given, Z_1 is a multi-variable function of the electric length of circumference (ka), the distance between centers of two loops D (or the length of sub-feed line l=(D/2)-a), and the distance between the loop and the reflector screen h (or between the real loop and its image H=2h). In order to suit the computer program, the 3-dimensional fitting of polynomial has been performed using a mixed process of the least square method (for ka and D/a) and the collocation method (for h/πa). The approximate polynomial is expressed as

$$Z_1 = \sum_{m=0}^{6} \sum_{n=0}^{7} \sum_{s=0}^{2} C_{mn}^{(s)} (h/\pi a)^s (D/a - 5.4)^n (ka - 1.1)^m \quad , \tag{5}$$

where $\{ C_{mn}^{(s)} \}$ are the fitting coefficients. For example, when (ρ/a)=0.03π , (D/a)=5.4 , (h/a)=0.60π , the formula (5) can be reduced to

$$Z_1 = \sum_{m=0}^{6} C_m \, (ka)^m$$

with coefficients: C_0 = - 12049.803 -j 48762.914
C_1 = 61724.301 +j 275656.296
C_2 = -125980.008 -j652560.145
C_3 = 129155.380 +j 821360.211
C_4 = - 67797.167 -j577299.213
C_5 = 16068.368 +j 214294.722
C_6 = - 1020.136 -j 32780.963

Let the sizes h, l, l_p and the parameters W, W_p , W_f be optimizing variables, the simplex method[9] which excludes the computation of derivatives has been used in a sub-routine of optimization.

OPTIMIZATION OF BALUN STRUCTURE

The broadband Balun as a common component is always designed for the operation state of pure resistance load, but a Balun used in TLA operates in the state of complex impedance load Z_f(ka). A Balun structure of resonant-type with a series complementary reactance is adopted (Fig.4), its equivalent circuit is a bandpass filter consisting of the reactances of the jumper, the series open-circuit line (W_s , l_s), and the shunt stub (W_b , l_b). Therefore the input impedance of TLA is

$$Z_{in} = j\omega L + Z_s + \frac{Z_b Z_f}{Z_b + Z_f} \quad , \tag{6}$$

where the jumper inductance L ≈(60~100)nH computed from reference[10] is determined by the shape and sizes of jumper, the reactances

$$Z_s = -j W_s \, ctg(k l_s) \quad , \tag{7}$$

$$Z_b = j W_b \, tg(k l_b) \quad . \tag{8}$$

The objective function of optimization of Balun is the maximum sample value of the VSWR at input point of TLA in frequency range (ka= 0.8~1.4), and the optimization means minimizing this (VSWR) which is determined by Z and W as

$$(VSWR)_{in} = \frac{|Z_{in} + W_f| + |Z_{in} - W_f|}{|Z_{in} + W_f| - |Z_{in} - W_f|} \quad . \tag{9}$$

Let the sizes l_s , l_b and parameters W_s , W_b be optimizing variables, then the simplex method is used again.

DESIGN EXAMPLE

There is an example of optimization based on following conditions:

$2\rho = 1.5$ cm , $2\pi a = 50.0$ cm , $L = 83.3$ nH ,

and corresponding to the design frequency of 600 MHz. The optimization results are obtained on computer. The optimal antenna sizes are :

$h = 13.37$ cm , $l = 8.73$ cm , $D = 33.37$ cm

The characteristic impedances are determined by the ratio of distance to diameter for the parallel pair of lines,or the ratio of diameters of outer- to inner-conductor for the coaxial lines. The absolute sizes can be selected in different conbination to suit practical limitations of the connection structure, for instance the distance between each parallel pair of lines should be equal, and the diameters of each outer-conductor should be equal too.

The frequency responses of $(VSWR)_f$ and $(VSWR)_{in}$ computed theoretically are shown in Fig.5 . The bandwidth of $(VSWR)_{in}$ is wider than that of $(VSWR)_f$, and a relative bandwidth of more than 36.4 % for $(VSWR)_{in} \leq 1.1$ is obtained .

REFERENCES

1. K.Endo, Y.Endo, I.Mikkeda, H.Okamura, I.Ito "Stacked-loop antenna" NHK Tech. Jour. (in Japanese) Vol.16 No.4 Oct. 1964 pp.193-206
2. K.Endo "TV.FM Broadcasting Antennas" (in Japanese) Japan Broadcasting Publication Society 1966
3. K.Endo, G.Sato, H.Kawakami, M.Sato, Y.Ishii "Moment method for a twin loop antenna" IEEE 1981 Antennas & Propagation (AP-S Intern. Symp.) pp.675-678
4. G.Sato, H.Kawakami, M.Sato "The analysis and some experiments on 2L-type twin loop antennas by moment method" Jour. of Inst. of TV Engineers of Japan (in Japanese) Vol.36 No.2 Feb. 1982 pp.132-137
5. Qin Ting Kai "Design of twin loop antenna for TV channel 8" Jour. of Broadcast & TV Tech. (in Chinese) Dec. 1979 No.4 pp.36-40
6. Li Ke Qin "Design and adjustment of twin loop antenna for TV channel 11" Jour. of Broadcast & TV Tech. (in Chinese) June 1983 No.3 pp.31-38
7. Zhang Wen Xun "The impedance computation and matching for twin loop antenna" Jour. of Broadcast & TV Tech. (in Chinese) Dec. 1984 No.5/6
8. Zhang Wen Xun, Yuan Jin Yun "On the impedances of twin loop antennas" contributed to ISAP'85 (Kyoto, Japan) Aug. 20-22, 1985
9. D.M.Himelblau "Applied Nonlinear Programming" McGraw Hill 1972
10. P.L.Kalentarov, L.A.Tzatlin "The Computation of Inductive Coefficients" (in Russian) Energy Press (Moscow) 1955

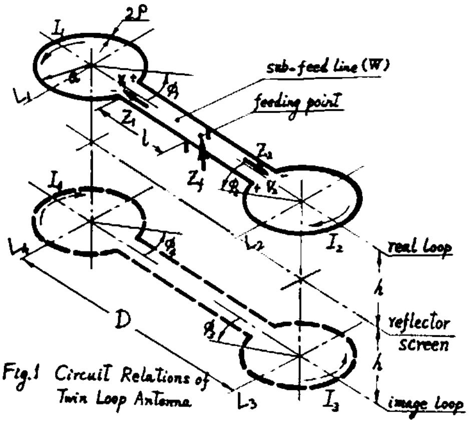

Fig.1 Circuit Relations of Twin Loop Antenna

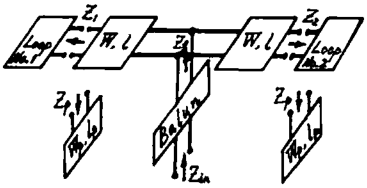

Fig.2 Impedance Relations of TLA

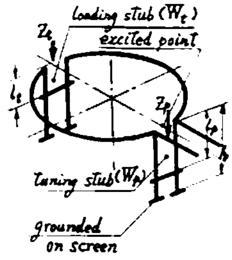

Fig.3 Loading & Tuning Loop

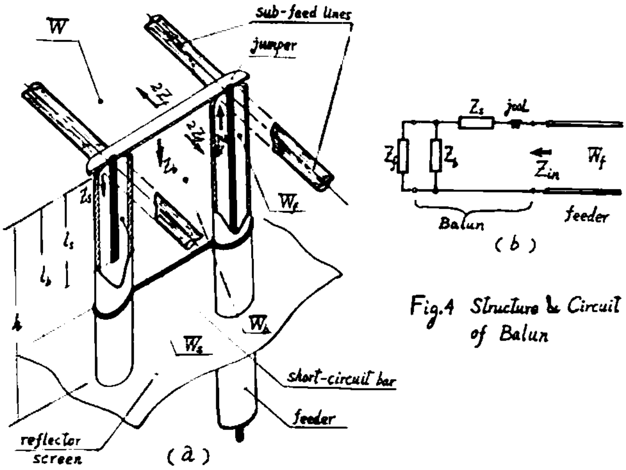

Fig.4 Structure & Circuit of Balun

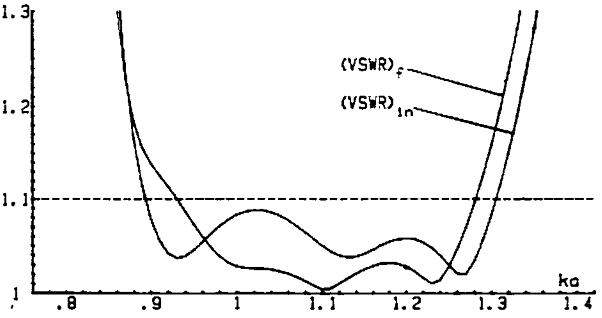

Fig.5 VSWR Response of Optimized TLA