1-II B4

The Circular Loop Antenna loaded with some Non-linear Elements

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1. Introduction

Recently, active elements are loaded in some antennas, but in any case, elements are used in their linear region, so the efficiency is restricted by the linearity.

In this paper, positive use of the harmonic frequency radiation caused by the nonlinearity of the loaded elements is considered.

The analysis of the unloaded linear loop antenna made by Hallen and Storer is refered as the base of this paper.

Under the following assumptions,
(i) The characteristic of the nonlinear element is a single valued function of V or I,
(ii) Current distributions of the fundamental and the desired harmonic frequency are considerably larger than that of the other harmonic frequencies,
the integral equation for the loaded circular loop antenna can be solved on the bases of Storer's Fourier series method. These assumptions can be realized easily in the experiment.

As an example, calculations and experiments are carried out for the nonlinear capacitor used as a nonlinear element.

2. Current distribution

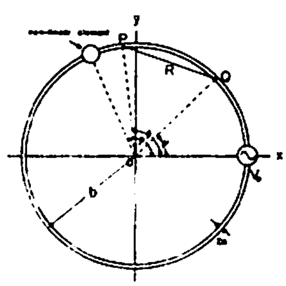

Fig.1 Coordinate system.

With coordinate system and dimensions as shown in Fig. 1, integral equation for the current distribution of thin-wire loop antenna loaded with a nonlinear element is obtained by expressing the electric field as a function of the current and the characteristic of the nonlinear element.

$$\frac{\mu_0 b}{4\pi}\int_{-\pi}^{\pi} K(\phi-\phi')\frac{I(\phi', t-\frac{R}{c})}{R}\,d\phi' = \frac{\partial}{\partial t}\left[V_0\delta(\phi)+f(Q)\delta(\phi-\varphi)\right] \quad (1)$$

where $I(\phi)$ is the total current at ϕ on the loop; V is the voltage of the slice generator exciting the loop at $\phi=0$; f is the characteristic of the nonlinear capacitor. The kernel of the equation (1) is given by

$$K(\phi-\phi') = b\cos(\phi-\phi')\frac{\partial^2}{\partial t^2} - \frac{c^2}{b}\frac{\partial^2}{\partial \phi^2} \quad (2)$$

According to the assumption (i), (ii), and considering the second harmonic frequency as the desired frequency, $I(\phi)$ is written as

$$I(\phi,t) = I_{-1}(\phi)e^{-j\omega t} + I_1(\phi)e^{j\omega t} + I_{-2}(\phi)e^{-2j\omega t} + I_2(\phi)e^{2j\omega t} \quad (3)$$

f is given by specifying the voltage as some arbitrary function of the charge; $v=f(Q)$ where Q is the charge on the nonlinear capacitor and v is the voltage across it.

In particular, for a varactor diode, it becomes

$$v = zQ^{r} \quad (4)$$

where z is the constant coefficient.

Using (4), (5), and rearranging the equation (1) for each frequency, (1) reduces to the simultaneous integral equations.

These equations can be solved by applying Storer's method respectively.

Thus integral equation (1) is translated into the simultaneous quadratic equations of four unknowns. Q_{-1}, Q_1, Q_{-2}, Q_2.

3. Radiation pattern

Primary interest is the positive use of the second harmonic frequency, let us consider the radiation pattern of the second harmonic frequency.

Current distribution on the loop is given by

$$I(2\omega,\phi) = -\frac{1}{j\pi\xi_0} Z\cdot\left[xQ_0^{x-1}Q_1 + \frac{1}{2}x(x-1)Q_0^{x-2}Q_1^{2}\right] \times \sum_{n=-\infty}^{\infty} \frac{1}{\alpha_n(2\omega)} e^{jn(\phi-\varphi)} \qquad (5)$$

From (5), the radiation pattern of E-plane is obtained easily.

$$E_\phi = A(Q)\cdot\sum_{n=-\infty}^{\infty} \frac{e^{jn(\phi-\varphi)}}{\alpha_n(2\omega)}\left(j^{n-1}J_{n-1}(kb) - j^{n+1}J_{n+1}(kb)\right) \qquad (6)$$

Inspection of (6) shows that the d.c. voltage across the diode affect $|E|$ only, but has no influence on the directional property.

In case of multi-loaded loop, a similar analysis is performed, but contrary to the former results, it is apparent that both $|E|$ and the directional property are quite sensitive to a change of the d.c. voltage.

4. Experiment

Experiments are performed on the following cases.

(a) The loop loaded with a varactor diode at $\varphi=\pi$.

For a simple case, results are shown in Fig. 2 under the condition; varactor diode is located at $\varphi=\pi$, characteristic of the diode is $f=Q^2$ total length of the loop is 1.09λ at 800MHz, input voltage V_0 is 1.0V at 400MHz, radius of the wire is 1.0mm.

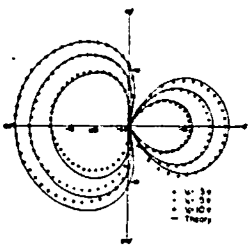

Fig.2
Radiation pattern.
(one element)
$\varphi=\pi$

(b) The loop loaded with two varactor diodes at $\varphi=\frac{\pi}{2}$ and $\varphi=\pi$.

When two varactor diodes are located in arbitrary position, the computation becomes rather tedious, but as expected, the directional properties are quite sensitive to the bias voltages.

Fig. 3 shows the numerical and the experimental results of the radiation pattern under the same condition as (a), except that the varactor diodes are located at $\varphi=\frac{\pi}{2}, \pi$ and the total bias voltage is 12V ($v_1 + v_2 = 12V$).

The radiation pattern of the E-plane is shifted continuously from one direction to another.

Considering this results, if three or more diodes are spaced in a loop at equal intervals, the main lobe can be continuously rotated along the circumference.

This fact means the possibility of the antenna pattern control.

The coincidence between the experimental results and the same of the theory is very good.

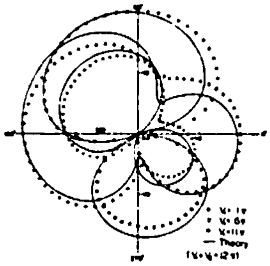

Fig.3
Radiation pattern.(two elements)
$\varphi=\frac{\pi}{2}, \pi$

Reference

(1) J.E. Storer, Impedance of thin-wire loop antennas, Trans. AIEE, vol. 75 (Communication and Electronics), pp. 606-619; November, 1956.