The Second Kind of Mixed System of Electric and Magnetic Currents

——An Electric Current Antenna Fed by a Magnetic Current Transmission Line——

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(Received December, 1, 1969)

Abstract

The second kind of mixed system of electric and magnetic currents is a thin strip dipole antenna fed by a two-slot transmission line. It is similar in appearance to the dual system of the first kind of mixed system of electric and magnetic currents which is a slot antenna fed by a two-strip transmission line.

The authors discovered this second kind of mixed system of electric and magnetic currents and deduced the expression of magnetic admittance. The magnetic admittance was compared with the electric admittance of the first kind of mixed system of electric and magnetic currents and the difference between these two mixed systems was shown in equivalent circuits.

In addition to above discussions, the methods of the same phase excitation were proposed and a discussion for practical uses was made.

1. Introduction

In 1959, G. H. Owyang[1] in an application of Babinet's principle experimentally and theoretically investigated the slot transmission system. The fundamental slot transmission system is a parallel two-slot transmission line cut into a prefectly conducting, infinitely thin and infinite plane (Fig. 1 (a)). This slot transmission system is the dual system of the two-strip transmission system, whereas the two-strip transmission system is ideally a pair of two-dimensional, perfectly conducting metal strip surfaces (Fig. 1 (b)).[2)~4)]

Slot antennas are usually fed by waveguids or parallel transmission lines. As an alternative method of driving, the slot transmission system is useful.

In 1955, Michio Suzuki[5] derived the electric admittance of a slot antenna fed by a

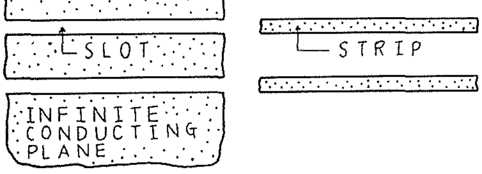

Fig. 1 (a) The two-slot transmission system
Fig. 1 (b) The two-strip transmission system

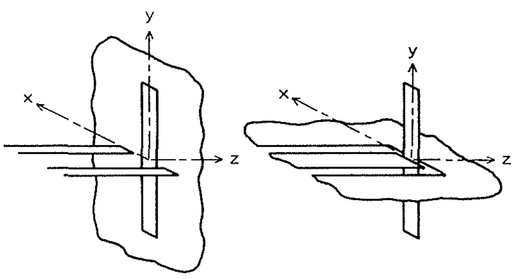

Fig. 2 (a) The first kind of mixed system of electric and magnetic currents
Fig. 2 (b) The second kind of mixed system of electric and magnetic currents

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parallel transmission line refering to the end of the feeder. He named this antenna system the "mixed system of electric and magnetic currents" (Fig. 2 (a)), for it was a magnetic current antenna excited by a electric current on a parallel transmission line.

Suggested by these two investigations the authors discovered the "second kind of mixed system of electric and magnetic currents†".[6] It is a strip antenna fed by a two-slot transmission line as shown in Fig. 2 (b), and it is an electric current antenna excited by a magnetic current on the feeder. This second mixed system closely resembles the dual system of the first mixed system.

In this paper the magnetic admittance of the second mixed system referring to the end of the feeder was derived by the same method of Suzuki's calculation, and it was compared with the electric admittance of the first mixed system. The difference between two mixed systems was shown as a difference in equivalent circuits. Then methods of same phase current excitation were proposed and the discussion for practical uses was made.

2. The magnetic admittance of the second mixed system

The boundary conditions of the first mixed system and the second mixed system are as follows;

the first mixed system (Fig. 2 (a))

(i) on the two-strip line

$$E_z+E^*_{-z}=0$$

(ii) on the $z=0$ plane

$$E_x+E^*_{-x}=\begin{cases} E_{sx} \text{ (on the slot)} \\ 0 \text{ (except on the slot)} \end{cases}$$

(iii) on the slot antenna

$$H_y+H^*_{-y}=H^*_{+y}$$

(iv) at $z=0$ on the two-strip line

$$V=0$$

the second mixed system (Fig. 2 (b))

(i) on the two-slot line

$$H_z+H^*_{+z}=0$$

(ii) on the $z=0$ plane (limited only on the strip antenna)

$$H_x+H^*_{+x}=H_{sx}$$

(iii) on the strip antenna

$$E_y+E^*_{+y}=0$$

(iv) at $z=0$ on the two-slot line

$$V^*=0$$

where E_z is the z-component of the electric field contributed by electric current sources and E^*_{-z} is the z-component of the electric field contributed by magnetic current sources which exist in the $z<0$ space. It is defined likewise for other field components. E_{sx} is the electric field component on the slot antenna and H_{sx} is the magnetic field component on the strip antenna. With the help of these boundary conditions, we calculate the magnetic admittance of the second mixed system.

For the simplicity of calculations, we assume in Fig. 2 (b) that the slot-width w is very small compared with the distance d between centers of two slots, the distance d is very small compared with the wavelength λ so that the directions of magnetic currents are parallel to the z-axis, and the width of the strip antenna is very small compared with its length so that the electric current on the antenna surface flows in the direction of y.

The field components contributed by the strip antenna are

$$\left.\begin{aligned} &E_x=-\frac{\partial\phi}{\partial x}, \quad E_y=-\frac{\partial\phi}{\partial y}-j\omega A, \quad E_z=-\frac{\partial\phi}{\partial z} \\ &H_x=-\frac{1}{\mu_0}\frac{\partial A}{\partial z}, \quad H_z=\frac{1}{\mu_0}\frac{\partial A}{\partial x}, \end{aligned}\right\} \tag{1}$$

† In this paper, the mixed system of electric and magnetic currents which is a slot antenna fed by a parallel line is called the "first kind of mixed system of electric currents" or briefly the "first mixed system", likewise the second kind of mixed system of electric and magnetic currents is called in short the "second mixed system".

where the electric scalar potential ϕ and the electric vector potential A are

$$\left.\begin{aligned} A &= \frac{\mu_0}{4\pi}\int_\tau J\frac{e^{-jkr}}{r}\,d\xi\,d\eta\ , \\ \phi &= \frac{-1}{4\pi j\omega\varepsilon_0}\int_\tau \frac{\partial J}{\partial\eta}\frac{e^{-jkr}}{r}\,d\xi\,d\eta\ , \end{aligned}\right\} \qquad (2)$$

by using the electric current $J(x, y)$ which is the sum of the antenna current $J_1(x, y)$ and its image current $J_2(x, y)$, that is,

$$\left.\begin{aligned} J(x, y) &= J_1(x, y) + J_2(x, y)\ , \\ J_1(x, y) &= J_2(x, -y)\ . \end{aligned}\right\} \qquad (3)$$

In eq. (2) $r=[(x-\xi)^2+(y-\eta)^2+z^2]^{\frac{1}{2}}$, and τ indicates the integration all over the antenna surface and its image surface.

The field components contributed by the magnetic current on the two-slot transmission line are

$$\left.\begin{aligned} &H^*_{\pm x} = -\frac{\partial\phi^*_\pm}{\partial x}\ ,\quad H^*_{\pm y} = -\frac{\partial\phi^*_\pm}{\partial y}\ ,\quad H^*_{\pm z} = -\frac{\partial\phi^*_\pm}{\partial_z} - j\omega A^*_\pm \\ &E^*_{\pm y} = \frac{1}{\varepsilon_0}\frac{\partial A^*_\pm}{\partial x}\ ,\quad E^*_{\pm x} = -\frac{1}{\varepsilon_0}\frac{\partial A^*_\pm}{\partial y}\ , \end{aligned}\right\} \qquad (4)$$

where $A^*_\pm$ is the magnetic vector potential, $\phi^*_\pm$ is the magnetic scalar potential. By using the surface magnetic current distribution $K^*_\pm$,

$$\left.\begin{aligned} &A^*_\pm(x, y, z) = \frac{\varepsilon_0}{2\pi}\int_{-\infty}^{0} d\zeta\left[\Psi(x, y, z, \zeta)\int_{-\frac{w}{2}+\frac{d}{2}}^{\frac{w}{2}+\frac{d}{2}} K^*_\pm(\zeta)\,dx\right]\ , \\ &\phi^*_\pm(x, y, z) = -\frac{1}{2\pi j\omega\mu_0}\int_{-\infty}^{0} d\zeta\left[\Psi(x, y, z, \zeta)\cdot\int_{-\frac{w}{2}+\frac{d}{2}}^{\frac{w}{2}+\frac{d}{2}} dx\,\frac{\partial K^*_\pm(\zeta)}{\partial\zeta}\right]\ , \\ &\text{where} \\ &\Psi(x, y, z, \zeta) = \frac{e^{-jkr_1}}{r_1} + \frac{e^{-jkr_2}}{r_2}\ , \\ &r_1 = [R_1{}^2+(z-\zeta)^2]^{\frac{1}{2}}\ ,\quad r_2 = [R_2{}^2+(z-\zeta)^2]^{\frac{1}{2}} \\ &R_1{}^2 = \left(x-\frac{d}{2}\right)^2 + y^2\ ,\quad R_2{}^2 = \left(x+\frac{d}{2}\right)^2 + y^2\ . \end{aligned}\right\} \qquad (5)$$

When we consider the potential difference between two slots, with the help of the boundary condition (i) and of eq. (4) we obtain

$$\frac{\partial}{\partial z}\left\{(\phi^*)_{\frac{d}{2}} - (\phi^*)_{-\frac{d}{2}}\right\} + j\omega\left\{(A^*)_{\frac{d}{2}} - (A^*)_{-\frac{d}{2}}\right\} = (H_z)_{\frac{d}{2}} - (H_z)_{-\frac{d}{2}} \qquad (6)$$

In eq. (6), since we consider the phenomena in the $y>0$ space the suffix $\pm$ is omitted. An alternative formula of (6) is

$$\frac{\partial V^*}{\partial z} + j\omega W^* = -j\omega\varepsilon_0\mu_0 H_e(z)\ , \qquad (7)$$

where V^* is the magnetic scalar potential difference $(\phi^*)_{\frac{d}{2}} - (\phi^*)_{-\frac{d}{2}}$, W^* is the magnetic vector potential difference $(A^*)_{\frac{d}{2}} - (A^*)_{-\frac{d}{2}}$, and $H_e(z) = (H_z)_{\frac{d}{2}} - (H_z)_{-\frac{d}{2}}$.

By the Lorentz's condition of magnetic potentials, that is,

$$\phi^* = \frac{-1}{j\omega\varepsilon_0\mu_0}\frac{\partial A^*}{\partial z}\ , \qquad (8)$$

we obtain from (7)

$$\frac{\partial^2 W^*}{\partial z^2}+k^2W^*=-j\omega\mu_0\varepsilon_0 H_e \tag{9}$$

In eq. (5), $\Psi\ (x=d/2)=\Psi\ (x=-d/2)$, it follows that

$$W^*\ (z)=\left[\frac{\varepsilon_0}{\pi}\int_{-\infty}^{0} d\zeta\left\{\Psi\ (x,y,z,\zeta)\int_{-\frac{w}{2}+\frac{d}{2}}^{\frac{w}{2}+\frac{d}{2}} K^*\ (\zeta)\ dx\right\}\right]_{y=0} \tag{10}$$

and then, with the help of $w\ll d\ll\lambda$, we can approximate that

$$W^*\ (z)=\frac{\varepsilon_0}{\pi}\int_{-\infty}^{0} I^*\ (\zeta)\Psi\ (z,\zeta)\ d\zeta\ ,$$

where

$$\left.\begin{aligned}\Psi\ (z,\zeta)&=\frac{e^{-jk\sqrt{\left(\frac{w}{4}\right)^2+(z-\zeta)^2}}}{\sqrt{\left(\frac{w}{4}\right)^2+(z-\zeta)^2}}-\frac{e^{-jk\sqrt{d^2+(z-\zeta)^2}}}{\sqrt{d^2+(z-\zeta)^2}}\ ,\\ I^*\ (\zeta)&=\int_{-\frac{w}{2}+\frac{d}{2}}^{\frac{w}{2}+\frac{d}{2}} E_{sx}\ d_x=wE_{sx}\ .\end{aligned}\right\} \tag{11}$$

In eq. (11) E_{sx} is the electric field component on the slot.

The general solution of (9) is given as

$$W^*\ (z)=P'e^{-jkz}+Q'e^{jkz}-\frac{j\omega\varepsilon_0\mu_0}{k}\int_0^z H_e\ (\zeta)\sin\ (z-\zeta)\ d\zeta\ , \tag{12}$$

and by using the boundary condition (iv) and the Lorentz's condition (8), $V^*=(\partial W^*/\partial z)=0$ when $z=0$, and therefore we find $P'=Q'$.

Likewise under Suzuki's calculation[5], (12) reduces to

$$W^*\ (z)=P\cos kz-\frac{\omega\varepsilon_0\mu_0}{4\pi k}\int_\tau J\ (\xi,\eta.\ z)\ \Phi\ (\xi,\eta,z)\ d\xi\ d\eta\ , \tag{13}$$

by using a new undetermined coefficient P, where

$$\begin{aligned}\Phi\ (\xi,\eta,z)=&\frac{d/2-\xi}{(d/2-\xi)^2+\eta^2}\ e^{-jk\{z+\sqrt{(d/2-\xi)^2+\eta^2+z^2}\}}\\ &+\frac{d/2+\xi}{(d/2+\xi)^2+\eta^2}\ e^{-jk\{z+\sqrt{(d/2+\xi)^2+\eta^2+z^2}\}}\end{aligned}$$

On the other hand, since $kd\ll1$, (12) is given approximately by

$$W^*\ (z)\doteqdot\frac{\varepsilon_0}{\pi}\,\Omega I^*\ (z)\ ,\quad \Omega=\ln\frac{4d}{w} \tag{14}$$

Then it is apparent with reference to (13), we obtain

$$\left.\begin{aligned}I^*\ (z)&=\frac{\pi}{\varepsilon_0\Omega}P\cos kz+I_e^*(z)\ e^{jkz}\ ,\\ I_e^*\ (z)&=\frac{V_e^*(z)}{z_0^*}\ ,\quad z_0^*=\frac{1}{y_0^*}=\sqrt{\frac{\varepsilon_0}{\mu_0}}\frac{\Omega}{\pi}\\ V_e^*(z)&=-\frac{1}{4\pi}\int_\tau J\ (\xi,\eta)\ \Phi\ (\xi,\eta,z)\ d\xi\ d\eta\ ,\end{aligned}\right\} \tag{15}$$

where z_0^* is the magnetic characteristic impedance of the two-slot transmission line which is defined by using the magnetic voltage V^* and the magnetic current I^* on the infinite long two-slot transmission line, as $z_0^*=1/y_0{}^*=V^*/I^*$, and z_0^* has a dimension equal to the electric admittance and $y_0{}^*$ (the magnetic characteristic admittance) has a dimension equal to the electric impedance. When the characteristic impedance and the characteristic admittance of the two-strip transmission line which is the dual system of the two-slot transmission line are z_0 and y_0, $z_0/z_0^*=\mu_0/\varepsilon_0$ and $y_0/y_0^*=\varepsilon_0/\mu_0$. And when the (electric) characteristic impedance and the (electric) characteristic admittance of the two-slot transmission line referring to the line voltage and the line current are z'_0 and y'_0,

$$z'_0=\frac{1}{4\,z_0^*}\ ,\quad y'_0=\frac{4}{y_0^*}\ . \tag{16}$$

Next we return to (12), and separate it into two parts, that is;

$$I^*(z)=I_0^*\ [e^{-jkz}-R^*(z)\,e^{jkz}]\ , \tag{17}$$

where

$$R^*(z)=-1-\frac{I_e^*\ (z)}{I_0^*}\ .$$

The primary part of (17) means the traveling wave toward the antenna and the secondary part of (17) means the traveling wave toward the end of the transmission line. If $z\rightarrow -\infty$, $R^*(z)=R^*(-\infty)=$constant, therefore we find that the equivalent circuit of the second mixed system may be shown as Fig. 3.

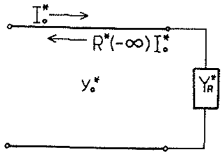

Fig. 3 An equivalent circuit of the second mixed system

In Fig. 3, the magnetic admittance Y_R^* is

$$\frac{y_0^*}{Y_R^*}=\frac{1+R^*\ (-\infty)}{1-R^*\ (-\infty)}=\frac{-I_e^*\ (-\infty)/I_0^*}{1-R^*\ (-\infty)}\ . \tag{18}$$

On the other hand, the electric field components on the strip antenna contributed by the magnetic current $I^*\ (z)$ are

$$\left.\begin{aligned} &E_y^*=E_y^{*\prime}+E_y^{*\prime\prime}\\ &E_y^{*\prime}=\frac{I_0^*}{2\pi}\{1-R^*\ (-\infty)\}\ \Phi'\ (x,y)\\ &E_y^{*\prime\prime}\doteqdot\frac{I_e^*\ (0)-I_e^*\ (-\infty)}{2\pi}\ \Phi'\ (x,y)\end{aligned}\right\} \tag{19}$$

where

$$\Phi'\ (x,y)=\frac{d/2-x}{(d/2-x)^2+y^2}+\frac{d/2+x}{(d/2+x)^2+y^2}\ .$$

With the help of the boundary condition (iii) and eq. (19), we obtain

$$E_y+E_y^{*\prime\prime}=\frac{I_0^*}{2\pi}\{1-R^*\ (-\infty)\}\ \Phi'\ (x,y)\ , \tag{20}$$

and substituting this equation into (19) gives

$$\frac{Y_R^*}{y_0^*}\ E_{ey}^*=E_y+E_y^{*\prime\prime}\ ,\quad E_{ey}^*=\frac{I_e^*\ (-\infty)}{2\pi}\ \Phi'\ (x,y)\ . \tag{21}$$

Eq. (21) is the integral equation to obtain Y_R^*. Multiplying both sides of (21) by $\tilde{J}$ ($\tilde{J}$ is the complex conjugate of J) and integrating all over the antenna surface lead to

$$\left.\begin{aligned} &Y_R^*=Y_R^{*\prime}+Y_R^{*\prime\prime}\ ,\quad Y_R^{*\prime}=\frac{W_h'}{W_r}\ y_0^*\ ,\quad Y_R^{*\prime\prime}=\frac{W_h''}{W_r}\ y_0^*\ ,\\ &W_h'=\frac{1}{2}\int_\tau E_y\,\tilde{J}\,dx\,dy\ ,\quad W_h''=\frac{1}{2}\int_\tau E_y^{*\prime\prime}\,\tilde{J}\,dx\,dy\ ,\\ &W_r=\frac{1}{2}\int_\tau E_{ey}^*\,\tilde{J}\,dx\,dy\ ,\end{aligned}\right\} \tag{22}$$

where W_h' is the complex power radiated from the strip antenna, W_h'' is the complex power of the higher modes on the two-slot transmission line which is generated by the radiation of the strip antenna, W_r is the complex power of the incident wave, and therefore $W_h'+W_h''$ is the total complex power radiated from the current on the strip antenna and the ratio of it to W_r is the magnetic admittance of the second mixed system.

With reference to (1), (15) and (19), we have

$$\left.\begin{aligned} E_y &= \frac{1}{4\pi j\omega\varepsilon_0}\int_\tau J\left(\frac{\partial^2}{\partial y^2}+k^2\right)\frac{e^{-jkr}}{r}\,d\xi\,d\eta \\ E_{ey} &= \frac{V_e^*(-\infty)}{2\pi z_0^*}\,\Phi'(x,y) = -\frac{\Phi'(x,y)}{8\pi\sqrt{\dfrac{\mu_0}{\varepsilon_0}}}\int_\tau J\,\Phi'\,d\xi\,d\eta \end{aligned}\right\} \tag{23}$$

and

$$\left.\begin{aligned} Y_R^* &= Y_R^{*\prime}+Y_R^{*\prime\prime} \\ Y_R^{*\prime} &= y_0^*\frac{\displaystyle\iint_\tau J(x,y)\tilde{J}(\xi,\eta)\left(\frac{\partial^2}{\partial y^2}+k^2\right)\frac{e^{-jkr}}{r}\,dx\,dy\,d\xi\,d\eta}{\displaystyle -j\frac{k}{2\Omega}\iint_\tau J(x,y)\tilde{J}(\xi,\eta)\,\Phi'(x,y)\,\Phi'(\xi,\eta)\,dx\,dy\,d\xi\,d\eta} \\ Y_R^{*\prime\prime} &\fallingdotseq y_0^*\frac{\displaystyle\int_\tau \tilde{J}(\xi,\eta)\,\Phi'(\xi,\eta)\left[e^{-jk\sqrt{(a/2)^2+\eta^2}}-1\right]d\xi\,d\eta}{\displaystyle\int_\tau \tilde{J}(\xi,\eta)\,\Phi'(\xi,\eta)\,d\xi\,d\eta} \end{aligned}\right\} \tag{24}$$

This is the magnetic admittance of the second mixed system in the $y>0$ space and likewise we can calculate. for the $y<0$ space

Finaly, we have the expression of the total magnetic admittance of the second mixed system, that is;

$$\left.\begin{aligned} Y_R^* &= Y_R^{*\prime}+Y_R^{*\prime\prime} \\ Y_R^{*\prime} &= 2y_0^*\frac{\displaystyle\iint_\tau J(x,y)\tilde{J}(\xi,\eta)\left(\frac{\partial^2}{\partial y^2}+k^2\right)\frac{e^{-jkr}}{r}\,dx\,dy\,d\xi\,d\eta}{\displaystyle -j\frac{k}{2\Omega}\int_\tau J(x,y)\tilde{J}(\xi,\eta)\,\Phi'(x,y)\,\Phi'(\xi,\eta)\,dx\,dy\,d\xi\,d\eta} \\ Y_R^{*\prime\prime} &\fallingdotseq 2y_0^*\frac{\displaystyle\int_\tau J(\xi,\eta)\,\Phi'(\xi,\eta)\left[e^{-jk\sqrt{\left(\frac{a}{2}\right)^2+\eta^2}}-1\right]d\xi\,d\eta}{\displaystyle\int_\tau \tilde{J}(\xi,\eta)\,\Phi'(\xi,\eta)\,d\xi\,d\eta} \end{aligned}\right\} \tag{25}$$

$Y_R^{*\prime}$, upon introducing the expression for the magnetic admittance, corresponds to the radiated power and $Y_R^{*\prime\prime}$ corresponds to the higher modes on the two-slot transmission line.

3. The equivalent circuits of the second mixed system

Comparison of the magnetic admittance of the second mixed system introduced previously with the (electric) admittance of the first mixed system which is introduced by Michio Suzuki shows that if J and y_0^* in (25) are replaced with J^* and y_0, $Y_R^{*\prime}$ coincides with Y_R' which corresponds to the radiated power in the first mixed system and $Y_R^{*\prime\prime}$ equals one half of Y_R'' which corresponds to the higher modes on the two-strip transmission line. The function J^* and the function J may be the same, if $y_0=y_0^*=1$ we have the equivalent circuits as shown in Fig. 4 (a) and (b). The difference between the coefficients of Y_R'' and Y_R'' shows the non-duality between two mixed systems, and it is caused by the difference of boundary conditions (iii). It is remarkable that the non-duality between two complex systems is not shown in the difference between $Y_R^{*\prime}$ and Y_R'' which correspond to the radiated power, but is shown in a difference between $Y_R^{*\prime\prime}$ and Y_R'' which correspond to the

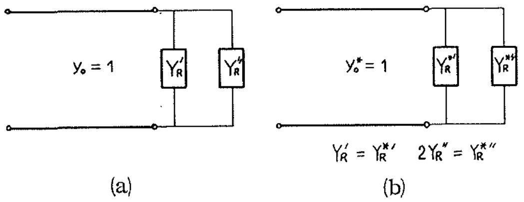

Fig. 4 (a) An equivalent circuit of the first mixed system
Fig. 4 (b) An equivalent circuit of the second mixed system

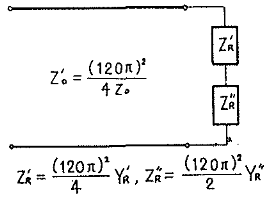

Fig. 5 An equivalent circuit of the second mixed system shown as a series electric impedance

effects of disturbances on the feeder. Generally, $Y_R^{*\prime\prime}$ or Y_R'' is very small compared with $Y_R^{*\prime}$ or Y_R'' in all practical cases, it can be assumed, therefore, that the second mixed system is a quasi-dual system of the first mixed system.

Now it is possible to obtain the electric impedance of the second mixed system with reference to (16). The electric impedance referring to the voltage and the current of the two-slot transmission line is

$$Z_R = \frac{1}{4\,Z_R^*} = \frac{Y_R^{*\prime} + Y_R^{*\prime\prime}}{4} = \frac{(120\,\pi)^2}{4}\,(Y_R' + 2\,Y_R'')\ , \qquad (26)$$

then this expression can be shown in a equivalent circuit. Fig. 5 is the electric impedance equivalent circuit, and comparing with Fig. 4 (a), we find that $\{(120\,\pi)^2\,(Y' + Y'')\}/4$ is the quantity of the duality and $(120\,\pi)^2\ Y''/4$ is the quantity of the non-duality.

4. Methods of same phase excitation

In Fig. 2 (b), the magnetic currents on a slot and on its reverse side flow in the opposite direction from each other. Therefore, in the $y>0$ space and $y<0$ space each direction of antenna currents is likewise opposite. In all practical cases, it is desirable that the conducting plane of the two-slot transmission line has finit dimensions. When the conducting plane is finit in extent, the total field radiated from unipoles in the $y>0$ space and in the $y<0$ space cancels out on the $y=0$ plane. To avoid this ploblem at the $y=0$ plane, we use the method shown in Fig. 6 of the same phase excitation, and it is necessary in order to prevent the unbalanced current of the antenna to make the width of the slot narrow and bring the two unipoles towards each other.

An alternative method is to use only one unipole. Then the boundary condition (i)

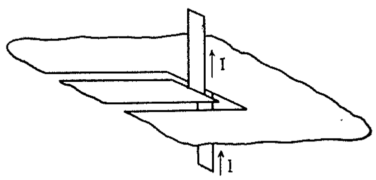

Fig. 6 A method of the same phase excitation

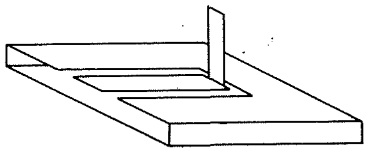

Fig. 7 A thin metal strip unipole antenna fed by a half shielded slot transmission line

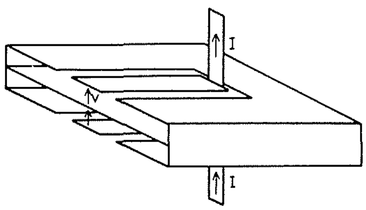

Fig. 8 A thin metal strip dipole antenna fed by a shielded symmetrical double slot transmission line changes into $H_z^* + H_{+z}^* = H_{-z}^*$, consequently, the magnetic admittance is given as one half of Y_R^* in Eq. (25). In this case, it is desirable to shield one side of the two-slot transmission line where the unipole does not exist as shown in Fig. 7, and by using this half shielded two-slot transmission lines, we can feed a dipole in the same phase as shown in Fig. 8.

5. Conclusion

The second kind of mixed system of electric and magnetic current is a quasi-dual system of the first kind of mixed system of electric and magnetic currents namely a slot antenna fed by a two-strip transmission line. The non-duality between two mixed systems was found not to be the difference of admittances which correspond to the radiated power but rather the difference of admittances which correspond to the disturbed power on the feeder.

In the fundamental second kind of mixed system of electric and magnetic currents, the directions of currents on two unipole antennas oppose each other, and this results in a difficulty for practical uses. In this paper, the authors have tried to provide solutions for avoiding this problem.

6. Acknowledgment

The writers are greatly indebted to professor Michio Suzuki for his guidance and encouragement in working on this theory.

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