Leaky Coaxial Cable with Adjustable Coupling Loss for Mobile Communications in Complex Environments

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***Abstract*—A new kind of leaky coaxial cable composed of an axially-slotted line covered with periodic metallic patches is proposed. The basic cable sets up a surface wave and does not radiate itself, but excites the patch apertures into radiation. The direction of the radiation field can be changed by adjusting the size and period of the patches according to the environmental application. A combined method that involves FDTD iteration and integration of the equivalent surface magnetic current is introduced in order to determine the radiation field accurately.**

***Index Terms*—Dyadic Green's function, FDTD method, leaky coaxial cable.**

I. Introduction

In conventional leaky coaxial cables (LCX), RF energy is coupled or radiated into the environment through the braided shield [1], periodic slots [2], or continuous slots [3]. The coupling losses of these kinds of leaky cables are fixed and cannot be changed after fabrication. These cables are useful in areas such as a mine tunnel, subway, railway, and automatic highway. However, for mobile communications in complex environments, such as a larger building [4], these designs are too inflexible. In this paper, we propose a new kind of leaky cable that can overcome the disadvantages of the conventional LCX. Our design includes an axially-slotted leaky cable covered with periodic metallic patches attached to the cable jacket by clips. These patches disturb the field leaky from the cable and cause radiation. By adjusting the size, shape, and axial periodicity of the patches, different coupling loss, polarization, radiation directionality, and even the operating frequency band can be obtained.

II. Theory

The configuration and coordinates of the patched leaky coaxial cable (PLCX) are shown in Fig. 1. The basic cable used in this letter is an axially-slotted cable with slot angle of $2\phi_0$ (other leaky cables that support a surface wave can also be selected instead). The slot angle of the axially-slotted cable used in practice independently is about 110°. The basic cable we used here has a smaller slot angle, and the energy coupled outside is concentrated near the slot aperture.

In order to determine the radiation field theoretically, we surrounded the PLCX with a closed mathematic cylindrical surface coincident with the outer surface of the arc-patches as shown by the dotted circle line in Fig. 1. We used FDTD method to find the electrical field on this surface. The problem becomes one of finding the radiation field from the magnetic current density $\boldsymbol{M}(\boldsymbol{R}')$ on this surface, which can be solved by means of the dyadic Green's function [5]

$$\boldsymbol{E} = \iint \nabla \times \overline{\overline{G}}_{e2}(r,\, \phi,\, z;\, r_s,\, \phi',\, z') \cdot \boldsymbol{M}(r_s,\, \phi',\, z')\, ds', \tag{1}$$

where

$$\boldsymbol{M}(r_s,\, \phi',\, z') = -\hat{n}' \times \boldsymbol{E}(r_s,\, \phi',\, z') \quad \text{and} \tag{2}$$

$\boldsymbol{E}(r_s,\, \phi',\, z')$ is the electric field on the mathematic surface, $\hat{n}'$ is the normal direction of the surface pointing outward.

The computational region in our FDTD iteration involves only a few periods of the line structure due to the limited capacity of our computer. We selected the period in the middle of the computational region as a standard period. The magnetic current density within this period is denoted by $\boldsymbol{M}_p(r_s,\, \phi',\, z')$. The effect of the patches outside the computational region on $\boldsymbol{M}_p(r_s,\, \phi',\, z')$ can be neglected if the computational region is large enough. Hence, $\boldsymbol{M}_p(r_s,\, \phi',\, z')$ can be considered to be the magnetic current density within one period of an infinite long patch array.

Because the structure is periodic, so $\boldsymbol{M}(r_s,\, \phi',\, z')$ should also be periodic. Therefore

$$\boldsymbol{M}(r_s,\, \phi',\, z' + mP) = e^{-jkmP}\boldsymbol{M}_p(r_s,\, \phi',\, z') \tag{3}$$

where P is the period of the patches, and k is the wavenumber in the z-direction. From this relationship, (1) can be rewritten as

$$\boldsymbol{E} = r_s \sum_{m=-M}^{M} \int_{-\pi}^{\pi} \int_{-P/2}^{P/2} \nabla \times \overline{\overline{G}}_{e2}(r,\, \phi,\, z;\, r_s,\, \phi',\, z' + mP) \cdot e^{-jkmP}\boldsymbol{M}_p(r_s,\, \phi',\, z')\, d\phi'\, dz'. \tag{4}$$

(4) represents the field of the array. The field for a single array element (one period) is

$$\boldsymbol{E}_0 = r_s \int_{-\pi}^{\pi} \int_{-P/2}^{P/2} \nabla \times \overline{\overline{G}}_{e2}(r,\, \phi,\, z;\, r_s,\, \phi',\, z') \cdot \boldsymbol{M}_p(r_s,\, \phi',\, z')\, d\phi'\, dz'. \tag{5}$$

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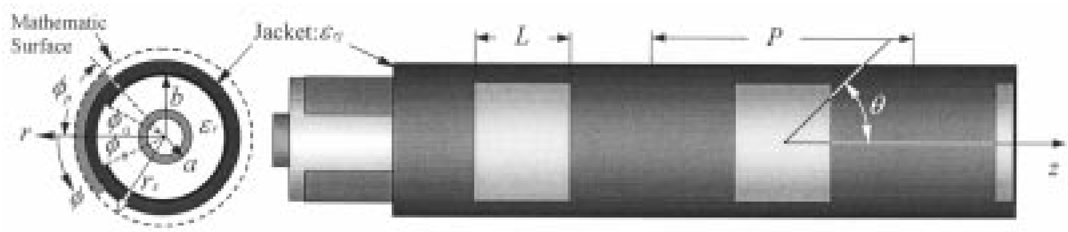

Fig. 1. Configuration and coordinates of the patched leaky coaxial cable.

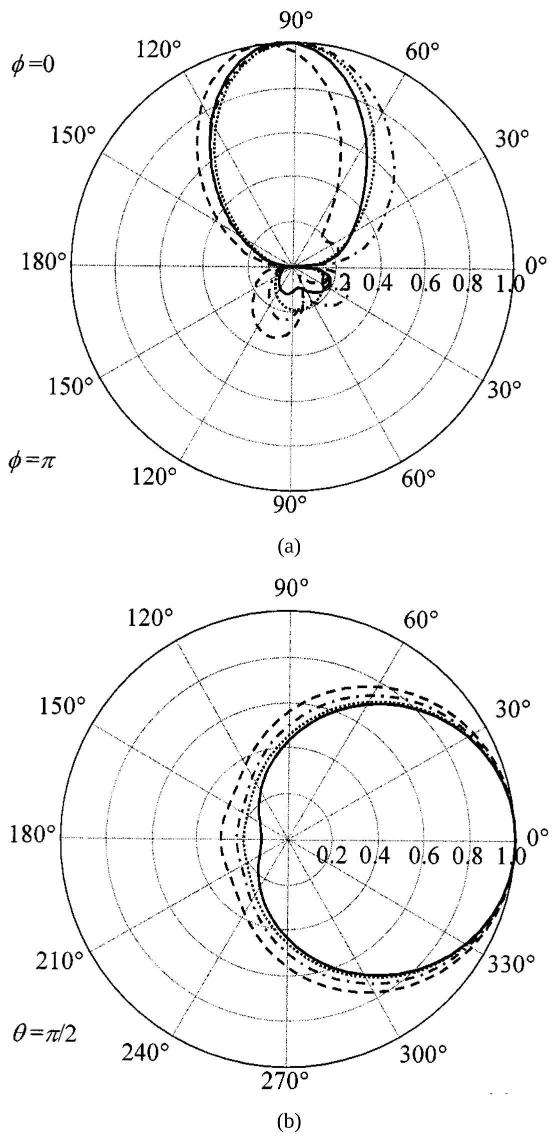

Fig. 2. Radiation patterns of the single array elements. (a) E-plane. (b) H-plane. — $r_s = 25.7$ mm, $\phi_0 = \pi/8$, $\phi_p = 3\pi/8$; – – $r_s = 23.2$ mm, $\phi_0 = \pi/8$, $\phi_p = 3\pi/8$; -·- $r_s = 25.7$ mm, $\phi_0 = \pi/8$, $\phi_p = 3\pi/16$; $* * *$ $r_s = 25.7$ mm, $\phi_0 = \pi/16$, $\phi_p = 3\pi/8$.

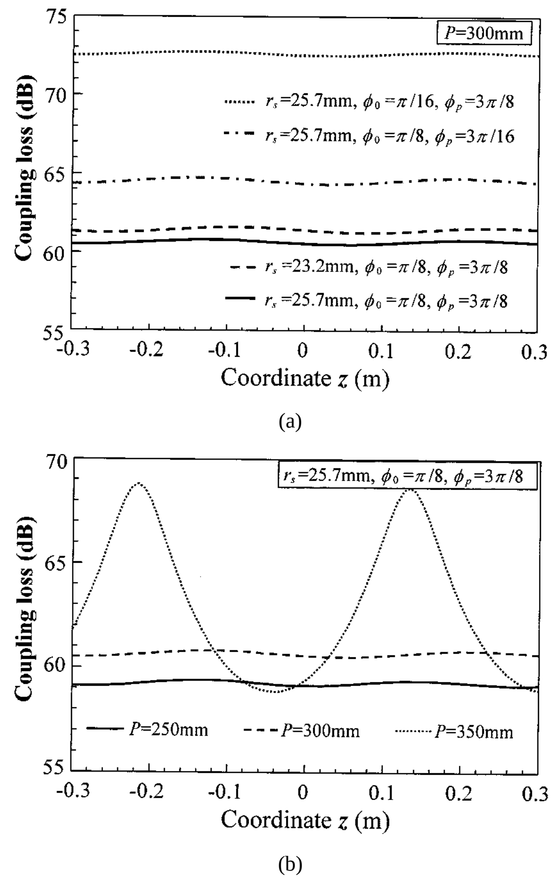

Fig. 3. Coupling losses of the PLCX as functions of structural parameters: (a) as functions of patch size and slot angle and (b) as function of period.

$\boldsymbol{E}_0$ is important when judging the performance of the PLCX. $\boldsymbol{E}_0$ will reduce to the field of a single patch if the coupling with the adjacent elements becomes insignificent.

III. Results and Discussion

The expansion of (4) is given in [6]. With the method described above, we are able to analyze complicated patch structures. Here, we only give some examples. The cable's structural parameters used in this paper are $a = 4$ mm, $b = 20.65$ mm; dielectric permittivities are $\varepsilon_r = 1.26$ (inner dielectric) and $\varepsilon_{rj} = 2.3$ (jacket). The operating frequency is 900 MHz. The patch length L was fixed at 132 mm (about $0.45\lambda_g$). Only the dominant axial component E_z of the field was considered. The coupling loss is given by $A_c = 10\log(P_t/P_r)$, where P_r is the received power of a standard half-wavelength dipole antenna placed two meters from the axis of cable in the front of the patches at $\phi = 0$. P_r was evaluated by multiplying the Poynting vector with the effective area of the half-wavelength dipole. P_t is the power transmitted in the cable. In our computation, the cable length was fixed at 50 m. The number M in (4) was obtained from $M = 25/P$.

Fig. 2 illustrates the normalized radiation patterns for the single array element defined by (5) for different structural parameters r_s, ϕ_0, and ϕ_p (see Fig. 1). The field was calculated at points located 6 m from the centers of the elements. From this figure, we see that the single patch with length slightly smaller than $\lambda_g/2$ will radiate broadside. Actually, the field generated by the patch is identical to that generated by two vertical slots separated by a distance slightly greater than the patch length.

Fig. 3 gives the coupling losses of the cable for the corresponding structural parameters given in Fig. 2. This figure clearly shows that different coupling losses are readily obtained by adjusting the size and period of the patches. The curve with large fluctuations in Fig. 3(b) corresponds to the case of multi-harmonic radiation. At 900 MHz, the condition for mono-radiation of the 1st spatial harmonic is $P < 314$ mm [7] (P should be not less than the patch length). Beyond this limit, the second spatial harmonic begins to radiate, and interferes with the desired radiation field from the first harmonic. Therefore, larger fluctuations result.

IV. Conclusion

In summary, the coupling loss of the patched leaky coaxial cable can be altered by adjusting the size and period of the patches. Therefore, for applications where different coupling losses are needed, the PLCX design is preferable.

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