2D4-3

Target Detection with Surface and Radiation Mode of Leaky Coaxial Cable

#Kenji Inomata[1], Takashi Hirai[1], Yoshio Yamaguchi[2], and Hiroyoshi Yamada[2]
[1] Adv. Tech. R&D center, Mitsubishi Electric Corp.
8-1-1 Tsukaguchi-honmatch, Amagasaki, Hyogo, 661-8661, Japan,
Inomata.Kenji@dy.MitsubishiElectric.co.jp
[2] Department of Information Engineering, Niigata University
8050 Igarashi-ninomachi, Niigata, 950-2181 Japan

1. Introduction

We propose a target detection technique with both surface and radiation modes of leaky coaxial cables in a surveillance application. The characteristics of the target response in surface and radiation modes are different. Using these two modes, the proposing technique provides the ability for detecting target size without relation to the location. Leaky coaxial cables are used in train communication, wireless communication in tunnels, and target detection sensors. In a surveillance application, the leaky cables are laid on the surface or underground along the perimeter of the surveillance area. The sensor transmits microwaves through the transmitting leaky cable and receives the target scattering wave through the receiving leaky cable and then analyzes the response power for judgment.

In this paper, we describe the propagation mode related to both the signal frequency and the slot pitch of a leaky cable, the formulation of target response with leaky cables, and demonstrate the target detection properties with two modes of the leaky cable before concluding.

2. Radiation Harmonics and Propagation Mode of the Leaky Coaxial Cables

The previous excellent studies according to the propagation of leaky cable are based on the infinite straight structure as shown in Fig. 1(a) [1], [2]. For a periodic structure, the field around the cable can be written as

$$E(r,\phi,z) = E_p(r,\phi,z)\exp(-jk'z) \tag{1}$$

where $k' = k_0\sqrt{\varepsilon_r}$ is the wave number in the leaky cable. ε_r is the relative permittivity of the dielectric material in the leaky cable. $E_p(r,\phi,z)$ is the periodic function of z and can be expanded into the Fourier series $E_p(r,\phi,z) = \sum_{m=-\infty}^{\infty} E_{p,m}(r,\phi)\exp(-j2m\pi z/P)$, where P is the period of slots. Therefore,

$$E(r,\phi,z) = \sum_{m=-\infty}^{\infty} E_{p,m}(r,\phi)\exp(-jk'_m z)\,, \tag{2}$$

where $k'_m = k' + 2m\pi/P$ is the wave number of the mth spatial harmonic in the z direction. The wave number of the mth harmonic in the radial direction is

$$k_r^2 = k_0^2 - (k' + 2m\pi/P)^2\,, \tag{3}$$

where k_0 is the wave number of free space. If $k_r^2 < 0$, then no radiation in the mth harmonic occurs in the radial direction. The leaky cable works in a surface mode in the mth harmonic.

ISBN: 978-4-88552-223-9 C3055©IEICE

The condition for radiation in the m th harmonic can be written from (3) as

$$-mc/P(\sqrt{\varepsilon_r}+1) < f < -mc/P(\sqrt{\varepsilon_r}-1) \quad (4)$$

where $m < 0,$ and c is the wave velocity of free space. In the region defined by (4), the leaky cables work in a radiation mode in the m th harmonic. In the region of $-c/P(\sqrt{\varepsilon_r}+1) < f < -2c/P(\sqrt{\varepsilon_r}+1)$, the leaky cables work in a single radiation mode. In the region of $2c/P(\sqrt{\varepsilon_r}+1) < f$, these work in a high order radiation mode radiating the beams to multiple directions. In general usage, however high order mode can be eliminated by adding subslots as shown in Fig. 1(b). In the region of $0 < f < c/P(\sqrt{\varepsilon_r}+1)$, no radiation occurs in all of the m th harmonic. In this region, the leaky cables work in a surface mode. Thus we can change the propagation mode of the leaky cables by changing the frequency band adequately.

3. Target Response with Leaky Coaxial Cables

We consider the layout model of two leaky cables as shown in Fig. 2. We treat the slots as antenna arrays of magnetic current and determine the slot array vector, the curve length from the reference point, and the propagation matrix. The slot array vector is determined by

$$\boldsymbol{v} = [hT_1 \quad -hT_2 \quad hT_3 \quad -hT_4 \quad \cdots \quad hT_N]^T , \quad (5)$$

where h is the effective length of a slot, $T_n = \exp(-jk' d_n)$ is the n th transmission coefficient, $k' = \sqrt{\varepsilon_r}\, k$ is the wave length in the leaky cable, d_n is the curved length of the n th slot from the reference point, and the sign of h is positive when the slot angle $\phi \geq 0$, and negative when the slot angle $\phi < 0$. Considering the positional relation of the leaky cable and the target, the propagation matrix is determined by

$$\boldsymbol{X} = \begin{bmatrix} S\exp[-jk(R_1^t + R_1^r)]/(R_1^t R_1^r) & \cdots & S\exp[-jk(R_N^t + R_1^r)]/(R_N^t R_1^r) \\ \vdots & \ddots & \vdots \\ S\exp[-jk(R_1^t + R_M^r)]/(R_1^t R_M^r) & \cdots & S\exp[-jk(R_N^t + R_M^r)]/(R_N^t R_M^r) \end{bmatrix} \quad (6)$$

where S is the target scattering coefficient, k is the wave number in free space, and R_n^t, R_n^r are the distance from the n th slot to the target. For simplicity we assume the target is an isotropic scatter object and ignore some coefficients. We determine the receiving slot array vector $\boldsymbol{u}$ in the same way as (5). The target response can be written as

$$E_r(f) = \boldsymbol{u}^T \boldsymbol{X} \boldsymbol{v} E_t(f) \quad (7)$$

where $E_t(f)$ is the sine wave, and f is the frequency. The time domain response of the target is given by

$$S_r(t) = \frac{1}{2\pi}\int_{f_0-B/2}^{f_0+B/2} W[2(f-f_0)/B] E_r(f) \exp(j2\pi f t)\, df \quad (8)$$

where f_0 is the center frequency, B is bandwidth, and $W[\cdot]$ is the weight function.

4. Results with Numerical Analysis and Discussion

To demonstrate the difference in the target detection performance, we analyzed the distribution of the response power and the observation distance of the target using the simple layout model. Leaky coaxial cables whose slot pitch P is 1 m, contraction rate $\kappa = 1/\sqrt{\varepsilon_r}$ is 0.9, and attenuation of the leaky cable is 30 dB/km, are set in parallel at a 2 m interval. In this simulation, we determined the center frequencies CF to be $0.8 f_b$, f_b and $1.2 f_b$, where $f_b = c / P(\sqrt{\varepsilon_r} + 1)$, and the bandwidth to $B = c / 20P$, to which the spatial frequency reaches 10 times of the inverse of slot pitch. We used the leaky cable depicted in Fig. 1(b).

The results of the response power $|S_t|^2$ and observation distance of the target with cable layout are shown in Fig. 3(a)-(c). In these figures, the response power is depicted as a grey scale contour plot with 10 dB intervals, and the lines with numerical value indicate the contour plot with an observing distance whose unit is matter. Figure 3(a) shows the result in $CF = 0.8 f_b$. The leaky cables work in surface mode in this frequency band. The target response power at the center of the cable length reduces rapidly with the distance across to the leaky cable in proportion as $1/r^{10}$ in $r < 3$ and then increases slowly with r. This phenomenon is yielded by the emission from the edge of the leaky cables. Since the periodical slots are terminated suddenly, the leaky cables do not work in surface mode. Figure 3(b) shows the result in $CF = f_b$. In this frequency range, the lower side of the bandwidth is in surface mode, and the upper side is in radiation mode. Our simulation results showed that the reduction rate at the center of the cable is in proportion as $1/r^3$. The results in Fig. 3(c), which is in radiation mode, showed that the reduction rate was in proportion as $1/r^2$. To compare these results, we show the response powers at the center of the cable across to the leaky cable in Fig. 3(d). At the point of variation in the surface mode, the difference of response power between surface mode and radiation mode reached the maximum. In the region inside of this point, the difference value of the response power reduces gradually with r.

The measured target distance in Fig. 3(c) increases linearly through the leaky cable with r. In surface mode, a nonlinear region appeared as shown in Fig. 3(a) because of the edge radiation. In addition, the contour line was very complex outside the pair of leaky cables. Thus it is difficult to obtain the target distance with high accuracy in surface mode.

In a surveillance application, the ability to estimate target size is required. However, when the location of the target is not obtained, we cannot derive the target size from the target response. Here, we propose a solution that uses both surface and radiation modes. Since the difference of the response power between two modes is constant without target size, we can estimate the target distance across to the leaky cable using the difference value and then estimate the target radar cross section from the response power in radiation mode.

5. Conclusion

In this paper, the target responses in surface and radiation modes of leaky cables were calculated by slot array analysis. We demonstrated the distribution of response power and observation distance of the target using a simple layout. The results showed that the propagation mode of the leaky cables can be switched by changing the frequency band adequately. In surface mode, the target response power reduced rapidly with r compared to the rate in radiation mode. Using these differences, we can estimate the target distance across to the leaky cable, and the target size.

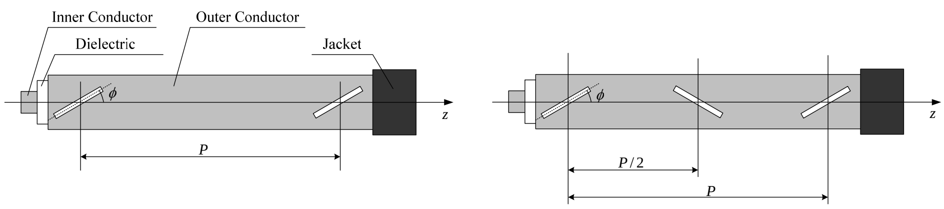


Figure 1: Configuration of leaky coaxial cables: (a) basic configuration: (b) wide bandwidth configuration with subslots

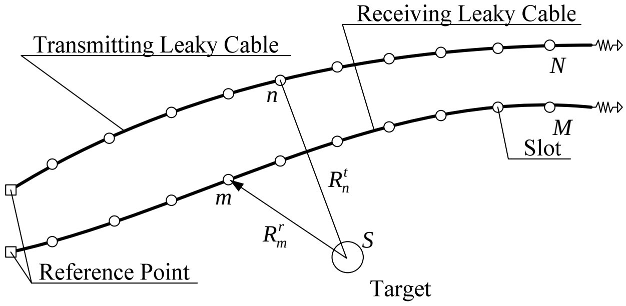
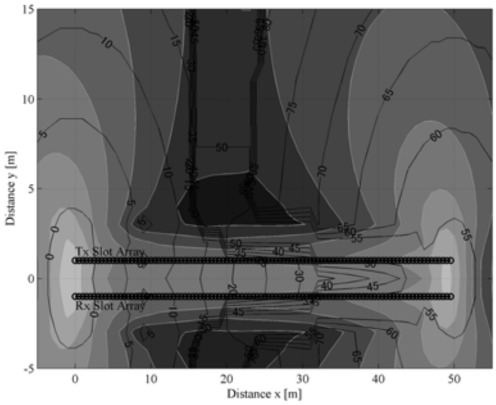
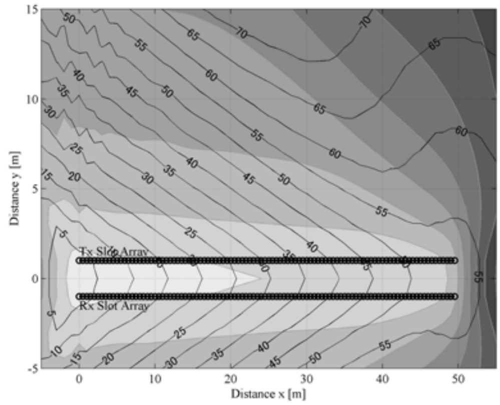


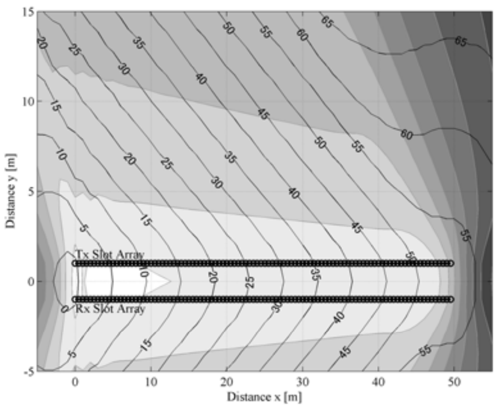
Figure 2: Layout model of two leaky cables



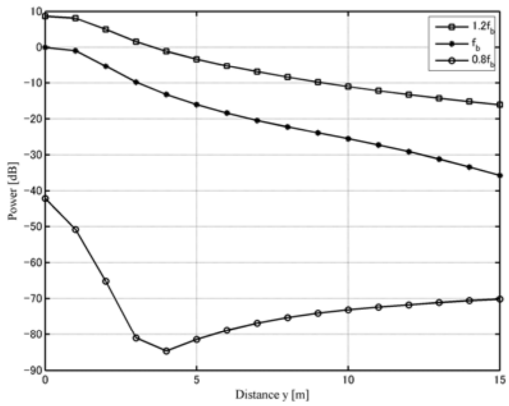
(a)



(b)



(c)



(d)

Figure 3: Distribution of response power and observation distance of target at: (a) $CF = 0.8 f_b$, (b) $CF = f_b$, (c) $CF = 1.2 f_b$; (d) response power of target at x = 25m normalized from maximum response power at f_b

References

[1] T. Sintani, M. Hori, and Y. Yamaguchi," Wide-Band Leaky Coaxial Cable," *Dainitch-Nihondensen-Jihou*, vol. 47, Mar 1971 (*in Japanese*).

[2] J. H. Wang and K. K. Mei, "Theory and Analysis of Leaky Coaxial Cable With Periodic Slots," *IEEE Trans. Antenna and Prop*., vol. 49, pp. 1723-1732, Dec 2001.

[3] K. Inomata, T. Hirai, H. Yamada, and Y. Yamaguchi, "2-Dimensional Measuring Method Using a Wide-area Surveillance Sensor with Leaky Coaxial Cables," *EuMA2006 Radar Conf.*, pp. 202-205, Sep 2006.