IEICE Communications Express, Vol.4, No.12, 358–362

Beam scanning capability and suppression of endfire radiation of dipole array antennas coupled to two-wire parallel transmission line

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Abstract: In this letter, radiation pattern of a dipole array antenna coupled to a two-wire transmission line is numerically investigated. The effect of array spacing on the main beam direction of the array antenna is shown. In addition, it is shown that the endfire radiation of the array antenna can be suppressed when series inductors are loaded with the two-wire transmission line.

Keywords: array antenna, leaky wave antenna, beam scanning

Classification: Antennas and Propagation

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DOI: 10.1587/comex.2015XBL0127
Received September 24, 2015
Accepted October 22, 2015
Published December 8, 2015

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1 Introduction

In recent years, antennas for the next-generation wireless communication system have received much attention. Beamwidth of such antennas is expected to be narrower than that for the existing wireless communication systems because high frequency band such as millimeter wave band will be used for the systems. In addition, propagation loss in high frequency band is much higher than microwave and main beam must be radiated directly from a transmitting antenna to a receiving antenna. Therefore, beam scanning capability is necessary for antennas of the next-generation wireless communication systems using the high frequency band.

Previously, various beam scanning antennas have been reported. A microstrip array antenna and transmit array with diodes have been reported as antennas with electronic beam scanning capability [1, 2]. On the other hand, antennas with mechanical beam scanning capability have received much attention [3]. One of the advantages of such antennas is low loss because its beam scanning capability is realized without using lossy microwave components such as diodes or phase shifters. Such low loss performance of the antennas with mechanical beam scanning capability can be a significant advantage when the antennas are used for the next generation wireless communication systems because the systems suffer from high propagation loss. The disadvantage of the antennas with mechanical beam scanning capability is slow-speed scanning. Therefore, the antennas with mechanical beam scanning capability can be useful for the next-generation indoor wireless communication systems in high frequency band because high-speed scanning is not necessary for tracking the movement of mobile terminals in an indoor environment. A dipole array antenna coupled electromagnetically to a two-wire transmission line is the one of these antennas [4]. In previous researches, mutual coupling between a dipole antenna and two-wire transmission line has been investigated experimentally [5]. In addition, radiation pattern of the array antenna has been clarified experimentally [6] and analytically [7]. However, to the best of our knowledge, the array antenna with beam scanning capability has not been reported so far.

In this letter, a dipole array antenna coupled to a two-wire transmission line with beam scanning capability is proposed. Results of numerical simulation show that the beam direction of the proposed antenna can be scanned when its array spacing changes. It is shown that the endfire radiation of the antenna can be suppressed when series inductors are loaded with the two-wire transmission line.

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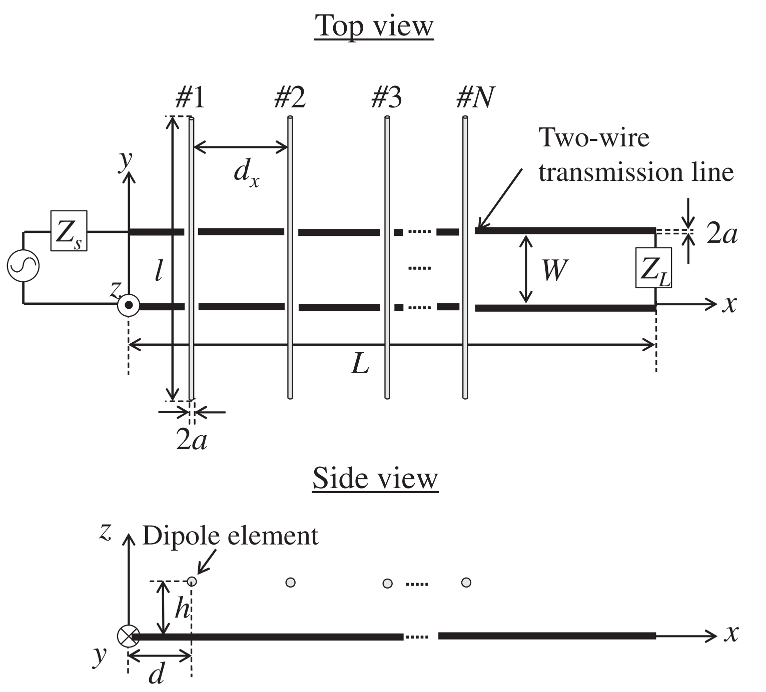

Fig. 1. An example of a dipole array antenna coupled to a two-wire transmission line.

2 Numerical simulation

A dipole array antenna coupled to a two-wire transmission line is shown in Fig. 1. The antenna operates at $f = 20\,\text{GHz}$. Dipole elements have the same length l and are separated with equal spacing d_x. Dimensions of the two-wire transmission line are designed so that characteristic impedance becomes $50\,\Omega$ using following formula.

$$Z_0 = \frac{1}{\pi}\sqrt{\frac{\mu_0}{\epsilon_0}}\ln\frac{W-a}{a}. \tag{1}$$

A voltage source is applied to the two-wire transmission line terminated in load resistance $Z_L = 50\,\Omega$ through a series resistance $Z_s = 50\,\Omega$. The Richmond's method of moments (MoM) was used for numerical simulation [8]. Conductivity of antennas and two-wire transmission lines is $\sigma = 5.8 \times 10^7\,\text{S/m}$.

Fig. 2 shows radiation patterns of the array antenna when array spacing $d_x = 0.5, 0.6, 0.7, 0.8\lambda$. It is found that the main beam direction of the array antenna depends on its array spacing. As shown in [9], main beam direction of a leaky-wave antenna can be obtained as follows.

$$\sin\theta_m \approx \frac{\beta_n}{k_0} \text{ where } \beta_n = \beta_0 + n\frac{2\pi}{d_x}, \tag{2}$$

where θ_m is main beam direction of the leaky-wave antenna and β_n is the propagation constant of the nth space harmonic. β_0 is the propagation constant in the two-wire transmission line and agrees with the wavenumber of free space k_0 because the TEM mode is dominant in the two-wire transmission line. Eq. (2) shows that endfire radiation shown in Fig. 2 corresponds to the dominant TEM mode and the scanned beam corresponds to $n = -1$th space harmonic. The main beam is radiated in $x \leq 0$ because $\beta_{-1} \leq \beta_0$. θ_m calculated by Eq. (2) is 42 deg. at

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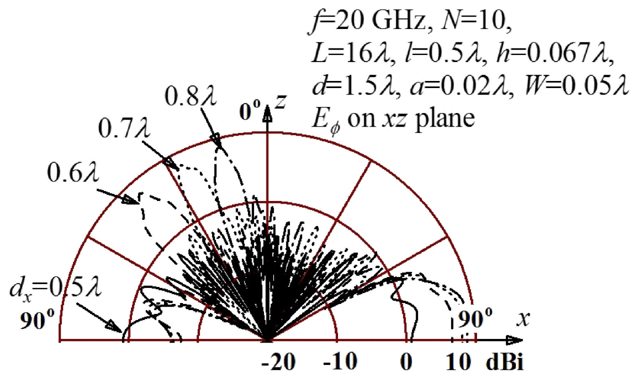

Fig. 2. Radiation patterns of the array antenna.

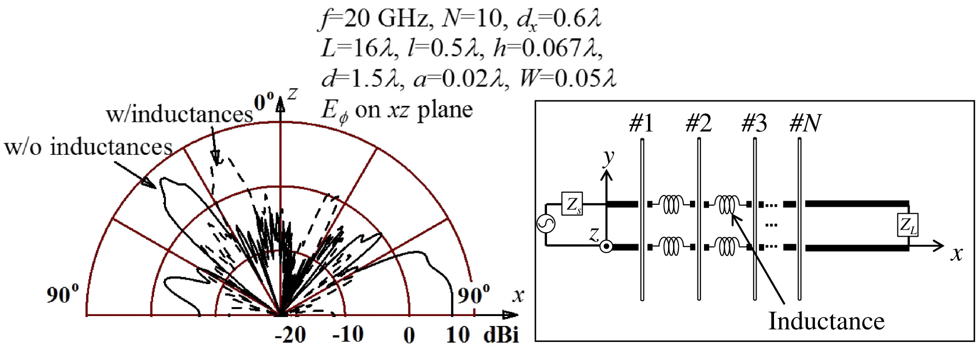

Fig. 3. Radiation patterns of the array antenna ($d_x = 0.6\lambda$).

$d_x = 0.6\lambda$, 25 deg. at $d_x = 0.7\lambda$ and 15 deg. at $d_x = 0.8\lambda$, respectively. On the other hand, θ_m calculated by MoM is 41 deg. at $d_x = 0.6\lambda$, 27 deg. at $d_x = 0.7\lambda$ and 14 deg. at $d_x = 0.8\lambda$, respectively. It is found that the main beam directions obtained by Eq. (2) agree well with those obtained by MoM.

Beam scanning capability of the array antenna was clarified but endfire radiation which is comparable to its main beam level can be observed in Fig. 2. For practical applications, this undesired endfire radiation must be suppressed as much as possible. In order to suppress the undesired endfire radiation, a dipole array antenna coupled to a two-wire transmission line inserted inductors are proposed. Propagation constant of the electromagnetic wave propagating on the two-wire transmission line is expected to be modified when these inductors are loaded with the two-wire transmission line. All of these inductors are 0.01 nH and loaded with the two-wire transmission line as a lumped element in the middle of all adjacent two dipole elements. An example of radiation pattern of the array antenna is shown in Fig. 3 when array spacing $d_x = 0.6\lambda$. As shown in this figure, it is found that the endfire radiation of the array antenna is suppressed when inductors are loaded with the two-wire transmission line. It is thought that the propagation constant β_0 corresponding to the dominant TEM mode which contributes the endfire radiation is modified by inductors. As a result, main beam direction is tilted when inductors are loaded with the two-wire transmission line because β_n is the function of β_0 as shown in Eq. (2). Even when the array spacing is changed mechanically, endfire radiation still can be suppressed without moving inductors because β_0 is almost independent of the array spacing.

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3 Conclusion

The dipole array antenna coupled to the two-wire transmission line with beam scanning capability was proposed and studied by numerical simulation. It was shown that array spacing between dipole elements affects beam direction of the array antenna. In addition, it was found that the main beam direction of the array antenna can be switched as a function of the array spacing. High level radiation at the endfire direction of the array antenna was suppressed when inductances are loaded with the two-wire transmission line.

Acknowledgments

We would like to thank staffs in Cyberscience Center, Tohoku University for their helpful advices. This work was financially supported by JSPS KAKENHI Grant Number 26820137 and JSPS Postdoctral Fellowships for Research Abroad.

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