New Type of Millimeter Wave Antenna by Using the High Permittivity LSE NRD Guide

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***Abstract* — A technique for construction of a millimeter-wave antenna has been developed based on the high permittivity LSE-NRD guide technology. The novelty of the present technique lies in use of a simple radiator, which consists of tapered dielectric strip with the length of about a guided wavelength and has the broad radiation pattern. The new type of fan beam antenna for marine radar use has been fabricated by locating the radiator in the focal point of the cylindrical parabolic reflector. A good fan beam pattern with the half-power beam widths of 4° in horizontal plane and 38° in vertical plane can be obtained.**

I. Introduction

A high performance millimeter-wave antenna which is compatible with integrated circuits is a key technology for developing novel millimeter-wave systems. Actually several transmission lines such as microstrip line and slot line have been used as antenna feeders [1].

Another candidate as the antenna feeder is the NRD guide [2], which consists of dielectric strips inserted in a below cutoff parallel metal plate waveguide and features no radiation nature at curved sections and discontinuities as well as low loss nature. Indeed the NRD guide has been used to build a millimeter-wave planar antenna successfully [3]. It is expected that the compactness and low loss nature in the feeder circuits can be improved by using high permittivity dielectric strips instead of usually used low permittivity ones, however the high permittivity NRD guide often suffers from irregular transmission phenomena [4]. In order to overcome such difficulty, the use of new operating mode, which has been regarded as a parasitic mode but has the lowest cutoff frequency in the NRD guide, has been proposed [5]. It has been apparent that the new mode has good transmission characteristics and interesting properties such as wide bandwidth and low loss nature.

With this in mind, a simple radiator has been proposed based on the high permittivity NRD guide and it has been applied in new type of antenna at 35GHz in this paper.

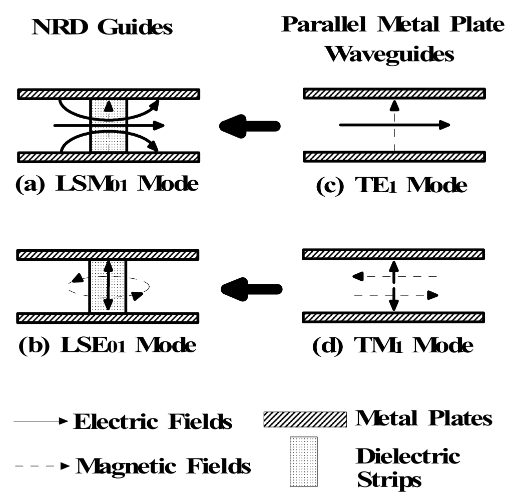


Fig.1 Dominant modes in NRD guide andparallel plate metal waveguide

II. Modes in NRD Guide

Modes in the NRD guide can be classified into the LSM and LSE modes, the former being featured by the magnetic fields in parallel to air-dielectric interfaces and the later by the electric fields in parallel to those interfaces. These modes are further classified by the mode number. The field distributions of these dominant modes so called "LSM_{01} mode" and "LSE_{01} mode" are shown in Fig.1(a), (b). The LSM_{01} mode having great advantages such as low loss nature and easy coupling to a rectangular hollow metal waveguide has been regarded as an operating mode, while the LSE_{01} mode has been eliminated as a parasitic mode [2].

By the way, TE_1 and TM_1 modes in parallel metal plate waveguide as shown in Fig.1(c), (d) have equal eigen value. By inserting a dielectric strip in the metal plates, that is, by constructing the NRD guide structure, the degeneracy is removed and these modes are transformed to the LSM_{01} and LSE_{01} modes, respectively. It is therefore evident that the separation between cutoff frequencies of these modes becomes to be expanded by using high permittivity dielectric strips and wide bandwidth of the single-mode operation of the lowest LSE_{01} mode can be obtained.

In this paper, we discuss the high permittivity NRD guide with LSE_{01} mode transmission for applications to millimeter-wave antennas. Such NRD guide is called high permittivity LSE-NRD guide in following chapters.

III. DESIGN OF HIGH PERMITTIVITY LSE-NRD GUIDE

The metal plate separation of the NRD guide is determined to be 3.5mm so as to be less than half a free-space wavelength at 35GHz. RT/duroid with the relative permittivity of 10.8, which is made by a composite of ceramic and PTTE, is chosen as a material of the dielectric strip because of its easy fabrication. The cross-sectional dimensions of the dielectric strip are 3.5mm in height and 0.635mm in width, respectively.

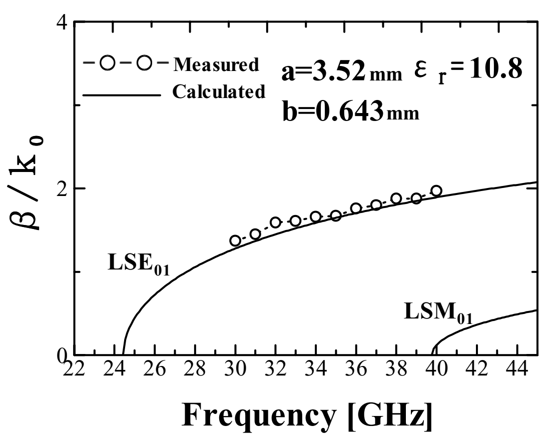


Fig.2 Calculated and measured dispersion curves of high permittivity NRD guide

The calculated dispersion curves of the LSE_{01} mode and the LSM_{01} mode are shown in Fig.2 as solid curves. The bandwidth of the LSE_{01} mode is enough to cover the Ku band from 24GHz to 40GHz. Measured dispersion curve is also shown in Fig.2 as a dotted curve. A good agreement between the theory and measurement can be obtained.

IV. RADIATION CHARACTERISTICS

A. Single Radiator

Figure 3 shows the structure of the radiator based on the high permittivity LSE-NRD guide. Since the dielectric strip is tapered asymmetrically at the truncated end, the radiating wave is occurred from the taper due to the mode conversion from the LSE_{01} mode to the TE_{01} slab mode. In order to optimize the taper length, the VSWR on the normal LSE-NRD guide was measured as a function of the taper length as shown in Fig.4. The minimum VSWR is about 1.5 for the length of larger than 7mm. Then the radiation pattern of the radiator with the taper length of 7mm was measured and the result is shown in Fig.5. A broad radiation pattern with a half-power beam width of about 80° is obtained. It suggests that the synthesis of desired antenna patterns can be performed by the addition of individual radiators.

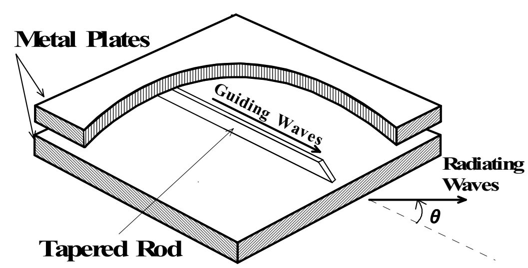


Fig.3 Structure of tapered high permittivity LSE-NRD guide

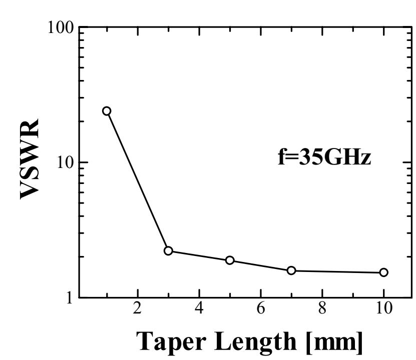
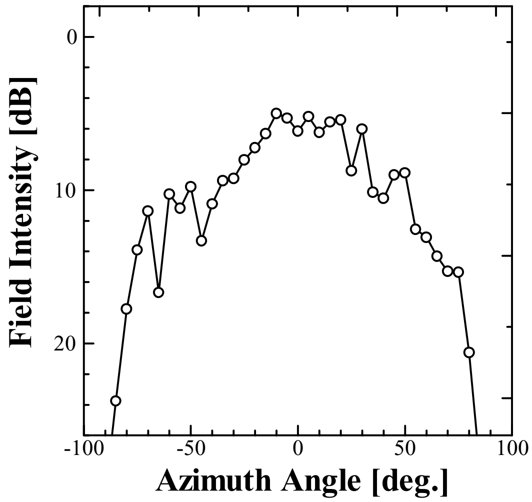


Fig.4 Measured VSWR versus taper length



Fi.g.5 Measured radiation pattern of single radiator

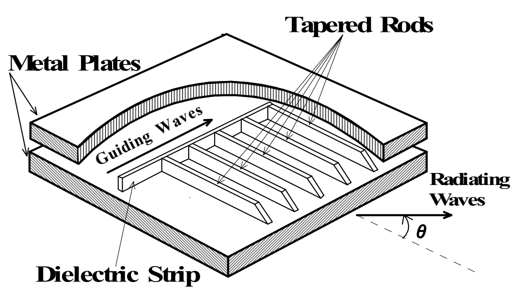


Fig.6 Structure of arrayed radiators fed by high permittivity LSE-NRD guide

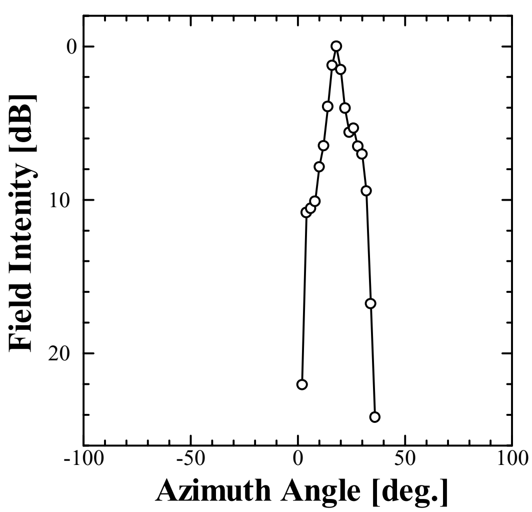


Fig. 7 Measured radiation pattern of arrayed radiators

B. Arrayed radiators

The structure of new millimeter wave antenna is shown in Fig.6. The nine radiators are transversely coupled to the high permittivity LSE-NRD guide, acting as a feeder, in a period of a guided wavelength. The feeder consists of the same material of the radiator and its cross-sectional dimensions are also identical with those of the radiator. Figure 7 shows the measured radiation pattern of the arrayed radiators. The half-power beam width , measured to be 12 ° , is improved compared with that of the single radiator as predicted. Moreover, main lobe level increases by 5dB.

Another advantage of the antenna is no grating lobe because the high permittivity LSE-NRD guide acts in a slow wave region as indicated in Fig. 2.

C. Parabolic reflector antenna fed by single radiator

Based on the fabricated LSE-NRD guide radiator, we have developed the fan beam antenna for marine radar use as shown in Fig. 8, where the top metal plate was removed to clarify the antenna structure. The radiator is located at the focal point of the parabolic reflector inserted in an oversized parallel metal plate waveguide with the height of 3.5 mm and the width of 240 mm. The edge of the parallel metal plate waveguide is shaped into a 2-dimensional horn with 14.5 mm × 240 mm aperture. Figure 9 shows the measured radiation patterns in the vertical and horizontal planes. Good fan beam patterns with the half-power beam widths of 4 ° and 38 ° , respectively, can be performed.

Fig. 8 Photograph of the parabolic reflector antenna fed by single radiator

V. CONCLUSION

The tapered high permittivity LSE-NRD guide has been investigated as a radiator. It has a broad radiation pattern as well as a simple structure. A new type of millimeter wave antenna based on the arrayed radiators has been also proposed. The synthesis of radiating waves from each radiator has been performed successfully. We are thinking positively to apply the high permittivity LSE-NRD guide in the fields of the millimeter wave antennas.

References

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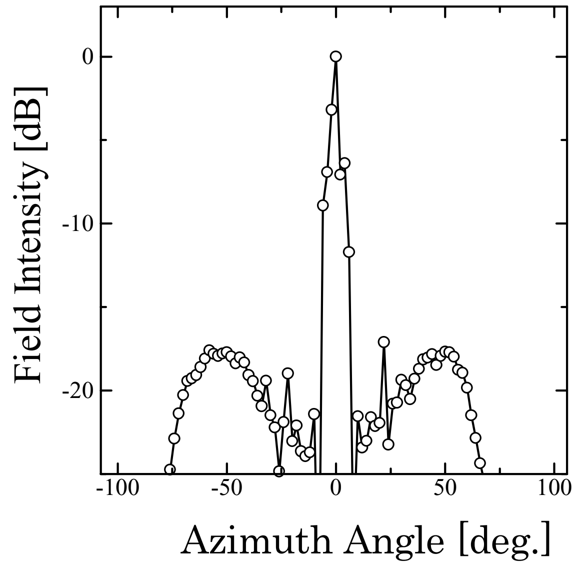
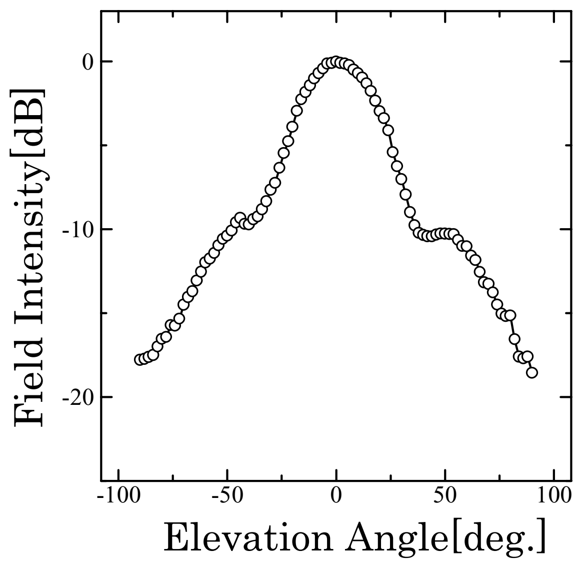


(a) Horizontal plane



(b) Vertical plane

Fig. 9 Measured radiation pattern of parabolic reflector antenna fed by single radiator