Mode Coupling Phenomenon in High Permittivity NRD Guide with Asymmetrically Remained Small Air Gap

Futoshi KUROKI, Kouichi YAMAOKA, and Motofumi YAMAGUCHI
Department of Electrical Engineering, Kure National College of Technology
2-2-11 Aga-Minami Kure 737-8506, Hiroshima, Japan

Tsukasa YONEYAMA
Department of Environmental Information Engineering, Tohoku Institute of Technology
35-1 Yagiyama-Kasumicho Taihaku-Ku Sendai 982-0831, Japan

***Abstract* — It is known that a high permittivity NRD guide, where an LSM01 mode mainly propagates, suffers from irregular transmission phenomena. Since high permittivity materials such as ceramics and alumina have rough and hard surfaces, we assumed that this problem was caused by asymmetrically remained small air gap between the metal plates and high permittivity dielectric materials in the NRD guide. From the theoretical and experimental investigations, it is clear that the LSM01 mode is liable to couple with an unwanted mode, while an LSE01 mode, being another nonradiating mode, is hard to couple with such mode.**

I. Introduction

An NRD guide, which consists of low permittivity dielectric strips inserted in a below cutoff parallel metal plate waveguide, is another candidate as a transmission medium for the construction of millimeter wave integrated circuits.

It is expected that the compactness and low loss nature are improved by using high permittivity dielectric materials, but high permittivity NRD guide with an LSM01 operating mode transmission often suffers from irregular transmission. It was pointed out that this phenomenon was caused by small air gaps remained between the dielectric and metal plate interface because the high permittivity materials such as ceramics and alumina have rough and hard surfaces, and this fact was analyzed by the NRD guide with symmetrical small air gaps [1].

Strictly considered, air gaps exist asymmetrically between the dielectric strip and metal plate interfaces. Such analytical model, consisting of low permittivity dielectric strip with LSM01 mode transmission, was previously discussed by Prof. Oliner [2], and Prof. Shigesawa [3].

In order to more investigate the irregular transmission phenomenon, we analyzed the high permittivity NRD guide with the asymmetrical air gap, which was exited by two types of non-radiating modes, namely, not only LSM01 mode but also LSE01 mode [4].

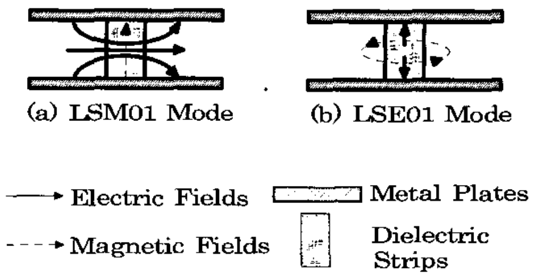


Fig. 1. Non-radiating modes in NRD guide

II. Analysis of NRD Guide with a Small Air Gap

The NRD guide is constructed by rectangular dielectric strips inserted in a below cutoff parallel metal plate waveguide as shown in Fig.1. The dominant modes can be classified into the LSM01 and LSE01 modes, the former being featured by the magnetic fields in parallel to the air-dielectric interfaces and the later being featured by the electric fields in parallel to the same interfaces. The LSM01 mode has been regarded as an operating mode, while the LSE01 mode has been dealt with as a parasitic mode.

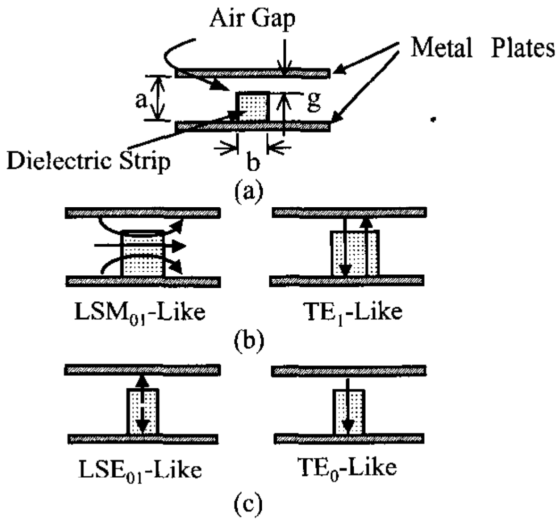


Fig. 2. NRD guide with asymmetrical air gap
(a) Cross sectional view, (b) LSM01-like mode and TE1-like mode, and (c) LSE01-like mode and TE0-like mode

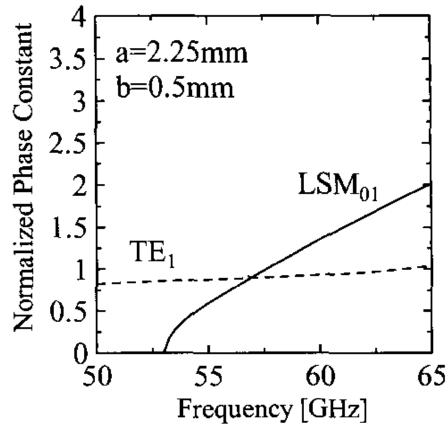
Figure 2 (a) shows the NRD guide with asymmetrical air gap , where the air gap with the length of g is installed in the NRD guide with the height of a and width of b. In this structure, it is considered that LSM01-like and TE1-like modes are generated from the LSM01 mode by the effect of the air gap as shown in Fig. (b), while LSE01-like and TE0-like modes are generated by exciting the LSE01 mode from the result of mode conversion as shown in Fig. (c).

Dispersion curves of the LSM01 and TE1 modes in the normal NRD guide, namely, the NRD guide without air gap, were calculated by conventional method as shown in Fig. 3 (a). From this figure, it seems that two modes will be couple, because the intersection point between two modes exists at a frequency of 57GHz. On the other side, it is considered that the LSE01 and TE0 modes, whose dispersion curves are shown in Fig. (b), are hard to couple due to the difference of their phase constants.

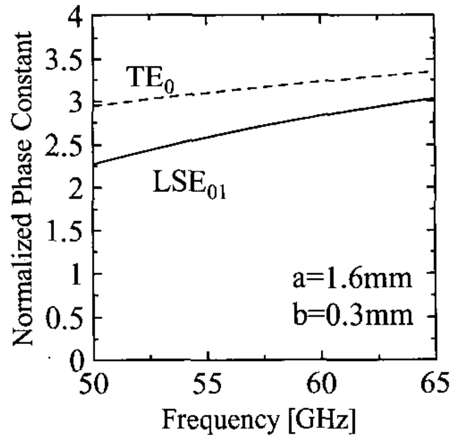
In order to clarify this fact, we calculated the normalized phase constants of the NRD guide with asymmetrical air gap by using HFSS (High Frequency Simulation Software). According to image theory, an image plane may be placed longitudinally along the vertical mid-plane of the dielectric strip as shown in Fig.4, where the image plane corresponds to an electric wall for the LSM01 mode exited NRD guide, while that corresponds to a magnetic wall for the LSE01 mode exited NRD guide. Considering the leaky wave radiation, a radiation boundary is installed at the side opening of the NRD guide.

Figure 5 (a) shows the calculated dispersion curves of LSM01 mode exited NRD guide with asymmetrical air gap. From this figure, it is cleared that mode coupling phenomenon between the LSM01 and TE1 modes occurs as predicted. The field distribution of the TE1-like mode is transferred to that of the LSM01 mode, while field distribution of the LSM01 mode is changed to that of the TE1 mode around a frequency of 58GHz.

Figure 6 (a) shows the dispersion curves of the LSE01 mode exited NRD guide with asymmetrical air gap. In this case, these modes are hard to couple due to the difference of their phase constants.



(a) LSM01 and TE1 modes



(b) LSE01 and TE0 modes

Fig. 3. Calculated normalized phase constant of high-permittivity NRD guide without air gap

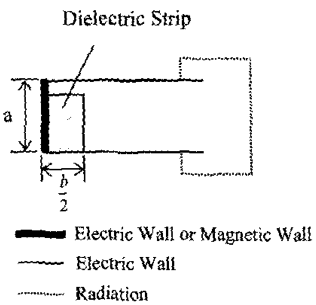
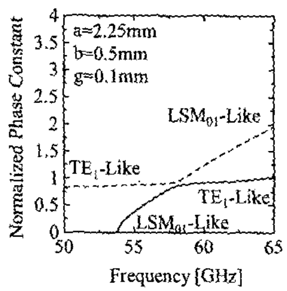
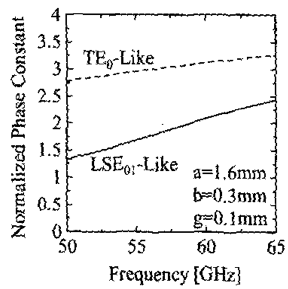


Fig. 4. Analytical model of NRD guide with asymmetrical air gap



(a) LSM01-like and TE1-like modes



(b) LSE01-like and TE0-like modes

Fig. 5. Calculated normalized phase constant of high-permittivity NRD guide with asymmetrical air gap

III. Experimental Consideration

In order to confirm the theoretical considerations, we investigated transmission characteristics of the LSM01 mode exited high permittivity NRD guide at first, which was made by alumina material with the relative permittivity of 9.7 and the cross-sectional dimensions were designed to be 2.7mm in height and 1.0mm in width for 50GHz use. The calculated dispersion curves of LSM01-like and TE1-like modes are shown as solid and dotted curves in Fig. 6, where we assumed the small air gap to be 0.1mm.

The standing wave pattern was measured in the neighborhood of the truncated end of a dielectric strip by using a uni-pole antenna consisting of an inner conductor of a very thin semi-rigid cable as shown in Fig. 7. Figure 8 shows the measured results. At 47GHz, an irregular transmission phenomenon was not observed as shown in Fig (a), although the minimum levels of the standing wave pattern gradually decrease toward the direction of a generator due to the transmission loss. The reason to exhibit a good standing wave pattern is that the phase constant of the LSM01-like mode is far from that of the TE1-like mode. From the result, the normalized phase constant was measured and plotted in Fig. 6. Well agreement between theory and measurement can be obtained.

However, irregular beats were tremendously generated at 52 GHz as shown in Fig. (b). From the beat wavelength, the phase constants of two modes are derived and plotted in Fig. 6. Measured phase constant of the LSM01-like and TE1-like modes roughly agreed with the theoretical values, and thus, it is confirmed that the irregular transmission phenomenon is caused by mode coupling between the LSM01 mode and TE1 mode.

Next consideration is concerned with the LSE01 mode exited high permittivity NRD guide, which was made by ceramic compounded Teflon material with the relative permittivity of 10.8 and was designed to be 2.25mm in height and 0.265mm in width at 60 GHz. The measured standing wave pattern is shown in Fig. 9. Good standing wave pattern can be measured, and thus, the validity of the theoretical consideration is confirmed.

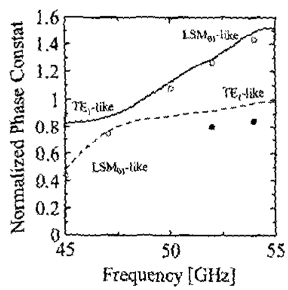


Fig. 6. Calculated and measured normalized phase constants of high- permittivity NRD guide exited by LSM01 mode.

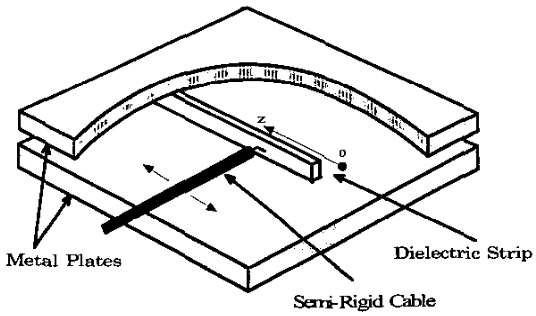
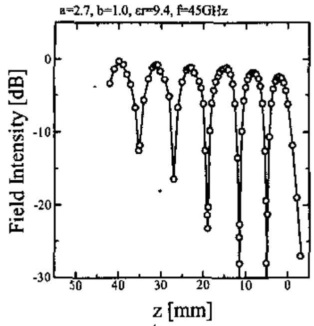
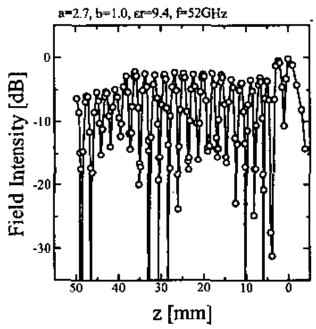


Fig. 7. Structure of NRD guide coupled by uni-pole antenna transversely



(a) 45GHz



(b) 52GHz

Fig. 8. Measured standing wave patterns of high- permittivity NRD guide exited by LSM01 mode.

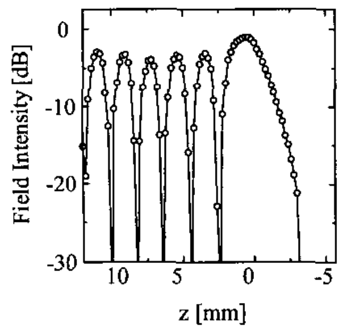


Fig. 9. Measured standing wave patterns of high- permittivity NRD guide exited by LSE01 mode.

IV. Conclusion

An effect of asymmetrical air gap in the high permittivity NRD guide was theoretically and experimentally investigated. It is evident that the LSM01 mode suffers from an irregular transmission phenomenon due to mode coupling between the LSM01 and TE1 modes, while the LSE01 mode has no irregular transmission characteristics

The LSE01 mode will be therefore expected to play key role in the high permittivity NRD guide integrated circuits at the millimeter-wave frequencies.

References

[1] S. Shinohara and T. Yoneyama : "Some Interesting Transmission Characteristics of Nonradiative Dielectric Waveguide Using High Permittivity Material", IEICE Trans., Vol.J73-C-I, No11, (1990).

[2] A.A. Oliner, S.T. Peng, and K.M. Sheng, "Leakage From a Gap in NRD Guide", Proceeding of IEEE MTT-S, pp.619-622 (1985)

[3] H. Shigesawa, M. Tsuji, and A.A. Oliner, "Effect of Air Gap and Finite Metal Plate Width on NRD Guide", Proceeding of IEEE MTT-S, pp.119-122 (1986)

[4] F.Kuroki, K.Ikeda, and T.Matsukawa, "Transmission Characteristics of LSE01 Mode in High Permittivity NRD Guide", APMC Proceedings, Vol.2, pp.593-596 (1997)