Wave Leakage From Groove NRD Structures

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***Abstract*— It is shown that the offset of grooves in the groove NRD structure causes the leakage of power from the operating mode fields. Numerical results based on a full-wave analysis are provided to show the complex propagation properties of the operating mode as a function of the offset dimension of the grooves and the frequency. Mode conversion behavior between the operating mode and the dominant mode is also illustrated. Some conclusions about the usage of the GNRD guide are drawn.**

I. Introduction

The groove nonradiative dielectric (GNRD) waveguide, as shown by the inset of Fig. 1, was proposed [1] as a modification of the NRD guide, in which shallow grooves are introduced for inlaiding the dielectric strip so that it can be fixed precisely, since in certain applications of the NRD guide, such as the directional coupler and the leaky-wave antenna [2]–[6], the position of the dielectric strip is extremely important.

The operation principle of the NRD guide is: when the two parallel metal plates are separated by a distance smaller than half a wavelength ($a' < \lambda_0/2$ in Fig. 1), the field of the operating mode is bound within the central dielectric region, and decays exponentially away from the dielectric region in the regions above and below. For the GNRD guide, however, the nonradiation condition requires not only that $a' < \lambda_0/2$, but also that the added grooves are symmetric about the vertical plane yoz. Any offset of the grooves with $d \neq d'$, which may happen easily during fabrication processes because of small dimensions at millimeter-wave frequencies, will convert an initially bound mode into a leaky mode, so that the structure is no longer *nonradiative*. Similar phenomena have been used for the development of new types of leaky-wave antennas [7], [8]. However, for the GNRD guide systems, this leakage of power will cause interferences between circuit components and deteriorate the performance of the systems.

The leakage of power from the operating mode fields makes the propagation constant be complex as $k_z = \beta - j\alpha$. In this letter, by using the full-wave mode-matching method proposed in [9], the behaviors of the phase constant β and leakage constant α of the offset GNRD guide are illustrated as a function of the normalized offset dimension d/a of the guide, and as a function of the frequency. Also, it is shown that under appropriate circumstances, mode conversion occurs between the operating mode and the dominant mode in the offset GNRD guide. This phenomenon dose not happen in the symmetrical GNRD guide and in the NRD guide.

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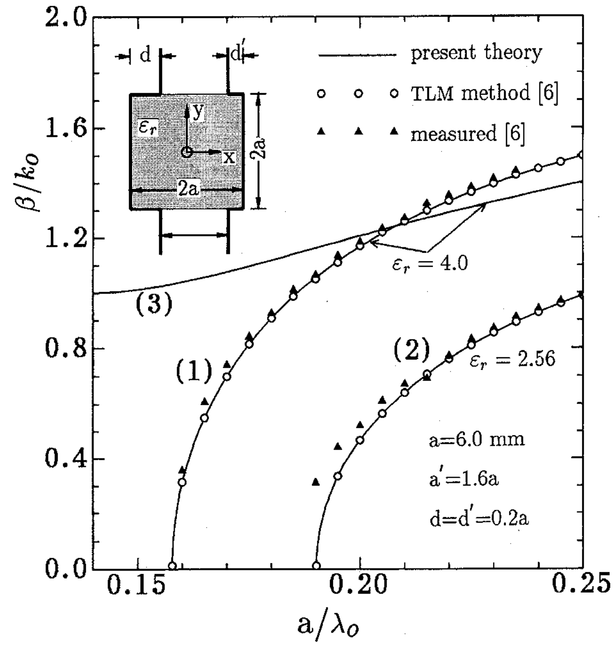

Fig. 1. Dispersion characteristics of symmetrical groove NRD guides. Mode (1) and (2) are the operating modes, mode (3) is the dominant mode.

II. Numerical Results and Discussions

The analysis process has been stated in a previous paper [9] and is abbreviated here for brevity. The reader is referred to [9] and [10].

For comparison, the dispersion characteristics of a symmetric GNRD guide is shown in Fig. 1 with geometric parameters given for the inset which are the same as those of [6]. In the diagram, the curves, (1) and (2), illustrate the dispersion characteristics of the basic operating modes of the GNRD guides with dielectric constant $\varepsilon_r = 4.0$ and $\varepsilon_r = 2.56$, respectively. These operating modes correspond to the LSM_{10} mode in the NRD guide with their electric fields predominantly parallel to the metal plates and the vertical symmetric plane yoz being a magnetic plane. It is seen that our results agree well with the measured data [6], and well with those of [6] computed by a different method, the transmission line matrix (TLM) method. The curve (3) indicates the dispersion behavior of the dominant mode of the GNRD guide (with $\varepsilon_r = 4.0$) whose electric field is predominantly perpendicular to the parallel plates, with the symmetric plane yoz being an electric plane. This mode corresponds to the LSE_0 mode (akin to the TEM mode) in the NRD guide, and is not used for the GNRD guide operation, like in the case of the NRD guide.

The complex dispersion behavior of the GNRD guide with a relative offset dimension $d/a = 0.125$ is shown in Fig. 2. The

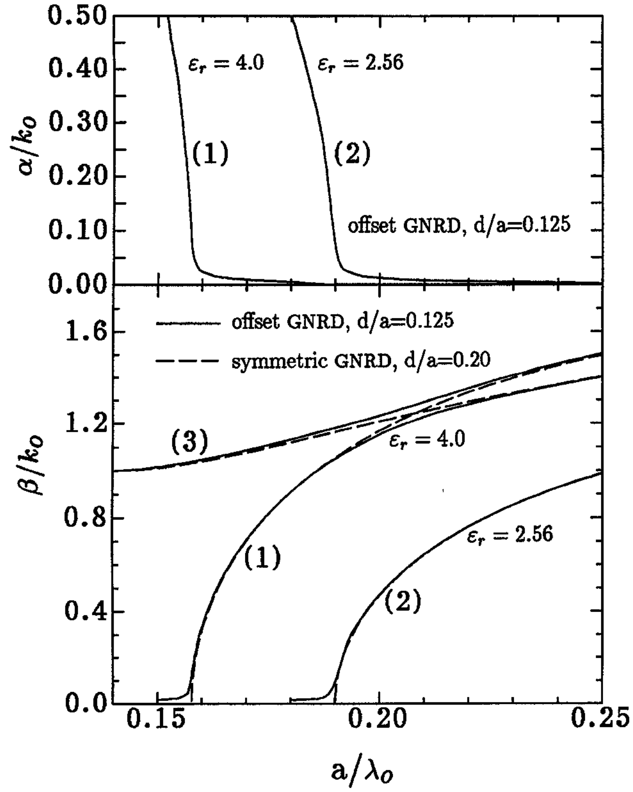

Fig. 2. Complex propagation characteristics of offset GNRD guides. The results for the symmetric GNRD guides are also plotted by dashed lines for comparison.

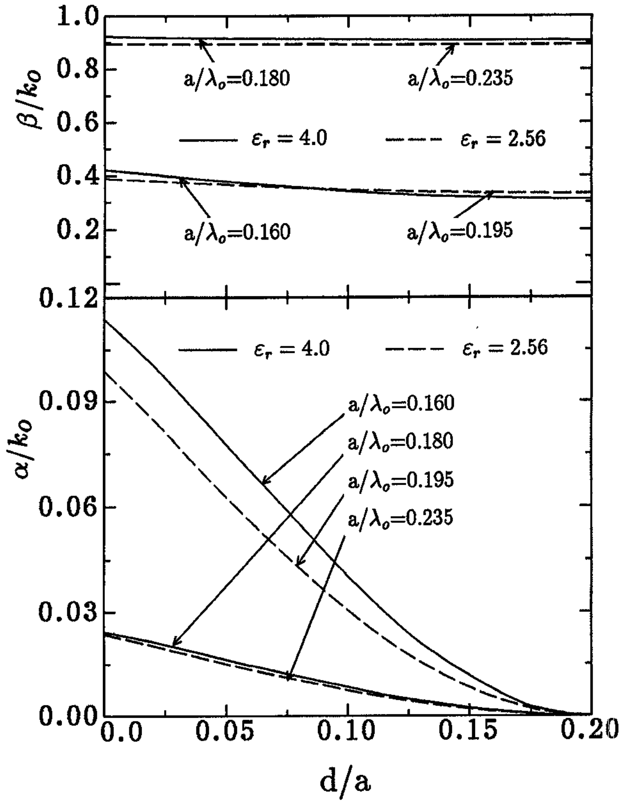

Fig. 3. Variations of the normalized phase constant β/k_0 and leakage constant α/k_0 with the normalized offset dimension d/a of the GNRD guide.

results for the symmetrical GNRD guide (d/a=0.20) are also plotted by dotted lines for comparison. The first we would like to note is that, when its value of β/k_0 is less than unity, the operating mode (mode (1) or (2)) of the offset GNRD guide is leaky, and its value of α/k_0 varies over a wide range, with special sensitivity near the cutoff frequency. The mechanism for the radiation is that, the offset of the guide produces some amount of net horizontal electric fields, and the mode LSE_0 is set up which propagates all the way between the parallel plates and, therefore, leaks power away from the central region [7], [8]. When the value of β/k_0 exceeds unity, however, the LSE_0 mode fields decay exponentially in the narrower parallel plate regions so that the leakage ceases with the value of α/k_0 descending to zero. As the value of β/k_0 of the dominant mode (3) is always larger than unity, it is always a bound mode.

The next to be noted is that, at about $a/\lambda_0 = 0.2075$, the dispersion curves of the operating mode (1) and the dominant mode (3) of the symmetric GNRD guide (dotted lines) cross each other without modal coupling because of their different field distributions. For the offset GNRD guide, however, both the operating mode (1) and the dominant mode (3) (solid lines) contain the LSE_0 mode constituent so that at about $a/\lambda_0 =$ 0.2075 the mode coupling and conversion between them occur. The coupling behavior in the β/k_0 curves results in typical directional coupling response, where one mode changes over into the other as one moves away from the coupling point.

Finally in Fig. 3, the normalized phase constant β/k_0 and leakage constant α/k_0 are shown as a function of the relative offset dimension d/a of the GNRD guide. For both $\varepsilon_r = 4.0$ and $\varepsilon_r = 2.56$, two curves are given at two different frequencies, respectively: one is near the cutoff frequency for which the value of the leakage constant α/k_0 is relatively large, and one far from the cutoff frequency for which the value of α/k_0 is small. At $d/a=$ 0.20, the grooves are symmetric, therefore $\alpha/k_0 = 0$. The value of α/k_0 increases almost linearly with the increase of the offset dimension of the guide. The value of β/k_0 also increases slightly, especially in the case near the cutoff frequency. This enables us to conjecture the reason why the measured data in Fig. 1 are larger than those computed, especially in the vicinity of the cutoff frequencies, if we assume that the GNRD guide used for the measurement had some offset because of the fabrication error.

III. Conclusion

The guiding and leakage behaviors of the GNRD guide with some offset have been illustrated with numerical results. We conclude that although the GNRD guide permits easier fixing of the dielectric strip, it requires a higher precision fabrication for the grooves in order to prevent possible leakages of power. In addition, the field of this leakage is horizontally polarized, therefore, it may also cause problems for the leaky-wave antenna constructed from the GNRD guide [1], where the vertically polarized radiation was used.

References

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