Study on Microwave Planar Antennas Using Leaky NRD Guide(濡れ波NRDガイドを用いたマイクロ波平面アンテナの研究)

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論　文　内　容　要　旨

Chapter 1 : General Introduction

Although leaky wave antennas have been studied extensively in the literature, their practical use is still limited. This work introduces a novel and unique application of leaky wave antennas and shows their substantial practical use possibilities.

Instead of using leaky wave structures as radiating antennas, we address their application as feeding systems for microwave planar antennas. For this purpose, we introduce a new leaky NRD guide based on a grating structure. In fact, because of the NRD guide attractiveness for microwave and millimeter wave system realizations, various leaky wave antenna structures based mainly on creating geometrical modifications in the uniform NRD guide have been proposed. However, These structures have not come into practical use because of difficulties in stability and construction.

The new leaky NRD guide is based on a grating structure consisting of creating a periodic array of grooves on the upper surface of the dielectric strip. This new leaky NRD guide presents the advantage of simplicity in construction and physical stability and is of interest because of its large of leakage rates and its ease of connection with NRD guide integrated circuitry.

Theoretical analysis of the structure is first presented. The analysis is based on a mode coupling theory between the operating mode of the NRD guide and an oversized multimode rectangular waveguide model. Using this method, we develop simple and practically useful formulae that express the principal coupling effects directly in terms of all the grating parameters. Series of accurate measurements of the propagation and leakage constants for various frequencies and geometrical paramenters have been taken. Very good agreement is found between the experiments and the theoretical predictions, showing that the presented theory yields accurate results while presenting the advantage of simplicity and ease of manipulation.

In the second part of this thesis, a novel application of this new leaky NRD guide is introduced. The leaky structure is used as the feeding system for microwave planar antennas. Various antenna configurations have been designed and a final structure giving satisfying characteristics was obtained. The antenna radiated, as designed, in the broadside direction and ideal field patterns with low sidelobe levels and narrow beam width were measured. The scanning performance of the antenna was also considered and promising characteristics were obtained.

A feeding system for circularly polarized antennas using leaky NRD guide is also proposed. The design is based on the same principle as that of the linearly polarized antenna. A design example was constructed and circular polarization with very low axial ratio was obtained.

Chaper 2 : Theoretical study of the new leaky NRD guide

The structure of the proposed leaky NRD guide is shown in fig. 1. The effect of the gratings is to create new field components that will excite the TEM mode in the parallel plate region away from the dielectric strip and change therefore, the guided mode from being purely bound to a leaky mode. This leakage of energy makes the propagation constant complex with an attenuation constant being a measure of the leakage and a change in the phase constant. 《insert fig. 1》

To assess the leakage characteristics of the structure, an analysis method is presented for the investigation of this leaky waveguide. The analysis is based on a mode coupling theory between the operating mode of the NRD guide and an oversized multimode rectangular waveguide model. The effective dielectric constant of the grated strip is expressed as a rectangular modulation, and the fields in the structure are expanded as a function of the transverse field components. A general coupling equation relating the coupled mode field amplitudes is developed. Since we are interested in structures without space harmonics, this equation was then solved small grating periods. Then, expressions were developed for the radiation angle and the leakage rate, which are the main characteristics for the design of leaky wave antennas.
The phase constant was found to be determined directly from the dispersion characteristics of the NRD guide and a simple formula expressing the effective dielectric constant of the structure

as a function of the grating parameters. Considering the coupling between the NRD guide operating mode and modes of the waveguide model with close phase constants, the leakage constant is determined from a closed form relation permitting ease of calculation and simplicity in manipulations. The developed theory was found to yield explicit formulae that express the principal coupling effects directly in terms of the known grating parameters. This theory is free of lengthy computations and convergence problem from which suffers most of the rigorous analysis methods, and the numerical results are introduced in a form that enables us to assess the role of each grating parameters and to predict the change in coupling performance as any of these parameters varies ; and are therefore particularly useful for design considerations.

Using this theory we have examined the various parametric dependence of the leakage characteristics on the constitutive and structural parameters of the leaky NRD guide. The leakage rate was found to depend strongly on the groove dimensions and presents a saturation effect after the groove thickness has reached sufficiently large values along with the apparition of a cut-off phenomenon for large grating dimensions. It was therefore, found that it is possible to design leaky NRD guides with any desired leakage amount and radiation angle by adjusting the different structural parameters of the gratings. Finally, the numerial results obtained using our theory are compared to those presented previously by Oliner et al. for the gap leaky NRD guide which can be treated as a particular case of our structure ; and it was shown that our results are in perfect agreement with the physical explanation of the leakage effect.

Chapter 3 : Experimental Study of the New Leaky NRD Guide

In the previous chapter, we presented an accurate theory for the leakage and phase constants of the new leaky NRD guide. Accurate measurements were taken of the leakage characreristics of the structure to verify the theory derived previously.

The present chapter, contains a systematic series of measurements of the phase constant and the leakage constant for the various frequencies and geometrical parameters, and compares those measurements with corresponding theoretical data. The purpose of the experimental study described here was to obtain experimental confirmation of the theory described in chapter 2 for the phase and leakage constant of this new leaky NRD guide. With that goal in mind, we designed, built, and made careful measurements on a 23 GHz model of the leaky structure that is actually intended for use at this frequency. The measurements were taken by probing the electric near field strength along the longitudinal direction for the leakage constant ; and the standing waves were used to derive the phase constant of the structure.

Some of the important features of the design of the leaky waveguide, mainly the dimensional features, with the choice and limitations of the structure design, are discussed along with the introduction of the real structure and the grating structural parameters is first reported. Next,

we present the exerimental investigation of the leakage effect. In the previous chapter, we have presented the principle of the structure, and allowing to the theoretical explanation of the leakage phenomenon, we have developed the theory for the analysis of the structure, in this sections those theoretical explanations are verified experimentally. Then, we proceed to the measurements of the leakage characteristics of the leaky NRD guide. The measurements procedure for the determination of the phase constant and leakage rate are explained and typical measurement results are shown. Finally the experimenal results obtained used the above method are presented. Comparisons between the theoretical results was made for different guide dimensions, grating structural parameters, and frequencies ; and have shown very good agreement as shown in the typical case of fig. 2. 《insert fig. 2》

The agreement between the theory and experiment is seen to be very good for the phase constant with the different parameters. For the attenuation constant, the experimental data is seen to follow closely the trend of the theoretical curves over the whole range of the different parameters. This shows that the theory employed describes well the coupling performance of the structure. The good agreement between the experimental results and the theoretical predictions is logic, since the method used for the analysis is essentially rigorous and systematic care was taken for the realization of the various experiments.

Chapter 4 : Leaky NRD guide fed planar antennas

Instead of using the leaky guide as a linear source radiating antenna, the new leaky NRD guide is used in a novel structure as a feeder for microwave planar antennas. the structure of the introduced antenna is shown in fig. 3. The grooved dielectric strip is sandwitched between two metal plates and the waves issuing from this leaky guide are used to feed the slots cut in the upper surface of the structure. A reflector is placed parallel to the guide so that the total leaky power is used to feed the slots. Since the leaky NRD guide radiates at an angle from the broadside, it is shifted from the vertical so that the wavefronts of the leaky waves are parallel to the slot plane exciting them thus longitudinally in phase. To eliminate the inherent grating lobes, a dielectric slab is inserted in the antenna cavity. The metal plate separation is reduced accordingly and the slots are created with an interval of the new wavelength. Two sections of quarter wave transformance are used to assure the transition between the feed system and the slot array. 《insert fig. 3》

A design example was built and measured at a center frequency of 23 GHz. The previously developed theory was used to decide the structural parameters of the leaky NRD guide that allow the radiation by leakage of more than 90%of the fed power over a total length of 250㎜. The total radiating area is 290×165 ㎜ made of slots of 1 ㎜ width and 9.1㎜ interval.

The measured radiation patterns in the planes parallel (θ) and normal (ϕ) to the slots are

shown in fig. 4. Broadside radiation is realized in both planes with excellent patterns and lowlevel sidelobes. The measured gain of this antenna is 32 dB.

The frequency bandwidth of this antenna, determined from the pattern beamwidth and the radiation angle frequency characteristics, was found to be 300 MHz. These antenna characteristics are sufficient for applications where large bandwidth are not needed, however the frequency bandwidth falls short from satisfying the requirements for the new generation of DBS receivers at this frequency. Ways to improve the bandwidth of the antenna were discussed.

《insert fig. 4》

The application of the structure as a beam scanning antenna was also discussed. The antenna was found to present various particular characteristics that make of it a very serious candidate for use as a beam scanning antenna. Sufficient beam scanning, compared to well known scanning antenna performnce, was found in one plane with a little beam variation in the other pl ane. The scanning occured with radiation patterns keeping low sidelobes and narrow beamwidths.

The obtained results, for both the broadside and the beam scanning antennas, confirmed the validity of this new application of leaky wave structure as planar antenna feeders and verified the exactness of the presented design concept. The measured antenna characteristics also showed the practical use possibility of this structure and presented it as a serious candidate for use as a broadside and beam scanning antenna for various application at this and higher frequency ranges.

Chapter 5 : Leaky NRD Guide Fed Circularly Polarized planar Antennas

In this chapter, we introduce the design concept of leaky NRD guide fed planar circularly polarised antennas and present the results of measurements carried out on a design example.

The principle of operation is based on the results obtained so far for the leaky NRD guide fed linearly polarized planar slot array antenna. The design concept is to use two identical antennas similar to the one investigated in previous chapter and orient them at a right angle to obtain circular polarization. The two leaky NRD guides are fed from the same source, and a feeding arrangement is designed to provide equal. and in phase quadrature, amplitude to both dielectric strips. The feeding system consist of using an NRD guide symmetric directional coupler which provides the desired power division to the different feeding structures of the antenna. The circularly polarized antenna was then actually constructed, and its different characteristics were measured at 23 GHz.

The structure and dimensions of the feeding system is the same as that used for the linearly polarized antenna. The radiating structure of the antenna is made of four layers, the metal groundplane, the metal step of the matching circuit, the teflon sheet, and finally the upper

metal plate on which the slot grid is created using etching technology.

The radiation patterns in both planes show very close characteristics to those obtained for the linearly polarized antenna which confirms the validity of the design principle. The measured gain of the antenna is 29 dB for a total radiating area of 160×160mm. Polarization measurements showed that good circular polarization is obtained with an axial ratio of 0.3 dB. The less than 1 dB axial ratio frequency band width is 350 MHz.

Chapter 6 : General Conclusion

In this thesis, a novel application of leaky waveguides which shows their practical use possibilities and enhances their attractiveness for microwave and millimeterwave system realizations is introduced.

Leaky waveguides have so far been very limited in practical use applications despite their frequent investigations in the literature. This thesis describes a new feeding system for microwave planar antennas which is based on a leaky waveguide structure. The purpose of this research was to investigate new methods for the developments of the design of new antenna configurations compatible with the ever progressing microwave and millimeter wave technology.

On the other hand, since its introduction, the nonradiative dielectric waveguide, has developed into a promising transmission medium and integrated circuit technology based on this structure is well established. Millimeter and microwave equipments using this technology are made so compact that the antenna is commonly the most bulky component of the system. Interest has been then stimulated for investigations of new ways to design microwave antennas to meet the new requirements of system realizations. For this purpose, a new leaky wave structure based on the NRD guide was then introduced. And the new leaky NRD guide was then used as the feeding system of a microwave planar slot array antenna.

The highly promising results obtained with the different antennas showed the validity of the design concept of this new feeding system and presented it as a serious candidate for microwave and millimeter wave system realizations.

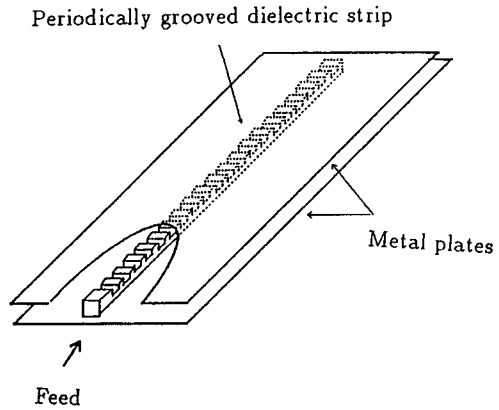

Fig. 1 Structure of the leaky NRD guide.

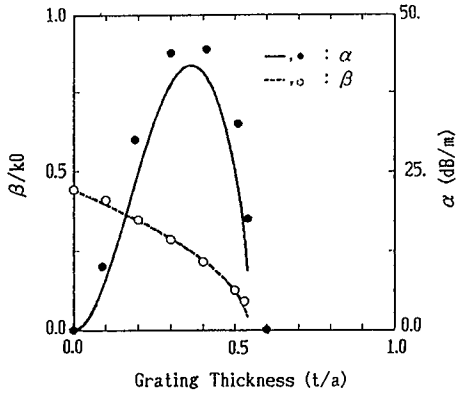

Fig. 2 Typical theoretical and experimental results for the grating parameter dependence of the leakage characteristics.

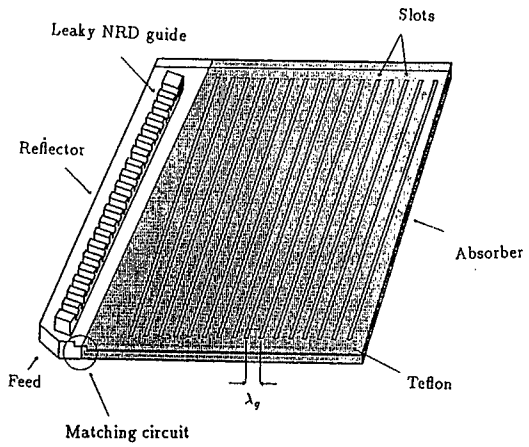

Fig. 3 Structure of the leaky NRD guide fed planar slot array antenna.

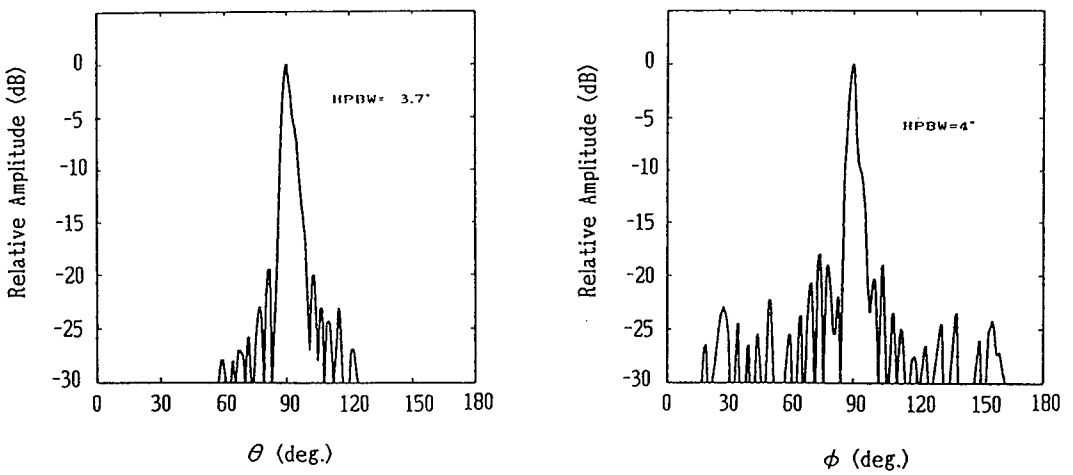

Fig. 4 Measured antenna radiation patterns in the planes parallel (θ) and normal (ϕ) to the slots.

審 査 結 果 の 要 旨

薄型で，利得の高い平面アンテナは，衛星放送受信あるいはレーダなど多様な分野で応用が期待されている。その際，問題となるのは給電系であり，常用されているマイクロストリップ線路などでは伝送損が大きく，所望の特性が実現できない。このような困難を解決するため，著者は，給電系に漏れ波を利用することを提案している。具体的には，ミリ波帯，マイクロ波帯で低損失なNRDガイドに周期的な摂動を設けて漏れ波を発生させ，これにより平面アンテナを励振するというもので，簡単な構造にもかかわらず，高い性能のアンテナが実現できる。

本論文は，漏れ波NRDガイド平面アンテナについて，理論，実験の両面から詳細に検討した成果を取りまとめたもので，全編6章よりなる。

第1章は緒論である。第2章では，モード結合理論に基づいて，漏れ波NRDガイドの特性を解析している。まず，誘電体ストリップに周期的に溝を配列して構成される漏れ波NRDガイドについて，一般的な結合方程式を導き，それを波長に比べて溝配列の周期が小さい場合に適用して，漏れ波の位相定数，減衰定数を与える理論式を導出し，さらに，広範な数値計算を行って，アンテナの設計に有用な多くのデータを得ている。

第3章では，前章で導いた理論式を実験的に検証する目的で，パラメータを種々変えて漏れ波NRDガイドを試作し，24GHzで実験している。その結果，理論と実験はよく一致し，上述の理論式が信頼性の高いものであることを実証している。

第4章では，漏れ波NRDガイド平面アンテナについて，24GHzで実験的に検討している。グレーティングローブの抑制や漏れ波の整合について配慮した結果，放射面寸法290㎜×160㎜のアンテナで，32dBの利得が得られたが，これは漏れ波NRDガイド平面アンテナに関する先駆的成果として高く評価される。

第5章では漏れ波NRDガイド円偏波アンテナについて実験している。放射面はスロット格子からなり，NRDガイド3dB結合器，直交する2本の漏れ波NRDガイドを用いることにより，中心周波数において軸比0.3dBという優れた特性が実現できた。第6章は結論である。

以上要するに本論文は，ミリ波帯，マイクロ波帯で低損失なNRDガイドに，周期的な摂動を設けて漏れ波を発生させ，それによってスロット列を励振するという全く新しい原理による平面アンテナを提案し，その設計理論を確立すると共に，実際に平面アンテナを試作し，その優れた特性を実証したもので，通信工学並びに電磁波工学に寄与するところが少なくない。

よって，本論文は博士（工学）の学位論文として合格と認める。