行政院國家科學委員會補助專題研究計畫成果報告

毫米波影像：前置之基本技術

Baseline MM-Wave RF Front-End Technology for MMV

計畫類別：□個別型計畫　　□整合型計畫
計畫編號：NSC　89--2213－E－009－071
執行期間：88 年 08 月 01 日至 89 年 07 月 31 日

計畫主持人：莊晴光　交通大學電信系　教授
共同主持人：

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- □赴國外出差或研習心得報告一份
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執行單位：國立交通大學

中華民國 90 年 01 月 15 日

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主持人：莊晴光　交通大學電信系教授
計劃參與人員：博士生　胡正南　陳學達
碩士生　何嘉振　陳毓喬林韶正

中文摘要：

本報告經由複雜的全波積分方程計算了微帶線之複數傳播常數及複數特性阻抗。此外　並展示了使用反對稱週期性結構之背向輻射洩漏波天線。

Abstract- This report presents the normalized complex propagation constant and complex characteristic impedance of the microstrip incorporating rigorous full-wave integral equation method. Furthermore, this report also shows a new backward leaky wave antenna employing the anti-symmetric periodic structure.

I. Introduction

The characteristic impedance [1] of a leaky line provides insightful circuit-domain view of the leaky line, thus enabling design of optimal feeding network. Given the propagation constant and the characteristic impedance of the leaky line, microwave circuit description and modeling of the guiding structure are fulfilled.

On the other hand, periodical planar structures had been widely applied in phase-array antennas and frequency-selective surfaces. Recently the stopband characteristics of the two-dimensional, periodical, patterned, conducting surface were employed to develop a high impedance surface and suppress surface waves [2]. New guiding structures however, that mingled a one-dimensional microstrip and a two-dimensional ground plane of periodical pattern, had enlightened many microwave circuit designs which demanded low surface leakage, high-Q reflection, and undesired leaky mode suppression, etc.

A new approach for designing an antenna based on the recent advance in the development of periodic structures. Qian and Itoh reported the propagation characteristics of a uniform microstrip could be altered with noticeable increase in slow-wave factor and a fairly large stopband by simply substituting a ground plane of periodic pattern into a uniform ground plane [3]. The forbidden frequency band is a familiar guiding property for such periodic structure, which prohibits the wave propagation for certain frequency band. Modifying the ground plane symmetry from even to odd pattern and choosing the appropriate microstrip dimension, the resultant microstrip can emit leaky waves when launched by a bound, dominant mode (EH_0) [4].

II. Characteristic Impedance and Propagation of the First Higher-Order Microstrip Mode in Frequency and Time Domain

N. K. Das showed that a three-dimensional circuit made of short-circuit slotline stubs could be modeled accurately by a one-dimensional leaky line when leaky mode plays the dominant role in the microwave circuit [1]. He proposed the definition of the characteristic impedance (Z_c) for a leaky strip-type line by the following expression:

$$Z_c = \frac{P_b}{|I_t|^2} = \frac{\frac{1}{2}\int_s da\,\hat{z}\cdot(\vec{E}\times\vec{H}^*)_{excluding\ leaky\ fields}}{|I_t|^2}, \qquad (1)$$

where I_t is the total modal currents and P_b is the bound-field portion of the Poynting power that excludes the exponentially growing parts of the leaky field in the modal solution of the leaky mode. Das referred to the leaky fields being only loosely attached to the central guiding region that are responsible for distributed radiation loss. Thereby the leaky-fields are not or loosely associated with circuit element in a circuit sense. Unless we experimentally verify the complex characteristic impedance like we did for the microstrip bound mode, there are still doubts about employing the complex characteristic impedance for circuit simulation.

In addition to the presentation of complex characteristic impedance obtained theoretically by Eq. (1) for the first higher-order mode of a microstrip line, this paper applies an experimental setup based on the differential TDR (Time-Domain Reflectometry) to: 1) excite the first higher-order odd mode of the microstrip, 2) explore the corresponding time-domain propagation characteristics theoretically and experimentally, 3) relate the group velocity of the odd mode propagation to the time-domain step response, 4) interpret the broadband time-domain propagation characteristics, and 5) confirm the validity of the definition for complex characteristic impedance. Therefore, the complete circuit level picture of the first higher-order microstrip mode is revealed clearly.

The structural parameters of a microstrip line shown in Fig. 1 are applied for analyses and experiments. The microstrip of width 16 mm is printed on a 30-mil (h=0.762-mm) thick ULTRALAM^{TM} substrate of $\varepsilon_r = 2.55$ and the sidewalls distance b is set equal to 480mm (30W). As shown in Fig.2, the normalized complex propagation constant (γ) of the first higher-order (EH) mode is plotted with vertical scales on the right axis. The real and imaginary parts of the complex characteristic impedance (Re (Z_c) and Im (Z_c)) obtained by the procedure described earlier are superimposed in Fig. 1 with scales on the left axis. Notice that two conducting sidewalls, separated by a distance b, are place at y-direction in Fig.1 in order to facilitate the discrete Fourier series. Because the bound-field energy is bounded around the central guiding region, the complex propagation constant and the complex impedance curves are insensitive to the distance of the sidewalls if such distance (b) is large enough. Extensive numerical studies show that when b is greater than thirty times of microstrip width (30W) in our case study, the sidewalls have negligible influence on the propagating characteristics of the leaky line.

Fig. 3 shows the measured differential TDR step responses, and compares with theoretical data obtained shown in Fig.2. Fig.4, Fig.5 show the propagation constant, the group velocity and that recover from the differential TDR data using theoretical complex impedance. Fig.6 shows Directly recovers Z_c by gating the beginning portions of the differential TDR data and compares this recovered Z_c with that of theoretical one. The differential TDR experiment shows very good agreement between theory and measurement extraction.

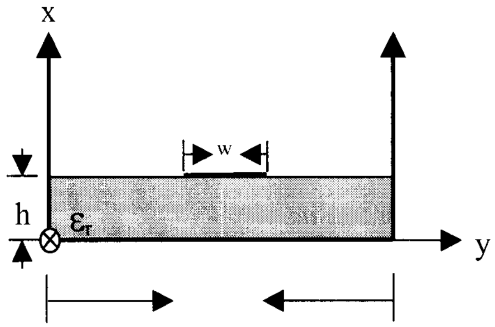

Fig. 1A general microstrip line and coordinate system. Z-axis is along with microstrip line. The structural parameters are used through this paper.

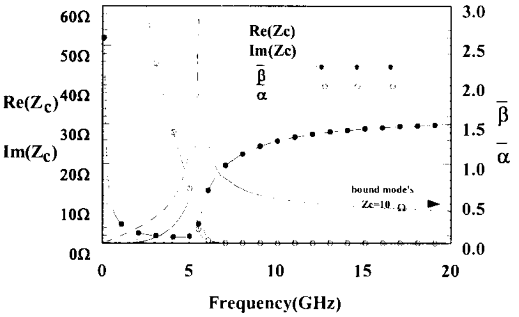

Fig. 2The normalized propagation constant and complex characteristic impedance of the first higher order microstrip mode.

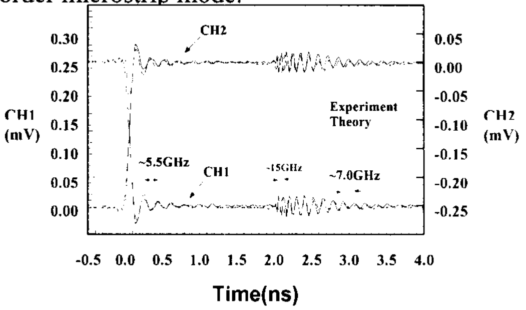

Fig. 3The experimental and theoretical differential TDR step responses of the microstrip. CH1 is the positive-going step voltage, displaying TDR voltage 0 ~ 500mV and corresponding to reflection coefficient ρ= −1 ~ ρ= +1. Similarly, CH2 is the negative-going step voltage, displaying TDR voltage 0 ~ -500mV and corresponding to reflection coefficient ρ= −1 ~ ρ = +1.

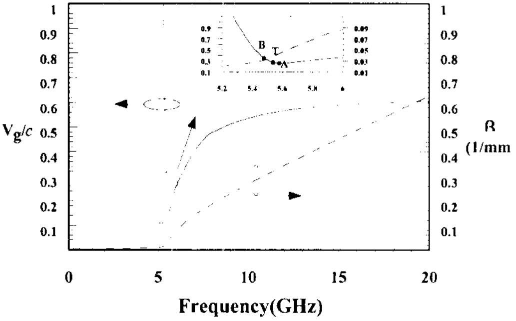

Fig.4 The phase constant (β) and normalized group velocity (V_g/c) of the first higher-order microstrip mode (h=30 mil, w=16 mm, ε_r=2.55)

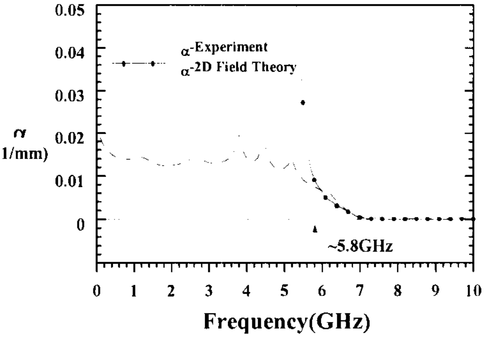

Fig.5 Comparison of the attenuation constants

obtained by differential TDR experiment and the 2D field theory. Noticed that α is not normalized to k_0.

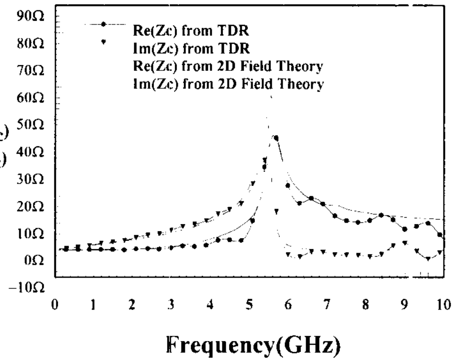

Fig.6 Comparison of the complex characteristic impedance

III. Brillouin Diagram of Microstrip with Symmetric Loadings

Recent advance in planar, two-dimensional, periodical surfaces has demonstrated great potentials for applying the stopband characteristics or leaky waves inherent in these guiding structures. The scattering parameters of microstrip under periodical perturbations by the two-dimensional surface have been applied for various microwave circuit designs. The knowledge of propagation characteristics of planar transmission line on the two-dimensional, periodical surface, however, is very limited. This report presents the theoretical results for the microstrip subject to periodic loadings, which are symmetric or anti-symmetric against the central plane of symmetry.

Without loss of generality, we propose a simplified model that incorporates the inductive loads made of notches positioned in either symmetric or anti-symmetric fashion. Fig. 7 shows the symmetric one. These loadings facilitate the necessary spatial modulation of currents flowing in the uniform microstrip in a similar way made by the two-dimensional, periodical surface. A dominant, bound EH_0 mode is launched at one end of the periodical microstrip structure. The surface currents J_s on the ground plane can be approximated by summing an infinite number of traveling wave components, which include the fundamental forward wave carrying J_0^+ component, the higher space harmonic of the forward wave of current amplitude J_n^+, the fundamental backward wave carrying J_0^- component and the higher space harmonic of the backward wave of current amplitudes J_n^-. The corresponding complex propagation constants are γ_0^+, γ_n^+, γ_0^- and γ_n^-, respectively.

The results show that the microstrip with symmetric loadings consists of four zones of propagation, namely, (1) propagating region below stopband, (2) stopband, (3) propagating region above stopband and (4) leaky-waves region. The microstrip with anti-symmetric loading, on the other hand, displays different propagation characteristics, i.e., (1) disappearance of the stopband, (2) additional leaky waves from excitation of higher-order EH_1 mode. Fig. 8. Shows the Brillouin diagram of the periodic planar guiding structure.

IV. Microstrip on an Anti-symmetrically Perforated Ground Plane

As shown in Fig. 9, the wide microstrip section is 9 mm (w) wide and 153.8 mm (L_1) long. It is printed on a ULTRALAM 2000™ substrate of thickness 0.762 mm (h) and relative permittivity 2.55 (ε_r). Two columns of the etched square holes on the ground plane have fourteen periods each. The periodicity of the etched holes is 12.0 mm (d_2). The tapered microstrip section is relatively long, 14.2 mm (L_2) in length. The total length L_3 of the microstrip is 182.2 mm, which comprises two tapered sections of length L_2 and a wide microstrip of length L_1. Removing the output taper at port 2 of Fig. 9, one develops an open-ended (one-port) leaky line as a line source. The coordinate system of Fig. 9 illustrates the leaky line being positioned along the x axis with the angle θ denoting the elevation angle from the broadside and ϕ the azimuthal angle referenced to the symmetrical plane (x-z plane or y=0). Notice that the positive (negative) sign of the elevation angle θ represents the forward (backward) radiation. Each square hole has the side length of 3.0 mm (d_1). The size and

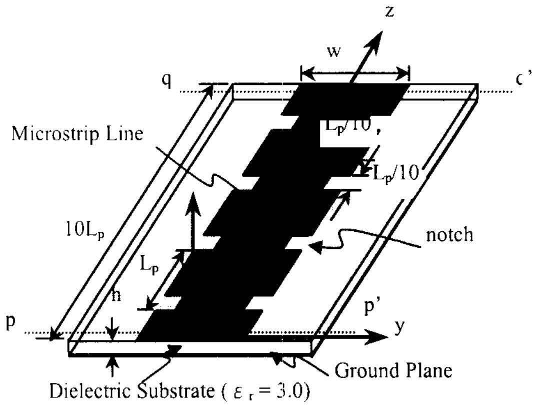

Fig. 7. A generic microstrip model subject t periodical perturbations of even symmetr (w=10mm, h=0.254mm, L_p=15mm, ε_r=3.0).

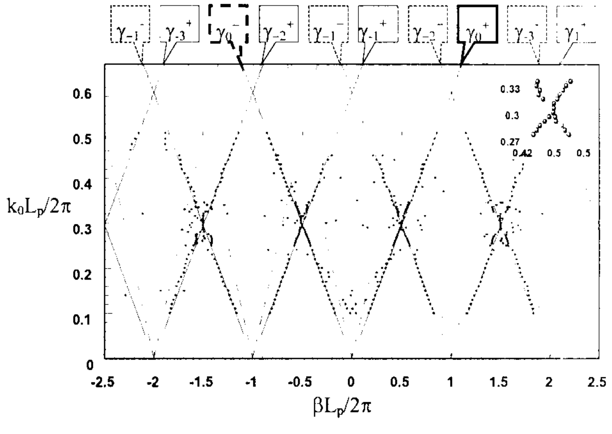

Fig. 8. Brillouin diagram of the periodic planar guiding structure of Fig. 7.

periodicity of the holes is therefore 0.11 λ_0 and 0.46 λ_0 with respect to the free-space wavelength of the operating frequency at 11.5 GHz, respectively. The etched pattern on the ground plane of the guiding structure thus produces weak, periodic perturbations on the modes propagating alongside the guiding structure.

The radiation beam angle of the periodic leaky line with the positive (negative) sign of the elevation angle θ (See Fig. 9) represents the forward (backward) radiation. The theoretical results in Table I indicate that, with magnitude in the descending order, a main beam and a second beam point to the elevation angles at –42° and +59°, respectively. An open-ended leaky prototype is built and tested according to the dimensions and material constant as shown in Fig. 9. The measured radiation contours are plotted in Fig. 10, which shows that the main beam points to –40° and the second beam to +60° in the elevation plane. Therefore the theory presented in the previous section is in excellent agreement with the experimental results. The radiation contours with relative power level below –20 dB have not been shown in Fig. 10. The measured directivity is 15.88 dBi and its 3-dB (half-power) contour spans 64° in the azimuthal direction and 15° in the elevation (See the lower part of Fig. 10). Since the main beam is thin in the elevation angle and wide in the azimuthal plane, we apply such advantageous radiation pattern for a low-profile microstrip array to construct a cone-shaped radiation pattern for use in the indoor WLAN application. Notice that the predominant E_ϕ radiation contour of the leaky line manifests the horizontal polarization of the leaky line. Thus the x-z plane is the H-plane.

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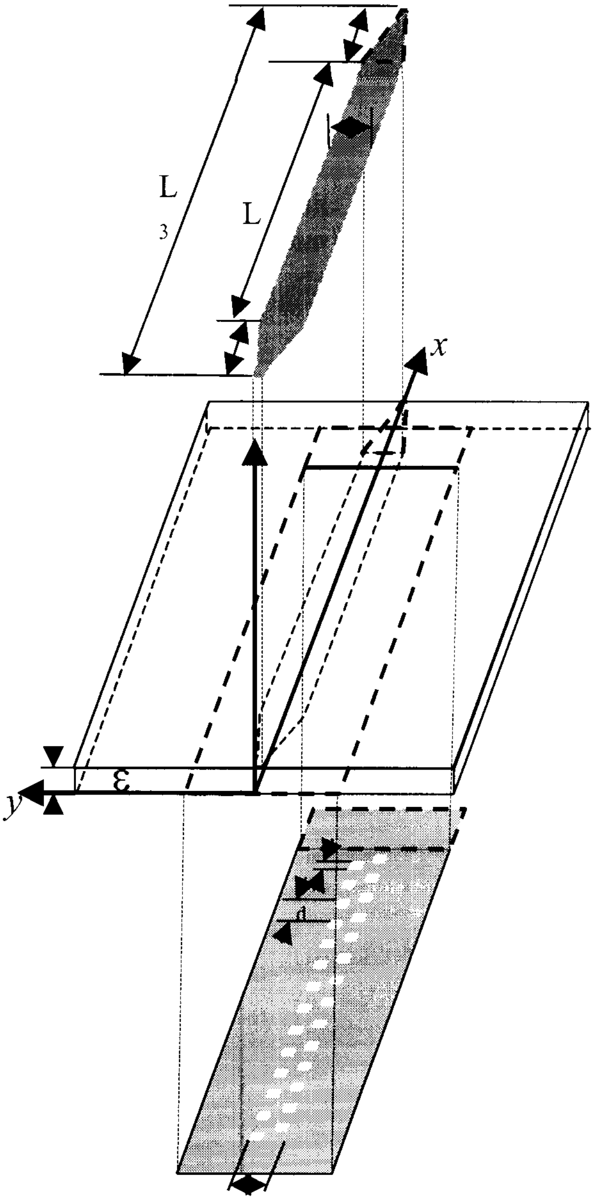

Fig. 9. The structure and coordinate system of the leaky line source with one or two port(s) attached for evaluation.

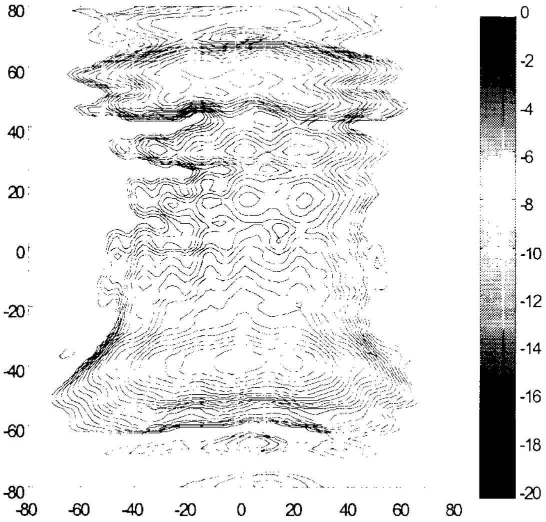

Fig. 10. Measured far-field radiation contour (E_ϕ) of the prototypal single leaky line at 11.5 GHz.

國科會補助專家學者出席國際會議報告

89 年 6 月 21 日

報告人：莊晴光 (國立交通大學、電信工程研究所、教授)

時間及地點：2000/7/5-14；美國劍橋

會議名稱：電磁波研究發展研討會(Progress In Electromagnetics Research Symposium)

發表論文題目(中文)：具對稱及反對稱負載之微帶線之傳導與輻射

發表論文題目(英文)：**Guiding and Radiation Characteristics of Microstrip with Symmetric and Anti-Symmetric Loadings**

一、 參加會議經過

本人此次承蒙國科會補助，得以參加此電磁波領域之重要國際研討會。今年度之電磁波研究發展研討會從 7 月 5 日至 7 月 14 日，爲期十天，於美國劍橋麻省理工學院舉行。此次會議除各相關領域之研討會外，並舉行十一場短期課程。

本人的論文：Guiding and Radiation Characteristics of Microstrip with Symmetric and Anti-Symmetric Loadings，是在 7/6(四)下午的場次 "Recent Advances in Integrated Open Waveguides" 中發表。該場次是由 Prof G. W. Hanson 與 Prof. D. R. Jackson 共同主持，與會人士皆爲當前微波界非常著名之專家學者，如微波週期結構領域的先趨：Prof. A. A. Oliner、Prof. D. R. Jackson、Prof. T. Tamir 等。本人能親身參與，並在會中發表論文，心中至感榮幸。本人首先由單向及雙向週期結構之文獻切入，分析過去所作研究之限制；接著，便提出我們所發明之結構，利用週期性擾動來實現帶拒濾波器，對於對稱負載與反對稱負載所表現出的特性之差異，亦詳細說明其中之物理現象。本人報告後，引起與會人士高度之興趣與關切，紛紛提出問題與意見。在本人一一回答後，許多人均留下了深刻印象。會後，更有聽眾再度向本人表示欣賞與肯定。

二、 與會心得

參加此次電磁波研究發展研討會，除於會中發表論文外，最大的收穫在於能由當前微波領域諸位著名之專家學者的論文報告中，得知此領域研究方向脈動、激發靈感。由這些研究發表中可以深深體會到各個研究團隊均投入大量時間與精力從事研究工作，對於相關領域各種議題之重要性具極高之靈敏性。如何感受到大環境的脈動，掌握時代的潮流，並永遠走在浪潮的先端，我相信有賴於對最新研究文獻的大量且深入的閱讀。對於既定的研究題目，更是要全力投入，不但要與自己的時間競爭，更要與世界上先進國家的研究團隊競爭。

對於研究的發表技巧，也是另外一項此行的收穫。事前充分的準備當然是最重要的因素，然而演說的技巧、生動的肢體語言、清楚的思考脈絡、以及合適

的畫面編排都是重要的關鍵。許多學者在本身的研究上都有很好的成果，但是在表達上就相對非常的吃虧。如何充分表達，而讓與會人士了解並留下深刻印象，有時是具有畫龍點睛的重要性。

三、　建議

此次參加國際會議，發現到一個現象。與會者大多仍是以西方國家爲最多，東方人較少。而東方人中，又以日本參加的人數爲最多。國內參加者，除了工研院、中科院、以及其他廠商企業外，在學的學生幾乎是鳳毛麟角。另外，我們也可以發現到，參加的人數多寡，與該國的研究水準有著很大的關係。參加人數越多的國家，在研究的成果上，無論是質與量，也多相對有較好的表現。其實，參加國際性會議，對於開闊視野、增廣新知、掌握趨勢脈動、甚至是激勵個人熱情與潛能上都有很大的幫助。個人認爲，我們不但應該多多鼓勵在學的研究生出國參加國際性會議，更應該主動積極爭取主辦國際學術會議，創造出更好的研究環境。

四、　攜回資料名稱及內容

1. PIERS 2000 (Progress In Electromagnetics Research Symposium) Digest 一本
2. PIERS 2000 (Progress In Electromagnetics Research Symposium) CD-ROM 一張

Guiding and Radiation Characteristics of Microstrip with Symmetric and Anti-Symmetric Loadings

Y.-C. Chen and C.-K. C. Tzuang
Institute of Electrical Communication Engineering
National Chiao Tung University
Hsinchu, Taiwan

Recent advance in planar, two-dimensional, periodical surfaces has demonstrated great potentials for applying the stopband characteristics or leaky waves inherent in these guiding structures [1]. The scattering parameters of microstrip under periodical perturbations by the two-dimensional surface have been applied for various microwave circuit designs [2, 3]. The knowledge of propagation characteristics of planar transmission line on the two-dimensional, periodical surface, however, is very limited. This paper presents the theoretical results for the microstrip subject to periodic loadings, which are symmetric or anti-symmetric against the central plane of symmetry.

Without loss of generality, we propose a simplified model that incorporates the inductive loads made of notches positioned in either symmetric or anti-symmetric fashion. These loadings facilitate the necessary spatial modulation of currents flowing in the uniform microstrip in a similar way made by the two-dimensional, periodical surface. A dominant, bound EH_0 mode is launched at one end of the periodical microstrip structure. The surface currents J_s on the ground plane can be approximated by summing an infinite number of traveling wave components, which include the fundamental forward wave carrying J_0^+ component, the higher space harmonic of the forward wave of current amplitude J_n^+, the fundamental backward wave carrying J_0^- component and the higher space harmonic of the backward wave of current amplitudes J_n^-. The corresponding complex propagation constants are $\gamma_0^+, \gamma_n^+, \gamma_0^-$ and γ_n^-, respectively

The results show that the microstrip with symmetric loadings consists of four zones of propagation, namely, (1) propagating region below stopband, (2) stopband, (3) propagating region above stopband and (4) leaky-waves region. The microstrip with anti-symmetric loading, on the other hand, displays different propagation characteristics, i.e., (1) disappearance of the stopband, (2) additional leaky waves from excitation of higher-order EH_1 mode.

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