行政院國家科學委員會補助專題研究計畫成果報告

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※ 近光學毫米波影像 ※

※ Quasi-Optical Millimeter-Wave Vision ※

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計畫類別：■個別型計畫　　□整合型計畫

計畫編號：NSC　89－2213－E－009－070

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

行政院國家科學委員會專題研究計劃成果報告

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計劃參與人員 ： 博士生　陳國丞

一. 中文摘要

本報告提出了三種獲得筆狀波束天線陣列之方法：1) 鄰近耦合洩漏模天線陣列；2) 微帶線高階洩漏模反射陣列；3)垂直堆疊微帶線。本報告所提出之高感度筆狀波束天線陣列可用來獲得微波影像。

Abstract

This report proposes three methods to obtain pencil-beam antenna arrays: 1) the closely coupled leaky-mode antenna array; 2) the microstrip leaky-mode reflectarray employing higher-order mode; 3) the vertically stacked microstrips. The proposed pencil-beam antenna arrays with high-resolution patterns are employed to obtain the microwave images.

I. Introduction

Recently we witnessed a rapid growth of wireless communication systems where antennas play a paramount role in establishing a communication link between different destination points. With diversified applications of wireless communications, there has been an increasing demand for high performance antennas for use in the commercial market that a low-cost, low profile, low weight, and more aesthetic antenna is often required. One popular design is the microstrip-array antenna, since it has the above-mentioned desired features. One problem with this type of antenna array, however, is the lack of efficiency when the desirable gain is high. The first study proposes a novel design of microstrip leaky-mode array that simultaneously tackles the two fundamental problems, thus enhancing the antenna efficiency over 80%. Fig. 1 illustrates the proposed,

Besides, reflectarray concept has experienced rapid development using microstrip antenna technology [1]-[4] mandating low-cost, high-gain, and aesthetically pleasing antenna for commercial applications. A printed reflectarray antenna consists of two basic elements: an illuminating feed and a thin reflecting surface that can be either flat or slightly curved.

Furthermore, the complex waves leaky properties of coupled EH_1 modes of the vertically stacked microstrips at Ka-band are presented. The investigation shows that the coupled leaky modes spread out much further in the millimeter-wave band, thus occupying much broader bandwidth than that of a single microstrip. One application to a narrow-beam leaky-wave antenna is discussed, showing that a significant beamwidth reduction of 43% is achieved.

II. Antenna Array Design

A. Coupled-Mode Antenna Design

Considering a single microstrip leaky-mode antenna with a balun matching circuit to excite the EH_1 leaky mode, the input signal is applied at the input end of the balun matching circuit where a T-junction splits the signal into two paths. One travels along a $1/4\lambda_g$ microstrip line while also acting as an impedance transformer. The other travels along a longer path of $3/4\lambda_g$, thus rendering 180° phase delay to the previous path as Fig.1 showing.

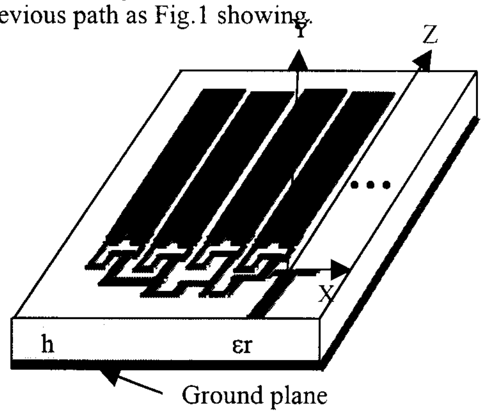

Fig.1 Proposed proof-of-concept design of an eight-element, closely coupled, microstrip leaky-mode antenna array.

There two paths terminate at microstrip of low impedance, respectively, which are the shunt stubs to compensate the inductive part of the input impedance looking into the leaky line. Realization of the compact balun matching circuit needs the quantitative assessment of the characteristic impedance for the microstrip leaky mode to provide insightful circuit-domain view of the leaky line.

B. Measured Results

Fig.2 plots the measured and theoretical far-field patterns corresponding to a single element and an eight-element microstrip leaky-mode antenna array, respectively. Excellent agreement between the theoretical and measured results is obtained near the mainlobe region. The patterns is measured along the H-plane along the y-z cut ($\phi = 90°$) and normalized by the peak value, showing that the back-lobe is greatly reduced from –12 dB (single element) to –25 dB (array).

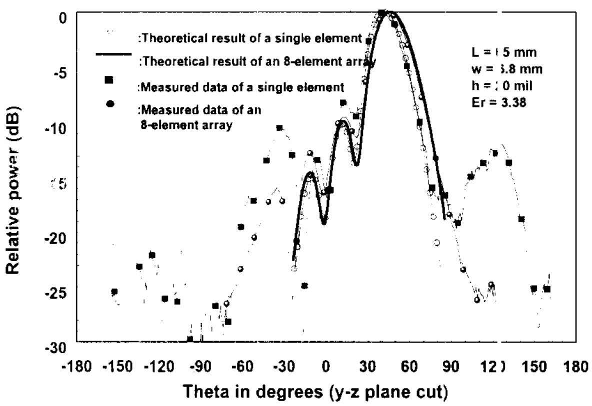

Fig. 2.Measured and theoretical patterns (y-z plane cut) of a single-element antenna and an eight-element array.

C. Reflectarray Design Incorporating Leaky EH_2 Mode

The analysis carried out here uses conventional array theory without considering mutual coupling and full-wave scattering effects. It would not be computationally economical to employ a full-wave technique for hundreds of patch elements. From the conventional array theory, when a two-dimensional planar array with M x N elements is non-uniformly illuminated by a low-gain feed at $\bar{\rho}$, as shown in Fig. 3.

It is has been reported that the corner-fed patch can be viewed as a circuit formed by two perpendicularly overlaid transmission lines that are truncated at the patch length . Such transmission-line circuit model can explicitly show that the leaky mode

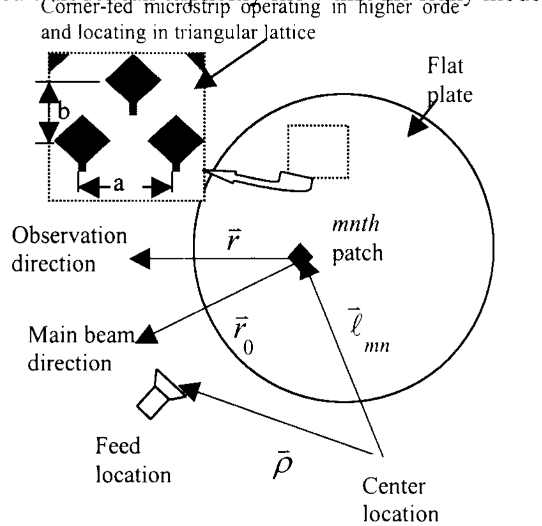

Fig.3 A tilt-beam reflectarray with corner-fe patch resonator incorporating leaky EH_2 mode

is primarily responsible for the resonance, i.e., patch currents displaying decayed two-dimensional standing-wave distributions. This phenomenon closely relates itself to a tilt angle beam, and thus the leaky mode, at the diagonal plane cut, namely, the E-plane. Full-wave integral equation MOM (method of moment) analyses confirm the tilt beam at 15°, validating the use of leaky EH2 mode for the corner-fed patch in the reflectarray design. Thus, the main beam of the array is intentionally cophasal in the desirable direction of 15°/0° (θ°/ϕ°) by using (2).

D. Design Example: 6.3″ Circular Offset Beam Reflectarray at 33.5 GHz

A circular (~6.3″ in diameter) microstrip reflectarray with a broadside feed and a main beam scanned 15° off broadside is built for testing. The prototype reflectarray uses 701 elements with $a = 0.72$ cm and b = 0.36 cm. The radiation patterns measured at 33.5 GHz are respectively given in Fig. 4 (H-plane) and Fig. 5 (E-plane), which show that all sidelobes are well below the designed value of – 22 dB level except for few high sidelobes around the main beam. All the cross-pol radiation in Fig. 3 and Fig. 4, except few cross-pol lobes around –30 dB, are all well below – 35 dB. We also measure the 3dB beamwidth slightly broader in elevation direction since beam scans to 15° off broadside of 3.9°/4.1° (AZ/EL), showing 3dB beamwidth

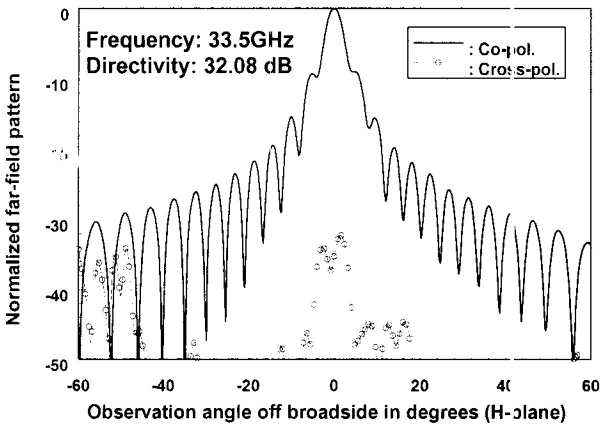

Fig.4 Measured co-pol and cross-po far-field patterns at H-plane

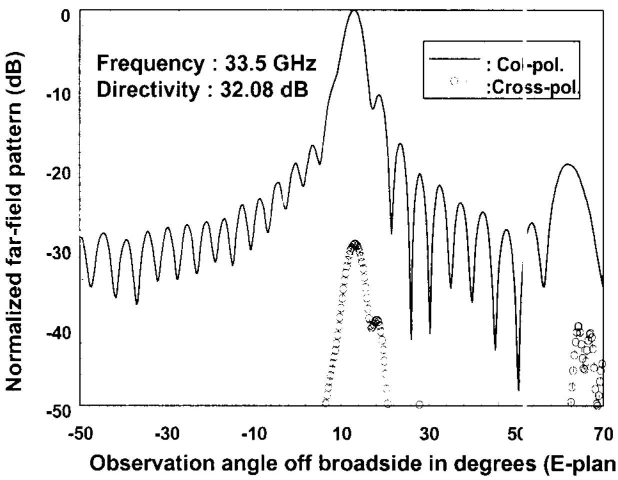

Fig. 5 Measured co-pol and cross-pol far-fiel patterns at E-plane

Measurements indicate the directivity of 32.08 dB and 51% aperture efficient. The efficiency of the prototype could be improved by using a feed antenna with an edge taper close to the optimal value of –10 dB.

E. Coupled EH_1 Leaky Modes of the Vertically Stacked Microstrips at Ka-Band

Fig.6 shows the two microstrip lines stacked vertically which are analyzed by the full-wave integral equation method as reported before [5]. Like the coupled bound modes, the number of coupled higher-order EH_1 leaky modes of Fig.6 is equal to that of the microstrips present in the guiding structure.

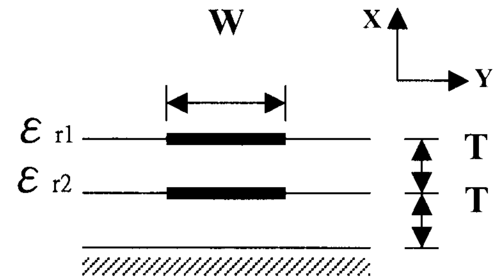

Fig. 6. The cross-sectional view of the verticall stacked microstrips that support coupled leaky modes at higher order.

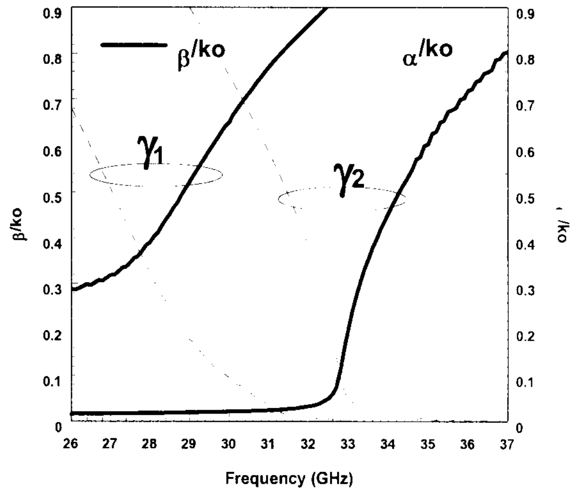

Fig. 7. The normalized phase constants β/k_o (solid line) and the normalized leakage constants α/k_o (dashed line) against frequency of the verticall stacked microstrip lines.

The full-wave solutions for the coupled leaky EH_1 modes are plotted in Fig.7, showing two complex propagation constants γ_1 ($\beta_1 - j\alpha_1$) and γ_2 ($\beta_2 - j\alpha_2$) respectively. The leaky region, from the bandwidth point of view, is enlarged, spanning from 27 GHz to 35 GHz in the Ka-band.

F. Radiation Characteristics of the γ_2 Mode from the Coupled, Stacked Microstrips

Cares must be exercised to excite γ_2 mode of

Fig.6, where the coupled lines are both 120 mm long. A 50 Ω transmission line is power-divided into to two paths abiding the power ration of (0.65). The first path is again evenly power-divided into two paths of 180° phase difference to excite the bottom microstrip. The second path, while properly designed to support differential inputs at the top microstrip, is further delayed by 168°. The resultant radiation pattern along the H-plane is plotted in Fig.8 at 36 GHz, at which β_2/β_o equals to 0.8. Fig.8 shows that the main beam points to θ=23.28° with 6.0° beamwidth; a reduction of 43% beamwidth is achieved as compared to the single microstrip case.

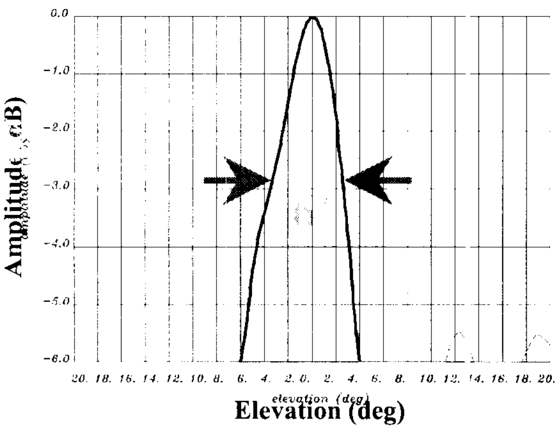

Fig. 8. The measured radiation pattern of th leaky γ_2 mode along the H-plan at 36 GHz.

G. Microwave Images

To obtain more clear microwave images, we should develop higher gain antenna arrays to increase the resolution. Fig. 9 and Fig. 10 show the images of the illuminated one and two metallic strips respectively by the scanning of a rectangular plane employing the pencil-beam antenna array.

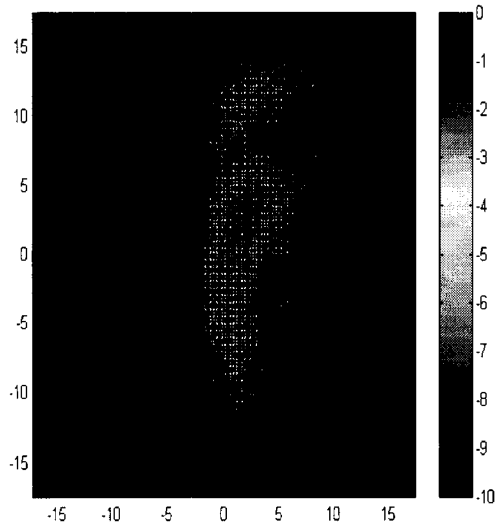

Fig.9 The images of the illuminated one metalli strip.

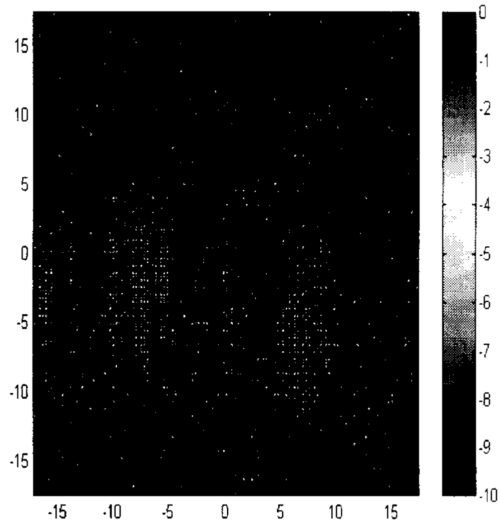

Fig.10 The images of the illuminated two metallic strips.

References:

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[1] J. Huang, "Microstrip reflectarray," *IEEE AP-S Symposium*, pp. 612-615, June 1991.

[2] D. C. Chang and J. M. Huang, "Multiple-polarization microstrip reflectarray antenna with high efficiency and low cross-polarization," *IEEE Trans on Antenna and Propagation,* vol. 43, No. 8, pp. 829-834, Aug 1995.

[3] D. M. Pozar, and T. A. Metzler, "Analysis of a reflectarray antenna using microstrip patches of variable size," *Electronics Letters,* pp. 657-658. April. 1993.

[4] J. Huang and R. J. Pogorzelski, "A Ka-band microstrip reflectarray with elements having variable rotation angles," *IEEE Trans on Antenna and Propagation,* vol. 46, No. 5, pp. 650-656. May 1998.

[5] G.-J. Chou and C.-K. C. Tzuang, "An integrated quasi-planar leaky-wave antenna," *IEEE Trans. Antennas Propagat.*, vol. AP-44, pp. 1078-1085. Aug. 1996.