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本主持人因爲要上課的關係， 當時參加國際會議時(IEEE VTC 2000, Tokyo , Japan , May 2000）， 由本實驗室的博士班同學王健仁代表前往， 可是因爲此國科會計劃規定除了主持人外， 不得報銷費用， 於是我們只得自付去參加了國際會議， 以下附上參加會議的論文·

主持人
周復芳

IEEE VTC 2000, Tokyo, Japan, 5月, 2000

An Active Microstrip Antenna for Satellite Communication

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Abstract - An active microstrip antenna for the satellite communication is developed in this paper. A varactor-tuned oscillator HEMT VCO, an active source, integrates with an X-band two-terminal asymmetrically feeding microstrip leaky-wave antenna on the same plane. This approach creates a dual-beam radiation pattern and has the advantages of multi-direction and suppression of the reflected wave caused by the open end of the radiating element, as compared to a traditionally single-terminal feeding leaky-wave antenna. Measured results on the experimental antenna show that the total scanning angle of two beams of this antenna configuration is approximately 44^0. The maximum Effective Isotropic Radiated Power (EIRP) are close to 17.5 dBm for the right beam and 16.67 dBm for the left beam at 10.4 GHz, and the power difference between the two beams is less than 1 dB. An asymmetrically beam-scanning leaky-wave antenna is also shown in this presentation

I. Introduction

Active microstrip planar antennas for the application of the satellite communication have been investigated and developed in the recently past years [1]-[2]. Fig.1 show the function of the active microstrip antennas of the satellite communication. Generally, the patch arrays are usually used in these systems. The scanning angle range is the drawback in patch arrays. It is necessary for patch arrays to scan wider that the structure is complicated and large. The cost of the specified antenna circuits is expensive and complicated and the whole size is also large. In order to perform a dual-beam scanning ability, two antenna arrays may be necessary. Here, a simple active dual-beam scanning antenna (see Fig. 2) by integrating a varactor-tuned HEMT VCO with the simple microstrip two-terminal feeding leaky-wave antenna is developed and demonstrated. Using this configuration, a dual-beam radiation pattern is created. We adjust the varactor DC bias voltage and tune operating frequencies to control the dual-beam position. Another advantage of this design is the suppression of the reflected wave due to the unmatched load of the open end of the leaky-wave in finite-length situation. Although the reflected wave can be suppressed by the array topology [3] or the longer length[4], this balanced matched load of two ports design can be thought as a matched load on both sides of the open end in this circuit; thus, this two-port design can suppress the reflected wave.

II. Design

The configuration of the active dual-beam scanning leaky-wave antennas (see Fig.2) is fabricated in this paper. We employed rigorous (Wiener-Hopf) solution mentioning by [5], to obtain the normalized complex propagation constant $\beta - j\alpha$ of the first higher order mode in its leak range for the leaky-wave antenna, where β is the phase constant and α is the attenuation constant. The variations in β/k_0 and α/k_0 with frequency are plotted in Fig. 3. k_0 is the free-space wave number. Leaky-wave antennas are operated in the radiation region, and the normalized phase constant β/k_0 is less than 1. θ can be calculated using the equation $\theta = Cos^{-1}(\beta/k_0)$, where θ is the elevation angle between the main-beam direction and the end-fire direction. We can use the characteristic of the variation of β as a function of the frequency to predict and change the scanning angle θ.

The circuit uses 0.508 mm thick RT/Duriod substrate with the relative permittivity ϵ_r =2.2, and a NE42484A low-noise GaAs HEMT is used as the oscillator device. The HEMT VCO, the matching circuit, and a two-terminal asymmetrically feeding leaky-wave antenna are integrated on the same plane. To excite the first higher order mode, this microstrip leaky-wave antenna is fed asymmetrically. The width W and the length L of the leaky-wave antenna are 11 mm and 15 cm, respectively.

III. Results

By adjusting the bias voltage of the varactor, the free-running frequency of the HEMT VCO can be varied from 9.7 GHz to 11.3 GHz. Under the far-field condition, a measured EIRP of 17.5 dBm for the right beam of this active antenna is observed at 10.4 GHz, and the EIRP of the left beam is 16.67 dBm at the same frequency. According to the equation $\theta = Cos^{-1}(\beta/k_0)$, we calculate and plot the theoretical beam-scanning radiation patterns (see Fig. 4) of this the active dual-beam scanning leaky-wave antenna. Fig. 5 shows the comparison of the theoretical and the measured radiation patterns for this microstrip dual-beam leaky-wave antenna operated at 10.4 GHz. Fig. 6 presents the measured dual-beam scanning far-field radiation pattern of this microstrip leaky-wave antenna for three frequencies, 9.7 GHz, 10.4 GHz, and 11.3 GHz. Measured result shows that the total scanning angle is 44^0, from 24^0 to 46^0 for the right beam and from 128^0 to 150^0 for the left beam. The measured scanning angles of the active two-beam scanning leaky-wave antenna for different frequencies are plotted in Fig. 7.

IV. Conclusion

An X-band active dual-beam scanning leaky-wave antenna has been developed. We successfully make use of this two-terminal feeding topology of the active leaky-wave antenna to create a dual-beam radiation pattern, and vary the frequency of the HEMT VCO, to control a dual-directional scanning beam. This antenna design can be useful in the satellite communication system, the mobile collision-avoidance system, and the personal communication system (PCS) due to the wide scanning region; meanwhile, it can also be easily implemented into the monolithic array module.

Acknowledge: This paper was supported by the National Science Council (NSC), Taiwan, R.O.C. under "Quasi-optical solid-state active beam-scanning antenna arrays" , NSC 88-2215-E009-099.

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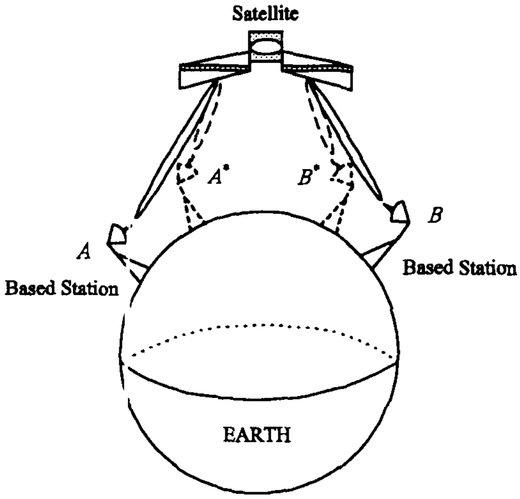

Fig. 1 The function of the active microstrip antennas of the satellite communication.

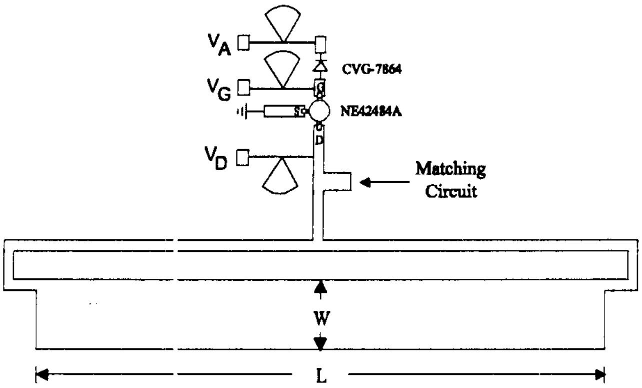

Fig. 2 Configuration of the active dual-beam scanning leaky-wave antenna.

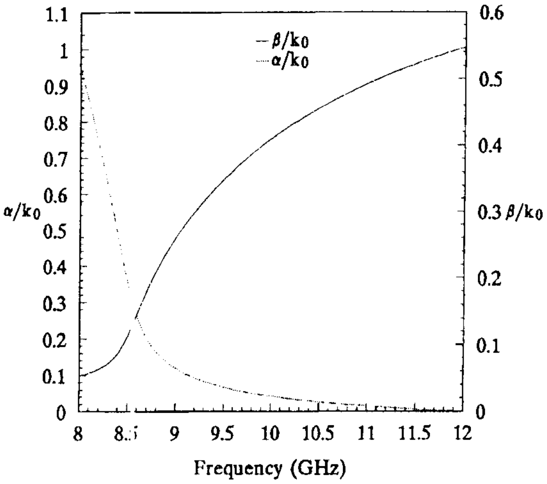

Fig. 3 Normalized complex propagation constant of the first higher order mode for the particular microstrip leaky-wave antenna. H=0.508 mm, W =11mm, and $\varepsilon_r = 2.2$. k_0 is the free-space wave number.

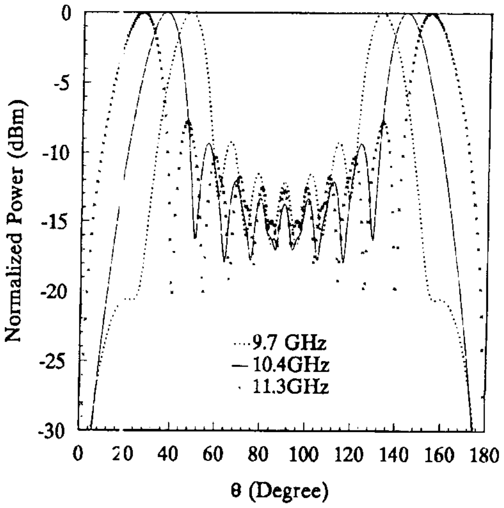

Fig. 4 The theoretical radiation patterns of the active dual-beam scanning microstrip antenna at 9.7 GHz, 10.4 GHz, and 11.3 GHz.

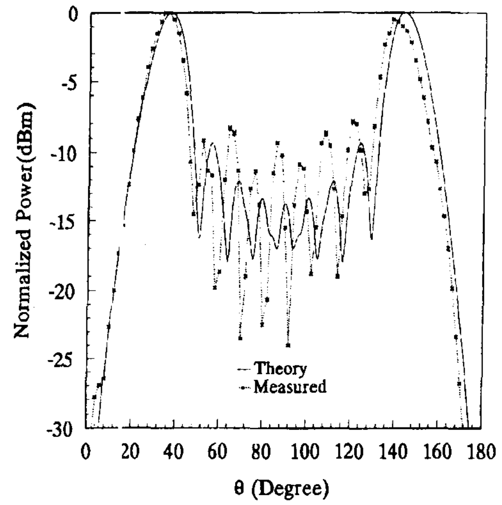

Fig. 5 A comparison of the theoretical and the measured radiation patterns for this microstrip two-beam leaky-wave antenna operated at 10.4 GHz.

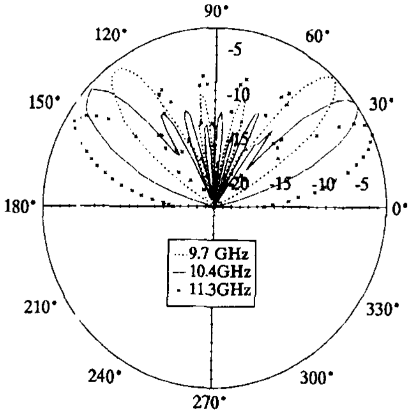

Fig. 6 The measured polar radiation patterns of the active dual-beam scanning microstrip antenna at 9.7 GHz, 10.4 GHz, and 11.3 GHz.

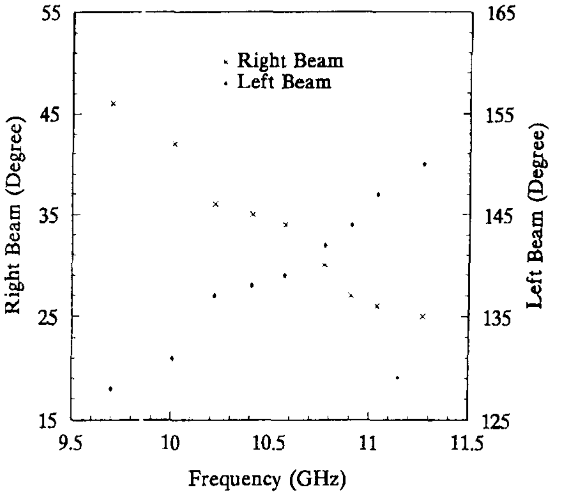

Fig. 7 The measured scanning angles of the active two-beam scanning leaky-wave antenna for different frequencies.

行政院國家科學委員會補助專題研究計畫成果報告

混光學固態掃描式主動天線陣列
Quasi-Optical solid-state Beam-Scanning Active Antenna Arrays

計畫類別：□個別型計畫　■整合型計畫
計畫編號：NSC 89-2213-E-009-056
執行期間：88 年 8 月 01 日至 89 年 7 月 31 日

計畫主持人：周復芳　交通大學電信工程系研究所副教授

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執行單位：

中華民國 89 年 10 月 23 日

混光學固態掃描式主動天線陣列
Quasi-Optical solid-state Beam-Scanning Active Antenna Arrays

計劃編號: 89-2213-E-009-056
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主持人: 周復芳
交通大學電信工程系研究所副教授

一、 中文摘要

本計劃共有三個模組，用以解決傳統波導系統在收發微波及毫米波訊號時所遇到的困難。相較於波導系統，準光學功率耦合主動微帶天線陣列(Quasi-Optical Power Combining Active Microstrip Antenna Array)提供了下列優點：(1)增加短天線的有效長度(effective length)及增益(gain)；(2)改善信號的噪音指數(noise factor)；(3)減小體積及重量；(4)降低每個陣列元件之間的互耦效應(mutual coupling between array elements)；(5)增加微波訊號源的輸出功率與效率；(6)主波束窄(narrow beam-width)。基於上述優點，可以看出主動元件(HEMT、MESFET、Gunn Diode)加上被動天線陣列可以改善天線的 performance，且由於單晶微波積體電路(MMIC: Monolithic Microwave Integrated Circuit)技術日趨成熟，未來將主動元件必須和被動天線接合(integrate)在同一塊基板上，這使得主動天線陣列成為熱門的研究課題[1][2]。

在第二年的計劃中, 我們完成下列三項目標,(1)利用已完成了 HEMT VCO ，並搭配匹配網路，與本實驗室所設計的單根被動掃瞄式天線結合，完成單根主動電子掃瞄式平面天線後，利用陣列分析法去設計多根天線陣列，使得主波束(Main Beam)在較好的反射波壓制下，完成一大角度的主動掃瞄式固態天線。(2)設計新的饋入方式使的掃瞄角度獲得雙倍的效果，同時也可得到壓制反射波效果。(3) 我們利用主動元件製作出穩定振盪的微波源 ，並利用出饋入結構，結合放大器電路，完成回授放大器主動天線，藉由控制天線架構而使該天線的反射波束獲得有效壓制。

關鍵詞：單晶，波束掃瞄，行進波天線，洩漏波天線，主動天線陣列，反射波束。

Abstract

In this project there are three main modules, which is employed in the smaller antennas, wider bandwidths, and better resolution for imaging and radar system. Compared with waveguide system from the microwave to millimeter wave spectrum the active antenna array has the advantages of the lake compact, reliable, high power solid-state source at these wavelengths. The advances in device technology make wafer-scale integrated power combining sources very attractive. In addition, free-space power combining is more efficient at high frequencies than power combining in guided wave structure, and transmitting and receiving system based on monolithic implementation have the potential to be smaller, lighter.

Quasi-optical techniques spurred the development of active integrated power combined in 1980's 1990's. As the operating frequency increases, the available power from solid state device decrease. Therefore, power combining of solid-state devices using quasi-optical techniques in the millimeter wave region became an important issue. There are two different approaches for quasi-optical power combining. One is the active antenna approach and the other is the grid approach.

The advantage of active antenna is: (l) increasing the effective length of short antenna (2) increasing the band-width (3) decreasing the mutual coupling between array elements (4) improving the noise factor.

The active antenna fabricated on Duroid substrates with a dielectric constant of 2.2 and thickness of 20 mils is successfully demonstrated in the 1997 project. From the forgoing advantages, we can see active devices and passive patch antenna fabricated on the same substrate can improve antenna performance. The technology of monolithic microwave active integrated circuit is mature, and makes the approach more promising.

We accomplish the three purposes desired in the second year plan. (1) We combine the accomplished HEMT VCO and match network with the single antenna element simultaneously. Then we design the antenna array by array analysis. Main beam can scan wide angle in the process of good suppressed reflected wave. (2) The new feeding type obtains the double scanning angle and the good suppression of the reflected wave. (3) We accomplish the active feedback amplifier antenna by combining the stable oscillator source and feedback structure with the amplifier circuit. The good controlling the antenna structure can also obtain the suppression of reflected wave.

Keywords: monolithic, beam scanning, traveling wave antenna, leaky-wave antenna, Reflected wave

二、 計劃緣由與目的

近年來外國若干研究機構發表許多研究報告，如 Itoh[3]、York[4]，顯示出功率整合、波束集中及波束指向性，均為目前國內外研究的重點。在一般研究中，多數是在主動天線陣列的模組中加入移相器(phase shifter)使各個天線間的相位不同，再經耦合效應使得主波束有掃瞄功能[5]。但因移向器製作不易且複雜，使得電路成本昂貴費時，因此製作不需移向器即可掃瞄的主動天線陣列已是眾多研究機構努力的方向[6][7]。在本文中，我們將發展無移向器之主動掃瞄式天線陣列研究，更進一步提高天線效率、增益及掃瞄角度.

三、 研究方法和成果

3-1 材料

所用的基版為 RT-Duroid，ε_r=2.2，厚度 20mil(貳，參)。ε_r=10.2，厚度 25mil(壹)。電晶體是用 NEC 公司所生產 NE42484 HEMT，varactor Diode 則是用 M/A –COM MA46410 和 ALPHA CVG 7864。

3-2 電路設計

壹：主動電子掃瞄式平面天線陣列

根據電晶體振盪器的理論確定 VCO 的架構後，結合 HEMT 電壓控制振盪器以及相同操作頻率的洩漏波天線。並加上匹配電路其電路結構如圖(一)所示。接著我們使用了 T-type power divider 搭配 HEMT 主動調變振盪器去設計 1X2 和 1X4 的天線陣列如圖(二)所示。

量測天線遠場的環境如圖(三)所示，使用儀器為 HP8563E 頻譜儀及 X-band 標準 horn antenna(16dB 增益在 10GHz)。在遠場條件下 H-plane 天線場型如圖(四)所示。同時也使用 Friis transmission 方程式來計算 EIRP(effective isotropic radiated power)。

$$EIRP \equiv P_tG_t = \frac{P_r}{G_r}\left(\frac{4\pi R}{\lambda_0}\right)^2$$

Pt :從洩漏波天線發射能量
Pr :從標準 horn 天線接受能量
Gt :洩漏波天線的增益
Gr :標準 horn 天線的增益
λ_0 :free space 的波長
R : 洩漏波天線和標準 horn 天線的距離

我們可以發現 EIRP 在 1X1 天線陣列有 18.67dBm 而在 1X2 和 1X4 的天線陣列下有 20.67 和 20.83dBm 的能量。我們發現洩漏波天線陣列比單根的洩漏波天線高 2 和 3.16dB。而且這種架構只需一個 active source 減少電路面積並增加所需之能量。當陣列元素越多，反射波瓣 (reflected back lobe）同時的被抑制。

貳：雙波辦掃描主動洩漏波天線

在衛星通訊系統上，一個主動的洩漏波天線常被應用在掃頻元件，在此我們設計一個雙端饋入洩漏波天線如圖(五)和 HEMT 的電壓控制振盪器整合並搭配一個 T-type power divider 如圖(六)去形成雙波辦的掃瞄。我們在電壓控制振盪器輸出加上匹配電路去匹配洩漏波天線輸入阻抗。當 varactor 電壓由 1 volts 到 11 volts，varactor 電容值由 11pf 降至 0.3pf，電壓控制振盪器頻率由 9.7GHz 變動至 11.3GHz。而雙波辦也會跟著頻率做同步掃描。

在遠場條件下（如圖三）量測 H-plane 天線場型如圖(七)所示。我們可以發現在 9.7 ，10.4 和 11.3GHz 下量測的掃描角度，右波辦在 46，34 和 24 度而左波辦在 128，140 和 150 度。而 EIRP 在 10.4GHz 下右波辦有 17.5dBm 而左波辦有 16.67dBm。這也說明雙波辦掃描主動洩漏波天線在衛星通訊系統上其應用如圖（八）。

參：回授放大器(feedback-amplifier)主動天線

在洩漏波天線設計上，由於 open-ended 架構形成反射波辦輻射(reflected back lobe radiation），如何減輕反射波辦輻射(reflected back lobe radiation)是個重要問題。在此處我們介紹如何在不增加長度的狀況下，使用 taper-ended 架構並整合回授放大器和頻率合成器來減低反射波辦輻如圖(九)所示。Taper-end 架構在洩漏波天線尾端減少造成反射波辦的不連續處。

在遠場條件(圖三)下，洩漏波天線整合回授放大器 H-plane 天線場型如圖(十)所示，整合回授放大器 H-plane 天線場型如圖(十一)所示。 由量測結果可發現主波辦和反射波辦在 9.25GHz 下相差 15dB 以上，而頻率合成器在 9.25GHz 到 9.37GHz 的內使得洩漏波天線約有 5 度的掃瞄角度。這種架構有著窄主波辦，壓低反射波辦和減短洩漏波天線長度的優點。

四、 結論與討論

（1） 微帶洩漏波天線與振盪器結合時，在做阻抗匹配時要小心考慮，因為並非如預期般在相同共振頻率輻射。

（2） 雙波辦掃描主動洩漏波天線未來可再利用陣列設計法去得到更大的角度掃瞄

（3） 天線陣列在設計上須考慮 in-phase 和 在天線正確的操作 mode 上振盪和幅射

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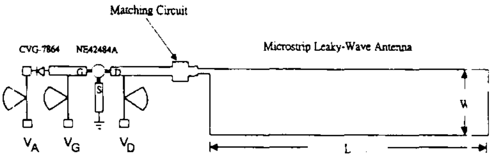
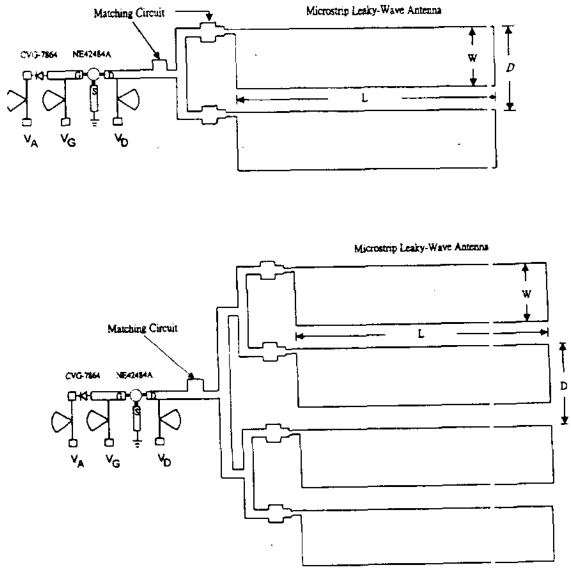
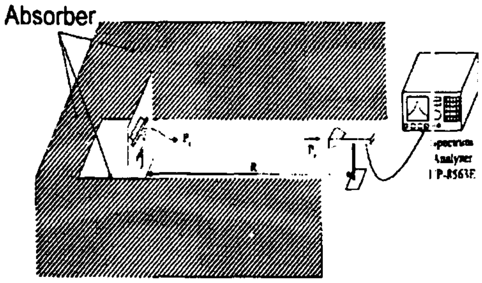
率合成器所量測之遠場 H-plane



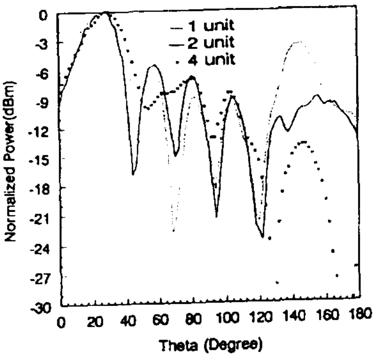
圖(一) 結合電壓控制振盪器的單根洩漏波天線 W=0.42cm L=6.734cm



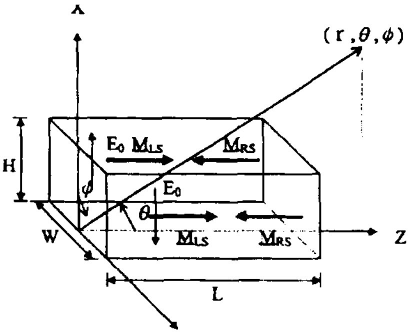
圖(二) 1X2 和 1X4 洩漏波天線陣列 D=0.7λ_0



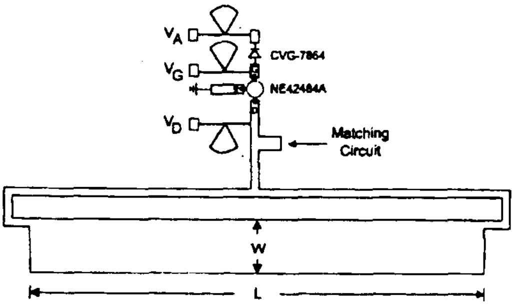
圖(三) 量測天線遠場的環境設定



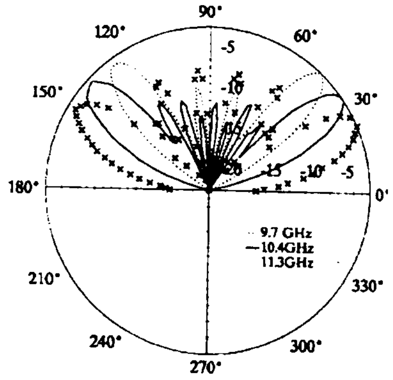
圖(四) 在 10.2GHz 1X1,1X2,1X4 主動洩漏波天線 H-plane 遠場場型量測



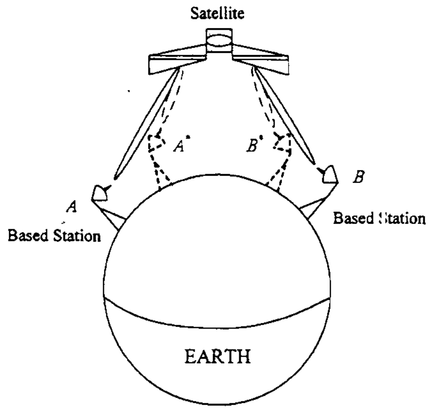
圖(五) 雙波辦洩漏波天線架構



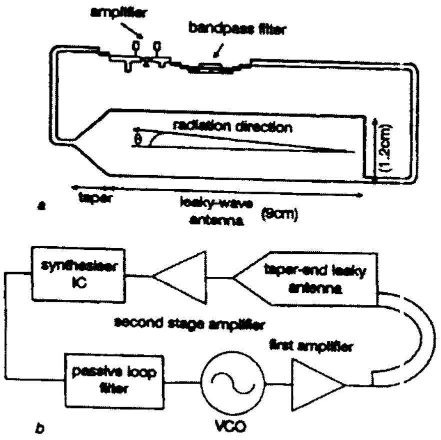
圖(六) 雙波辦掃描主動天線架構



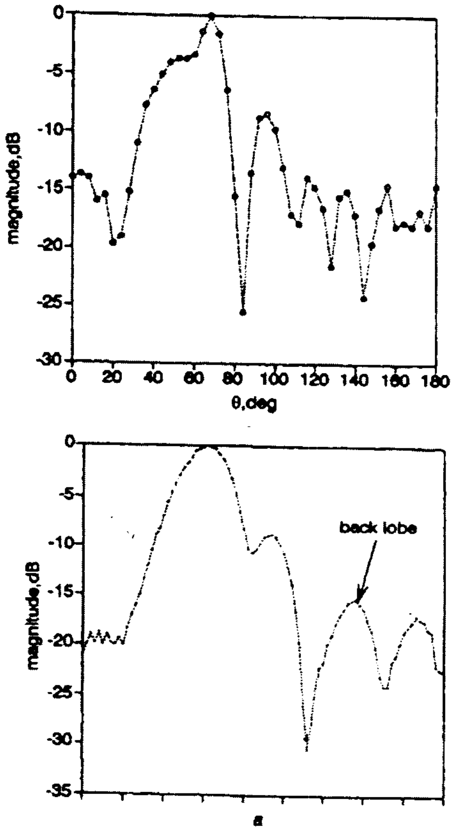
圖(七) 量測雙波辦掃描主動洩漏波天線的遠場場型(X-Z plane)



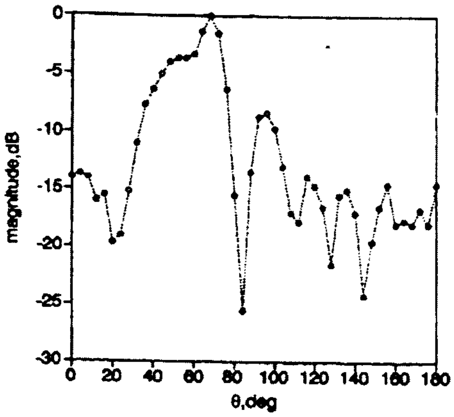
圖(八) 雙波辦掃描主動洩漏波天線的應用



圖(九) 整合主動洩漏波天線和回授放大器, 回授頻率合成器架構



圖(十) 整合主動洩漏波天線和回授放大器所量測之遠場 H-plane



圖(十一) 整合主動洩漏波天線和回授頻率合成器所量測之遠場 H-plane