行政院國家科學委員會專題研究計畫 成果報告

共面波導饋入介質透鏡天線
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 95-2218-E-002-056-
執 行 期 間 ：95 年 09 月 01 日至 96 年 07 月 31 日
執 行 單 位 ：國立臺灣大學電信工程學研究所

計畫主持人：陳士元

計畫參與人員：碩士班研究生-兼任助理：汪秉孝、施佑霖

處 理 方 式 ：本計畫可公開查詢

中 華 民 國 96 年 08 月 01 日

行政院國家科學委員會補助專題研究計畫 ■ **成 果 報 告**
□**期中進度報告**

共面波導饋入介質透鏡天線

Coplanar Waveguide-Fed Dielectric Lens Antenna

計畫類別：■ 個別型計畫　　□ 整合型計畫
計畫編號：NSC 95-2218-E-002-056
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計畫主持人：陳士元　　國立台灣大學電信工程學研究所
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計畫參與人員：汪秉孝、施佑霖

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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中　華　民　國　九十六　年　八　月　一　日

行政院國家科學委員會專題研究計畫成果報告

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I. 中文摘要

本研究計畫中，吾人設計並實作出一工作於 37 GHz 頻段之共面波導饋入介質透鏡天線。設計時，為了預測延伸式半球形介質透鏡之遠場輻射場形，吾人亦發展出一簡化之近似計算方法。我們先將整個介質透鏡表面分成四個區域分別討論，發現只有其中一個表面區域需要被考慮，利用該區域的表面等效波源並套入遠場積分公式，便可輕易計算得到其遠場輻射場形。透過與實作天線量測結果之驗證，我們所提出的近似方法雖然簡單卻也十分準確，相信對於未來延伸式半球形介質透鏡天線之設計者將有所裨益。

關鍵詞：共面波導、介質透鏡、遠場積分、高增益天線

II. ABSTRACT

A simple method to approximately calculate the far-field pattern of an extended hemispherical dielectric lens is proposed in this project. The entire lens surface is divided into four regions, of which only one is considered in our simplified method. By applying the far-field integral to the equivalent sources on that surface region, radiation patterns in the E- and H-planes can thus be obtained. Although the presented method is simple and approximate, satisfactory agreements are obtained through a 37-GHz prototype lens antenna.

Keywords: coplanar waveguides, dielectric lens, far-field integral, high-gain antennas.

III. INTRODUCTION

To achieve high radiation performances, such as high gain, pencil beam, and low side-lobe level, the dielectric lens antenna has been one of the most popular candidates, especially at millimeter- and submillimeter-wave frequencies [1]-[6]. The dielectric lens also has been often used to eliminate the substrate or surface-wave modes of planar antennas due to the finite thickness of the dielectric substrate used [4]-[6]. In addition, printed antennas placed on dielectric lenses tend to radiate more power into the lens side and reduce the backward radiation [7]. According to [8], the ideal shape of a dielectric lens is an ellipsoid. However, the elliptical dielectric lens is impractical regarding its complexity of fabrication. The extended hemispherical dielectric lens, which can be designed to approximate the ideal elliptical surface, is used throughout this project instead of the elliptical dielectric lens simply because of its simple structure.

In this project, a simple method to approximately predict the radiation pattern of the extended hemispherical dielectric lens is presented. The method is mainly based on that discussed in [4]. The main difference is that only the central part of the lens surface is considered and the corresponding surface integrals are taken to facilitate the far-field integral. With this method, a 37-GHz prototype lens antenna is designed, implemented, and tested. Satisfactory agreements between the predicted and measured results are obtained.

IV. LENS DESIGN

The geometry of an extended hemispherical dielectric lens is shown in Fig. 1. The upper part is a hemisphere of radius *R*, while the lower part is a cylinder of the same radius *R* and of length *L*. By properly choosing *L* and *R*, the upper hemispherical surface well approximates the ideal elliptical lens surface with the focus located at the origin. The feed antenna, which in most cases is of the printed type, is attached to the bottom of the dielectric lens and centered at the origin. Since the distance from the feed antenna to any point on the dielectric lens surface is always chosen to satisfy the far-field condition, the feed antenna is regarded as a point source located at the origin. Therefore, the far-field pattern of the specified feed antenna describes how it illuminates the lens surface. The illuminating fields radiated by the feed antenna are then decomposed into the TE and TM components to facilitate the analysis. The corresponding transmission formulas needed to obtain the equivalent sources just outside the dielectric/air interface are:

$$\begin{cases} \Gamma_{TE} = \dfrac{\sqrt{\varepsilon_r}\cos\theta_i - \sqrt{1-\varepsilon_r \sin^2\theta_i}}{\sqrt{\varepsilon_r}\cos\theta_i + \sqrt{1-\varepsilon_r \sin^2\theta_i}} \\ \tau_{TE} = 1 + \Gamma_{TE} \end{cases} \quad \ldots\ldots(1)$$

$$\begin{cases} \Gamma_{TM} = \dfrac{\sqrt{\varepsilon_r}\sqrt{1-\varepsilon_r \sin^2\theta_i} - \cos\theta_i}{\sqrt{\varepsilon_r}\sqrt{1-\varepsilon_r \sin^2\theta_i} + \cos\theta_i} \\ \tau_{TM} = \left(1 + \Gamma_{TM}\right)\dfrac{\cos\theta_i}{\sqrt{1-\varepsilon_r \sin^2\theta_i}} \end{cases} \quad \ldots\ldots(2)$$

where ε_r is the dielectric constant of the lens material, θ_i is the angle of incidence from the normal of the lens surface, and Γ and τ are the reflection and transmission coefficients for the TE and TM polarizations.

Once the electric and magnetic fields have been found, the equivalent electric and magnetic current densities are calculated just outside the lens surface using:

$$\vec{J}_S = \hat{n} \times \vec{H} \quad \ldots\ldots\ldots(3)$$

$$\vec{M}_S = \vec{E} \times \hat{n} \quad \ldots\ldots\ldots(4)$$

where $\hat{n}$ is the outward normal to the interface. In the far-field, the transverse electric field is equal to:

$$E_\theta = -\frac{jke^{-jkr}}{4\pi r}\left[L_\phi + \eta N_\theta\right] \ldots\ldots(5)$$

$$E_\phi = +\frac{jke^{-jkr}}{4\pi r}\left[L_\theta - \eta N_\phi\right] \ldots\ldots(6)$$

where $\vec{N}$ and $\vec{L}$ are defined by:

$$\vec{N} = \iint_{s'} \vec{J}_S e^{+jkr'\cos\psi} ds' \quad \ldots\ldots(7)$$

$$\vec{L} = \iint_{s'} \vec{M}_S e^{+jkr'\cos\psi} ds' \quad \ldots\ldots(8)$$

where *s’* is the closed surface just outside the lens, *r’* is the distance from the origin to the source point, *r* is the distance from the origin to the observation point, and ψ is the included angle between *r’* and *r*. The far-field pattern of the dielectric lens antenna can be determined using (1)-(8). To simplify the surface integrals taken in (7) and (8), we will neglect the surface regions that are not dominant in the far-field radiation.

V. DIVISION OF LENS SURFACE

The entire surface of the extended hemispherical dielectric lens except the bottom part is divided into four regions as shown in Fig. 2. The surface of the upper hemisphere is composed of regions 1 and 2, while that of the lower cylinder is composed of regions 3 and 4. Note that these regions as well as the lens structure are rotationally symmetric to the z axis. They are described in detail as follows:

A. Region 1

This is the main region responsible for the far-field radiation and is therefore the only one being taken into consideration in our simplified method. Within this region, rays from the origin are partially reflected and partially transmitted at the dielectric/air interface. From the geometry of Fig. 1, the following relation holds between θ and θ_{in}.

$$R\sin(\theta_{in}+\theta)=[R\cos(\theta_{in}+\theta)+L]\tan\theta$$

When $\theta_{in}=\theta_c=\sin^{-1}\left(1/\sqrt{\varepsilon_r}\right)$, which is the critical angle of total reflection, we reach the boundary between regions 1 and 2.

B. Region 2

Within this region, rays from the origin are totally reflected at the dielectric/air interface. As shown in Fig. 3, direct rays illuminating region 2 are totally reflected and would be totally reflected more than once by the hemispherical surface until going back to the cylindrical part. Although the fields just outside the dielectric/air interface of region 2 are not zero, they are evanescent fields that contribute very little to the far-field radiation. Therefore, they are neglected in this work.

C. Region 3

Similarly, total reflection occurs throughout region 3, which is a portion of the cylindrical surface. The total reflected rays may contribute to the lens radiation. However, the feed antenna is usually designed to have a sharp main beam for better illumination, and the field intensity radiated by the feed antenna degrades rapidly as the angle θ increases. Therefore, those rays totally reflected by region 3 are insignificant and also neglected in our analysis.

D. Region 4

As the angle θ increases beyond the region 3 boundary, where θ and the critical angle θ_c are complementary, or $\theta = 90° - \theta_c$, partial reflection and partial transmission occur at the dielectric/air interface of region 4. However, since this region is illuminated by the weakest field intensity part from the feed, which has a negligible effect on the lens radiation, we omit radiations from region 4 as well.

VI. FEED ANTENNA

A uniplanar hybrid-slot array antenna fed by a coplanar waveguide (CPW) is proposed in this project and used as the feed antenna for the dielectric lens. The geometry of the antenna is depicted in Fig. 4. It is fabricated on the alumina substrate with dielectric constant ε_r = 9.9, loss tangent $\tan\delta$ = 0.0005, and thickness h = 0.254 mm. Only one layer of metallization is used, on which the feeding CPW, the radiating slotline sections, and the interconnecting slotline sections are etched.

All the horizontal slotline sections of

dimensions $L_1 \times W_1$, $L_2 \times W_2$, or $L_3 \times W_3$ function as the radiating elements in the proposed design. The lengths L_1, L_2, and L_3 equal approximately a half guided-wavelength of the slotline at resonance, while the widths W_1, W_2, and W_3 are used to control the amplitude distribution of the slot array. To minimize the side lobes, the width of the central radiating slotline sections W_2 is determined to be much wider than the others leading to a quasi-binominal excitation of the radiating slotline sections. On the other hand, all the vertical slotline sections act as the feeding networks. To ensure the in-phase excitation of all radiating elements, the lengths of the vertical sections D_1 and D_2 are set to be slightly shorter than a guided-wavelength of the slotline at resonance. The widths G and w are chosen to be as narrow as possible to suppress the cross-polarized radiation. With the chosen slot width G, the central strip width S of the feeding CPW can then be determined to make the characteristic impedance 50Ω.

The arrangement of the radiating slotline sections results in very similar radiation patterns in the E- and H-planes (or yz- and xz-planes). The half-power beamwidths in both planes are about 52°, indicating that an effective illumination can be achieved through the presented feed antenna. On the other hand, the proposed uniplanar hybrid-slot array antenna radiates a broadside bidirectional pattern. However, using a high-permittivity dielectric substrate, say the alumina, can greatly reduce the front-to-back ratio of the bidirectional feed pattern [7].

VII. RESULTS

An extended hemispherical dielectric lens using the aforementioned feed antenna was designed at 37 GHz and implemented. The dielectric material of the lens is the polypropylene with dielectric constant ε_r = 2.35. Dimensions of the lens, R = 50 mm and L = 80 mm, are determined by means of our simplified method.

The measured input return loss response of the 37-GHz prototype lens antenna is plotted in Fig. 5. Although the response shifts to lower frequencies than as expected, the input matching condition remains satisfactory near 37 GHz. According to the definition of 10-dB return loss, the impedance bandwidth of the prototype lens antenna is about 6.5% ranging between 34.3-36.6 GHz.

The calculated and measured radiation patterns at 36.6 GHz for the prototype lens antenna are compared and shown in Fig. 6. Reasonable agreement between them can be observed. It is obvious that the discrepancy between the measured and calculated E-plane patterns is larger than that of the H-plane patterns. The main reason may be that the structure and the field distribution of the feed antenna are less symmetric in the E-plane than in the H-plane. In addition, the flange of the K-connector, the feeding cable, and the test fixture required in the experimental setup are electrically large in size and all influence the E-plane pattern of the feed antenna. The measured peak gain is about 28.0 dBi at 36.6GHz.

VIII. CONCLUSION

In this project, a simplified method for calculating the far-field pattern of the extended hemispherical lens has been presented. In this method, the lens surface excluding the bottom face is divided into four regions, among which only one region is taken into calculation. The effectiveness of this simple method has been demonstrated through a 37-GHz prototype lens antenna. The feed antenna used is the proposed hybrid-slot array antenna having similar E- and H-plane patterns. The measured and predicted radiation patterns for the prototype lens antenna are in good agreement.

IX. REFERENCES

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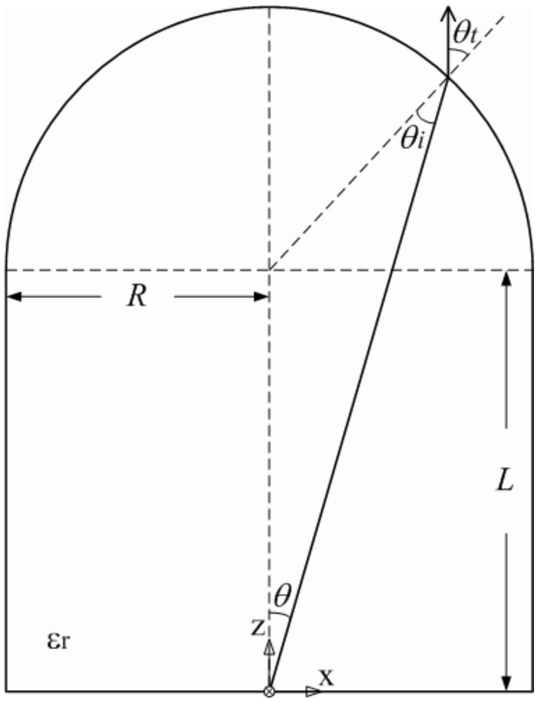

Fig. 1. Geometry of the extended hemispherical dielectric lens.

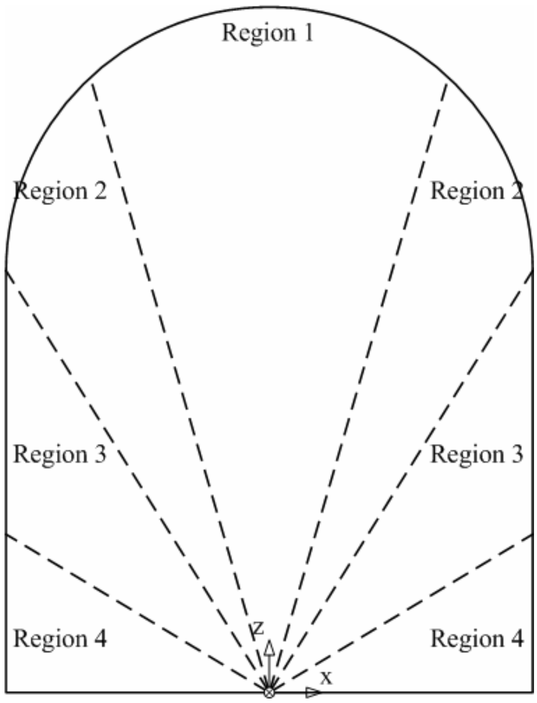

Fig. 2. Surface regions of the extended hemispherical dielectric lens.

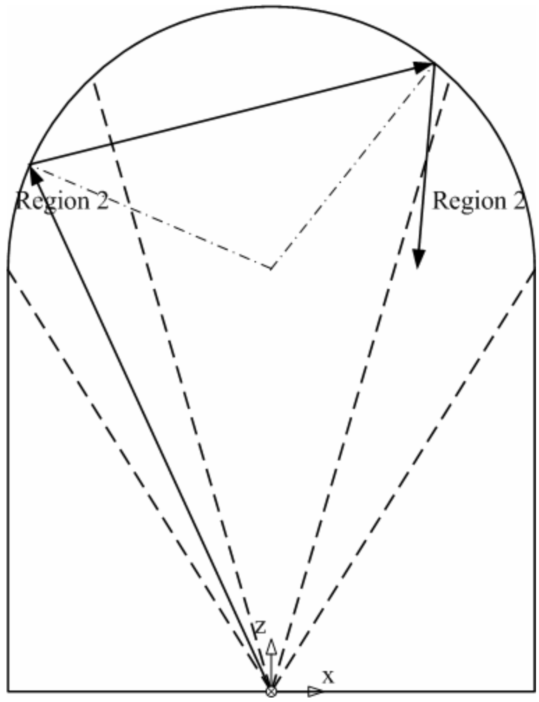

Fig. 3. Illustration of a ray totally reflected by region 2.

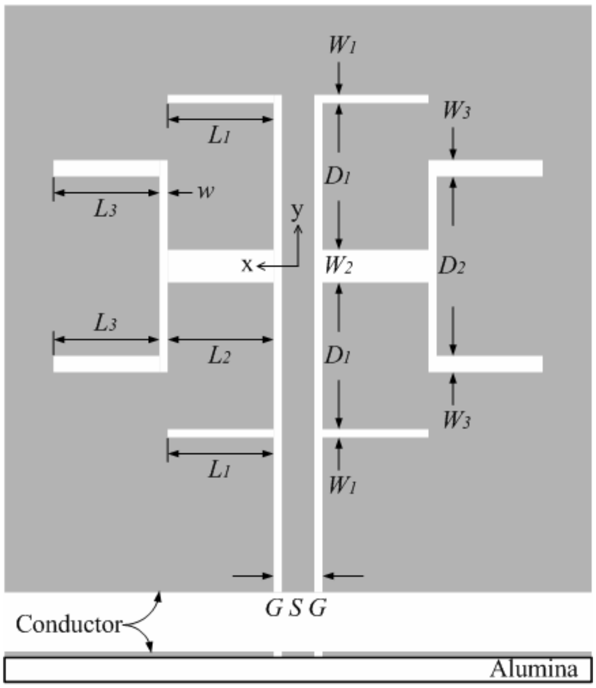

Fig. 4. Geometry of the proposed uniplanar hybrid-slot array antenna.

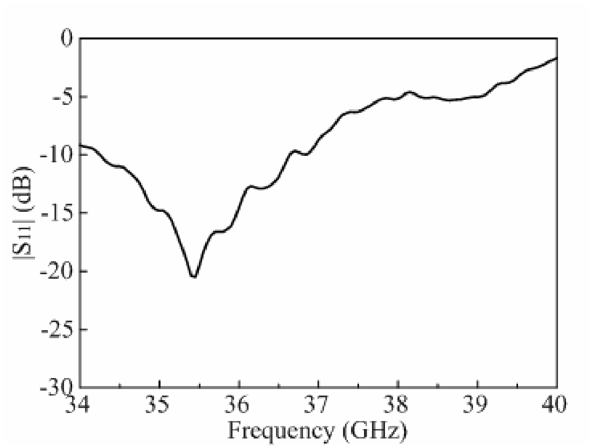

Fig. 5. Measured input return loss response of the prototype lens antenna.

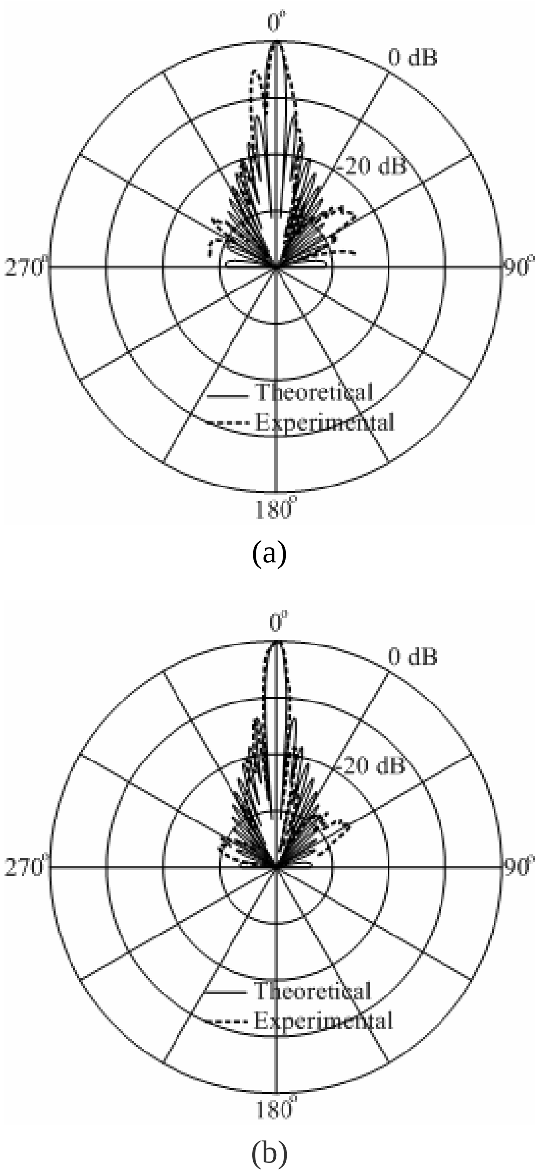

Fig. 6. Measured and calculated radiation patterns of the prototype lens antenna. (a) E- and (b) H-plane patterns.

計畫成果自評

本計畫之研究成果與原計畫完全相符，滿足預期目標且依照原訂進度完成。

最核心的研究成果有二，其一為實作出工作於 37GHz 頻段之共面波導饋入介質透鏡天線。由於該頻段天線在實作與量測上面臨許多困難及挑戰，本人所指導之研究生於計畫執行的過程中可因而習得相關的知識與技術經驗，對於國內發展下一代無線通訊技術產業，應能有所貢獻。

其二為吾人所提出之簡化設計方法。由於目前的數值電磁技術及商用套裝軟體仍無法有效地分析介質透鏡天線，吾人所提出之近似計算方法便顯得重要，利用該方法可以簡單且迅速地設計出延伸式半球形介質透鏡天線，且具有相當的準確度。

本計畫之研究成果預計將發表於 2007 年 12 月的亞太微波會議 (Asia-Pacific Microwave Conference, Bangkok)[1]。在此之前，吾人亦將所發展出的相關高頻天線技術整理發表於 2007 年 3 月的 URSI/SRS Radio Science Conference [2]與 2006 年 11 月的天線與傳播國際研討會 (International Symposium on Antennas and Propagation, Singapore) [3]。

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可供推廣之研發成果資料表

☐ 可申請專利　　■ 可技術移轉　　　　　　　　　　日期：96 年 8 月 1 日

國科會補助計畫	計畫名稱：共面波導饋入介質透鏡天線 計畫主持人：陳士元　國立台灣大學電信工程學研究所 計畫編號：NSC 95-2218-E-002 -056　學門領域：電信、電磁
技術/創作名稱	共面波導饋入介質透鏡天線之設計
發明人/創作人	陳士元　國立台灣大學電信工程學研究所
技術說明	中文： 吾人提出簡單的方法以設計延伸式半球形介質透鏡天線，首先將整個介質透鏡表面分成四個區域討論，我們發現只有其中一個區域需要被考慮，其他區域則可忽略，利用該區域表面的等效波源並套入遠場積分公式，便可輕易計算得到其遠場輻射場形。 英文： A simple method to approximately calculate the far-field pattern of an extended hemispherical dielectric lens is presented in this project. The entire lens surface is divided into four regions, of which only one is considered in our simplified method. By applying the far-field integral to the equivalent sources on that surface region, radiation patterns in the E- and H-planes can thus be obtained.
可利用之產業及可開發之產品	寬頻無線傳輸、衛星通訊等相關產業 點對點、點對多點之寬頻無線通訊系統天線、無線網路骨幹基地台天線等
技術特點	由於介質透鏡天線具有高增益之效能，且相較於其他高增益天線，其製作成本較低，且機械強度高。加上吾人所提出的簡單設計方法，將可大幅簡化此類天線之設計，促進其廣泛應用。
推廣及運用的價值	吾人所提出的近似計算方法雖然簡單卻也十分準確，相信對於未來延伸式半球形介質透鏡天線之設計者將有所裨益。

※　1. 每項研發成果請填寫一式二份，一份隨成果報告送繳本會，一份送　貴單位研發成果推廣單位（如技術移轉中心）。

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