行政院國家科學委員會專題研究計畫 成果報告

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※ **「40-48 GHz 超寬頻無線模組及電路技術」總計畫** ※

※ **(1/3) (2/3) (3/3)** ※

※ Research of 40-48-GHz Ultra Wide Band Wireless Module and Circuits ※

※ **(1/3)(2/3)(3/3)** ※

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「40-48 GHz 超寬頻無線模組及電路技術」總計畫 (1/3)(2/3)(3/3)

Research of 40-48-GHz Ultra Wide Band Wireless Module and Circuits **(1/3)(2/3)(3/3)**

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一. 中文摘要（關鍵詞：單晶微波積體電路、降頻器、升頻器、收發模組。）

本計畫執行時間為三年，在計畫執行期間，元件模型、電路設計及佈局、晶片製作、測試與收發模組均已完成。在計畫執行三年中，使用現有的單晶微波積體電路和高頻電路板設計組裝單一的模組，如天線、轉接器、濾波器、升頻器、降頻器與中頻訊號處理電路。每各單一模組之間使用高頻同軸線或Q頻段導波管相互連接，以達成收發模組的功能，同時並以中科院的基頻視訊模組做傳送測試，以驗證每個單一模組之設計規格是否滿足40-48 GHz無線收發模組之要求。

Abstract (Keywords： MMIC, Downconverter, Upconverter, Transceiver module.)

In this three-year project, device modeling, circuit design, layout, chip fabrication, testing and transceiver module have been completed. In the three years, we developed the key components, including the antenna, transition, up converter, down converter, local oscillator, and IF circuits, for the 40-48-GHz wireless transceiver applications. Some Coaxial lines and Q-band waveguides are used to connect the modules to complete a transceiver module, and the transceiver module is tested by transmitting the baseband video signal to prove the specifications of the each unit module for a 40-48-GHz wireless transceiver module.

二. 計畫緣由與目的

無線收發電路在無線通訊系統扮演很重要的角色，其主要功能為射頻訊號與基頻訊號的轉換器，其應用範圍可為通訊、雷達和遠端控制[1]-[3]。本計畫預備研究及設計製作 40-48 GHz 之無線收發模組及關鍵元組件技術。主要關鍵元組件技術包含有天線、共面波導與微帶線濾波器、共面波導轉接器之研製、升降頻電路之研製與放大晶片設計和中頻積體電路及後製程研究等相關技術。

三. 研究方法與結果

總計畫

本計畫成功設計製作 40-48 GHz 相關的元組件，項目包括有天線、轉接器、濾波器、放大器和升降頻器等相關晶片，圖一為 40-48 GHz 無線收發系統圖，根據系統鏈結參數，我們定出每一元件的規格，並且設計製作相關的晶片與元件。接著我們利用自行開發的晶片，來組裝並製作完成 40-48-GHz 之超寬頻無線收發模組，其發射器與接收器的照片分別如圖二與三所示。收發模組之操作頻率範圍在 40 GHz 至 48 GHz 間，發射機傳送功率大於 0 dBm 以

上，接收機靈敏度小於-70 dBm 以下。

此 40-48 GHz 毫米波無線模組與中科院的基頻(Baseband)與中頻(IF)電路模組做整合測試，完成了影像傳送展示平台，圖四為中科院的基頻與中頻電路模組，圖五可以看到網路攝影機的影像，經過中科院基頻電路模組的調變，載到 40-48 GHz 毫米波無線模組作發射與接收後，影像能清楚傳送並顯示在電腦上。

為了把業界 3-5 GHz 商用的 UWB 系統提升到毫米波頻段來應用，我們與瑞昱(Realtek)公司合作，我們把瑞昱提供的 3-5 GHz UWB 系統模組當作是中頻(IF)，與我們的 40-48 GHz 毫米波無線模組做系統整合測試，圖六與圖七可以看到瑞昱 3-5-GHz UWB 模組透過 PCMCIA 介面卡與筆記型電腦連接，之後利用我們 40-48-GHz 毫米波無線收發模組，把訊號升頻發射並接收降頻，最後由瑞昱提供的測試軟體來量測封包錯誤率(Package Error Rate)，圖八是 Multi-band OFDM Band 1 訊號在毫米波的輸出頻譜，圖九是量出來的封包錯誤率，可以看到在速率低時(<400Mbps)，可以達到 0%的錯誤率，在高速 480Mbps 距離一公尺時也可以達到 0%的錯誤率，但在 480Mbps 距離兩公尺時錯誤率開始增加，不過這已滿足 UWB 系統的要求。

各子計畫的研究成果分述於下：

子計畫一：寬頻共面波導天線

於本子計畫中，提出了一個適用於毫米波平面式超寬頻之圓極化天線。此天線是利用印刷電路板(PCB)以及一圓柱形共振腔來實現此原型天線。2×2 之陣列天線乃採用循序式相位 90^{o}，且旋轉每個單元並搭配一饋入網路來實現寬頻之 3-dB axial ratio。

此天線之寬頻特性包含 10-dB 的反射損耗頻寬超過 36%、穩定且高之天線增益約為 9~11dBic、極化之隔離(cross polarized)約為 20dB、 front to back ratio 約為 25dB 左右以及 3-dB axial ratio 之頻寬超過 30%。

於製作方面，已可完全於國內製作完成，此計畫之後可大幅提升國內於毫米波之研製能力。且毫米波之量測暗室已建置完成，對於往後相關毫米波元件之研製，將有很大的幫助[4]。

子計畫二：平面濾波器

本子計畫以髮夾型並接共振器為基礎，利用其產生傳輸零點的特性，使低通濾波器擁有更低的止帶響應，完成了一個超寬頻微帶線四階低通濾波器。

再以$\lambda/4$短路截線段為基礎，完成一個適用於第一操作模態的五階超寬頻帶通濾波器，以及一個適用於全部操作模態的六階超寬頻帶通濾波器。而此兩種$\lambda/4$短路截線段帶通濾波器，亦使用了步階阻抗來得到更好的高頻抑制。同時利用巧妙的摺疊與縮短短路截線段的技巧，使整體電路面積大大的縮小至原來的二分之一。使得這種濾波器具有頻帶寬、低止帶響應以及小面積的特性，相當適合應用在微波積體電路中。

在毫米波濾波器的研究方面，本研究以平行耦合線共振器為基礎，同時設計並製作濾波器所需之外部金屬封裝，完成了系統所須之毫米波五階微帶線帶通濾波器模組。所有的製作及組裝過程皆在國內實驗室完成，其成果可與其他主、被動元、組件之研究配合，相輔相成，因此於提升國內無線通訊毫米波電路技術的目標上，此成果相當具有學術與實用的重要性。

本子計畫接著藉由引入間隙電容與對地並聯電感兩種元件，並以$\lambda/4$型耦合線共振器為基礎，另完成一個新式平行耦合型微帶線帶通濾波器。此濾波器除了擁有傳輸零點改善頻率選擇度外，並可藉由調整平行耦合線的長度，來提高假通帶響應發生的頻率，而擁有更

好的止帶響應。本研究另實現了毫米波共面波導帶通濾波器，成功的避開使用貫穿孔的程序而達到所需之帶通濾波器響應 [5]-[31]。

子計畫三：超寬頻平面電路與轉接的最佳化

本研究中提出了各種不同結構之間的轉接設計、製作、以及理論、模擬與量測結果之間的比較。包含了微帶線至矩形波導管的轉接設計、平面電路之間鎊線轉接的設計、以及微帶線到介質合成波導之間的轉接。

微帶線至矩形波導的轉接的部分，利用微帶線饋入後耦合至槽線，再從槽線傳至天線，輻射至波導管完成能量傳遞。不需用到任何連通柱或空氣橋，即可達成寬頻的轉接設計。鎊線轉接的部分，本研究提出了分別設計串接殘株匹配式轉接、多段串接殘株匹配式轉接、以及縱橫式補償轉接等三種不同的轉接補償結構。此外本研究亦使用多層的低溫供燒陶瓷來製作微帶線至基板合成波導的轉接，基板合成波導保有傳統矩型波導的優點，也容易與平面電路整合，相當適合用來製作毫米波頻段的系統。利用 LTCC 製程所製作的轉接結構當頻率上升時，介質損耗也會跟著提升，到 60 GHz 時，插入損耗會增加大約一倍，因此若是未來希望製作在更高的頻率上，必須使用損耗較小的基板製作，才可能在高頻上滿足實際應用的需求。

子計畫五：超寬頻射頻收發電路之研製

升降頻電路晶片，主要是利用國家晶片製作中心所提供的半導體製程來進行設計，其電路包括有升降頻混波器、低雜訊放大器、功率放大器和單刀雙擲開關，每一電路包括有微帶線和共面波導版本。每個電路的中心操作頻率以 40-48 GHz 為準。經實晶圓測試，低雜訊放大器(一)，其增益大於 15 dB 以上，其反射損耗大於 9 dB，雜訊指數為 5.5 dB。低雜訊放大器(二)，其增益大於 25 dB 以上，其反射損耗大於 8 dB，雜訊指數平均為 7.5 dB。大輸出功率的 18.5-GHz 二倍頻器，量測的轉換增益最高為 9 dB (輸入信號頻率為 7.5 GHz)，量測的效益最高為 17.5% (輸入信號強度為 5 dBm)。33-50 GHz 次諧波主動混波元件，當 LO 功率等於 15 dBm 時會有最大的轉換增益，RF 到 LO 和 LO 到 RF 的隔絕度(Isolation)，量測結果均大於 40dB。量測轉換增 35-45 GHz 有大於 -6.5 dB 的轉換增益(Conversion Gain)。此混波器的 P1dB 為-6dBm。

本子計畫成功的實現了一個頻段 40-48-GHz 超寬頻射頻收發機所需的電路研製。經實際量測，這些電路可滿足收發模組之系統要求。由本計劃產出的論文有 19 篇，請參閱文獻[32]-[50]。

子計畫六：超寬頻系統整合及發射器線性化技術

本子計畫研製了毫米波頻段之單晶體電路與線性化電路。積體電路之製程使用 CIC 以及穩懋公司所提供之 0.15 微米之高速場效電晶體(HEMT)之製程。本計劃所研製之單晶積體之電路，包括放大器、混頻器及線性化電路。

我們在計畫的第一年中，已成功地研製出毫米波 40-48GHz 功率放大器與混頻器，並且針對毫米波放大器提出一線性化電路。而第二年的研究成功地整合線性化電路與功率放大器，並將這些積體電路完成封裝，使用在系統測試上。在第三年的計畫中，配合總計畫系統整合及測試，並針對線性化的電路設計加以改善，其中包括寬頻放大器、功率放大器及混頻器。以上單晶積體電路皆已完成量測，並獲得不錯的成果。

在計畫執行的三年間，有七篇國際期刊論與七篇會議論文[51]-[64]。

子計畫七：毫米波超寬頻量測技術

在本子計畫中所提之多模 TRL 校準方法

由於假設多模傳輸線中各模態的傳播常數須不同，並不適合使用於一般使用相同傳輸線的多埠網路。針對使用相同傳輸線的多埠網路，在第一年我們發展了新的 TLS 校準方法可以處理具有相同傳播常數的狀況，此時由於傳播常數及線長均相等，因此必須處理相同特徵值 eigenvalues 及特徵向量 eigenvectors 時的矩陣計算，相當的複雜。由於特徵值為傳播常數及線長的乘積，因此若能使用不同長度的線段，即可使得特徵值不相同，而大幅簡化計算複雜度。

本研究提出了擁有高製程變異容忍度之耦合電感。為了驗證我們所提出的耦合電感確實能在系統中發揮他們的效果，我們將其用來實現傳輸零點與單頻帶帶通濾波器之電路。用我們所提出的耦合電感來設計傳輸零點之電路時，即使有上下層不對正 50 微米的情況發生，傳輸零點的位置也幾乎沒變，只有的＋2.8%至-1.4%之間的變化。比起由傳統的耦合電感去實現電路時，傳輸零點位置劇烈變化從+11.5%至-8.6%的情況實在好了很多[65]-[69]。

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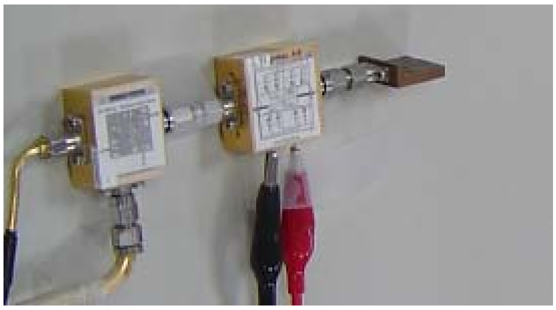
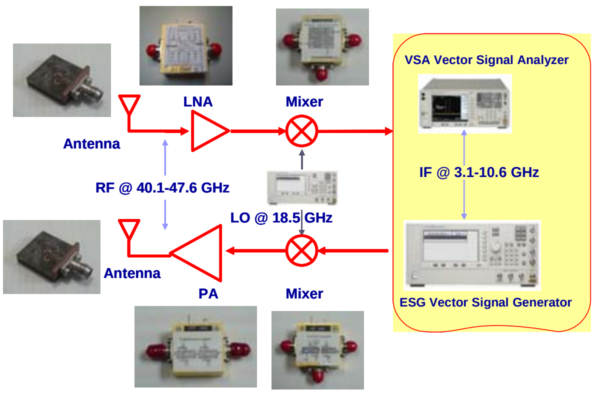
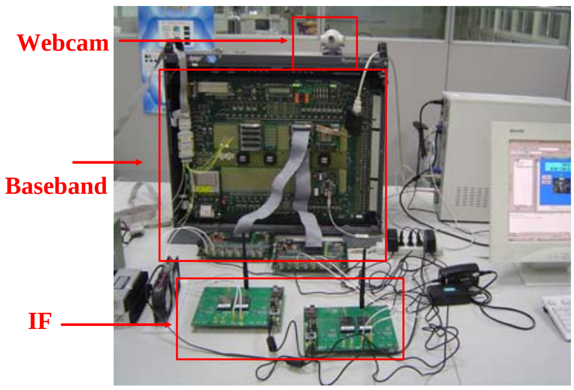
圖二，發射器模組照片



圖三，接收器模組照片

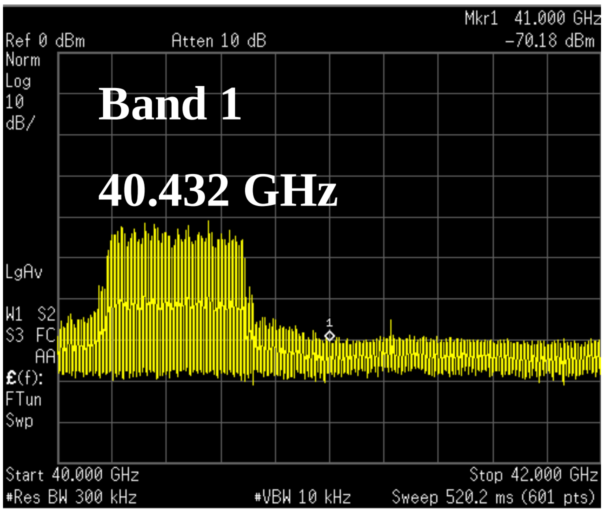


圖一，40-48 GHz 無線收發系統

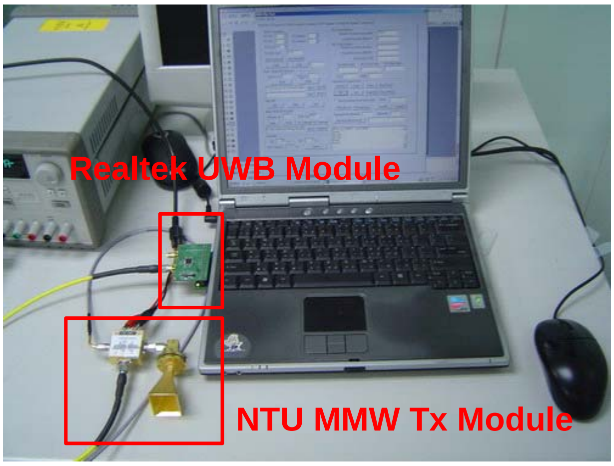


圖四，中科院基頻與中頻電路模組(20 Mbps CDMA)

圖五，影像傳送展示平台



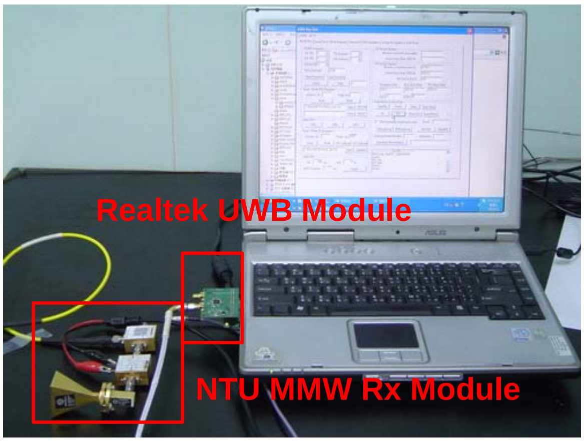
圖八，MMW UWB Output Spectrum



圖六，MMW UWB Transmitter

PER (%)		antenna to antenna distance (m)					
		1	2	1	2	1	2
mode		5	5	6	6	7	7
data rate (Mbps)	53	0%	0%	0%	0%	0%	0%
	80	0%	0%	0%	0%	0%	0%
	106	0%	0%	0%	0%	0%	0%
	160	0%	0%	0%	0%	0%	0%
	200	0%	0%	0%	0%	0%	0%
	320	0%	0%	0%	0%	0%	0%
	400	0%	0%	0%	0%	0%	0%
	480	0%	0.97%	0%	0.06%	0%	8.2%

圖九，Measurement of PER



圖七，MMW UWB Receiver