國科會電信國家型研究計畫成果報告

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「38-GHz 無線收發系統關鍵元組件技術」子計畫二：單面濾波器（1/3）
Uniplanar Filters（1/3）

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計畫類別：□ 個別型計畫　☑ 整合型計畫
計畫編號：NSC 90－2219－E－002－003
執行期間：90 年 8 月 1 日至 91 年 7 月 31 日

計畫主持人：陳俊雄　國立台灣大學電機系教授

本成果報告包括以下應繳交之附件：

□赴國外出差或研習心得報告一份
□赴大陸地區出差或研習心得報告一份
☑出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

執行單位：國立台灣大學電機工程學系

中華民國 91 年 7 月 29 日

「38-GHz 無線收發系統關鍵元組件技術」子計畫二：單面濾波器（1/3）

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計畫參與人員：王琦學、林祐生、嚴育盟、張振元、池榮聖、辜偉志

一. 中文摘要

(關鍵詞：單面結構、濾波器。)

為配合發展毫米波無線通訊收發系統，本研究特研發數種低通及帶通單面濾波器，以建立相關收發系統之關鍵元組件技術。本研究將提出數種新型縮小化單面濾波器結構，以達成電路短小輕薄的目的。

本研究的內容包括：設計用等效電路模型的建立，分析用電腦軟體程式集的完成，再結合理論分析與實驗量測，進行低通及帶通單面濾波器各種特性之詳盡探討。

第一年研究，利用共面波導容易串接與並接的特性，以四分之一波長（λ/4）串接開路截線與 λ/4 並接短路截線的交錯結合方式，進行帶通濾波器的設計工作，並在較低的 2.4GHz 操作頻率，完成兩種共面波導帶通濾波器的研製及詳盡探討工作。

Abstract

(Keywords：Uniplanar structure, filter.)

The purpose of this investigation is to develop and study several low-pass and bandpass uniplanar filters so as to establish the key component technologies for millimeter-wave wireless communication systems. The goal is to establish suitable equivalent circuit models for practical design and associated computer software for theoretical analysis. In this study, novel reduced-size uniplanar filters are proposed and investigated in detail. Specifically, various properties of proposed uniplanar filters are carefully examined, both theoretically and experimentally.

In the first-year research, novel coplanar-waveguide (CPW) bandpass filters are proposed, by suitably incorporating the λ/4 series open stubs and λ/4 shunt short stubs into a CPW structure. Specifically, two CPW bandpass filters with center frequency at 2.4GHz are implemented and carefully examined.

二. 緣由與目的

隨著電信產業的快速成長，無線通訊技術的進展甚為迅速，頻帶的需求也更形殷切，促使通訊系統往更高頻段發展，相關硬體電路也朝短小輕薄的目標邁進。

單面單晶微波積體電路(Uniplanar monolithic microwave integrated circuit)的構

想，首由 Hirota 及 Ogawa 等人提出。單面電路的元、組件及導體，僅佔用基板的單一平面，而具有以下的優點：串聯與並聯主、被動元、組件容易，易於加接直流偏壓，因此可簡化積體電路的製程，大幅降低電路的價格。

連接單面電路元、組件的要件為單面傳輸線(Uniplanar transmission lines)，依結構可分成：共面波導(Coplanar waveguide, 簡稱 CPW)、槽線(Slotline, SL)、及共面帶線(Coplanar stripline, CPS)。共面波導、槽線、及共面帶線之導體部分均共用同一平面，三者經適當組合，可簡化積體電路架構及製程，也可改善電路特性，因此於單晶微波及毫米波積體電路的發展過程中，頗受世人的注意。

濾波器是微波及毫米波無線通訊系統中之一重要組件，過去有關微波濾波器的研究工作，較偏重於以矩形金屬波導(Rectangular metallic waveguide)、帶線(Stripline)、以及微帶線(Microstrip line)為基礎的濾波器，因具有精確的設計公式可供使用，而廣泛地應用於微波電路中。

隨著毫米波無線通訊系統的開發，以共面波導、槽線、共面帶線等為基礎的單面電路及系統，也普受世人的重視，而開發出各種型式的單面濾波器。

構成濾波器的要件為：電容(C)、電感(L)、及 LC 所組成的串、並聯共振電路。在毫米波頻段，因研製集總型電容及電感不易，均以截線(Stub)來形成 L、C 的效應，而開發出各種實用的單面截線或共振器(Uniplanar stubs or resonators)，可作為發展單面濾波器的基礎。

已開發單面濾波器依耦合方式，可分為端邊或縫隙耦合型(End or gap coupled)，側邊或邊緣耦合型(Side or edge coupled)，端側邊耦合型(End/side coupled)，寬端邊耦合型(Broadside/end coupled)，以及背墊導體耦合型(Backed-conductor coupled)等數種。若依結構分類又可分為：截線型(Stub type)，階段阻抗型(Stepped-impedance type)，以及集總元件型(Lumped-element type)等各類。另在單面濾波器電路中，加入二極體或電晶體，也開發出可調式濾波器(Tunable filters)。

濾波器頻寬與結構之耦合方式息息相關。端邊耦合型濾波器之耦合量較小，其頻寬較小；寬邊耦合型及背墊導體耦合型濾波器之耦合量較大，其頻寬也較大；側邊耦合型濾波器之耦合量在上述兩種之間，頻寬則為中等。

以往所發展的單面濾波器，均用到四分之一波長(λ/4)或二分之一波長(λ/2)的截線或共振器，所佔面積較大，因此有研發縮小化單面濾波器的必要。

為配合總計畫「38-GHz 無線收發系統關鍵元組件技術」的開發工作，本子計畫的目標為：完成兩種「單面濾波器」的設計、研製、及分析工作，而擬開發結構有「低通濾波器」及「帶通濾波器」兩種。為密切配合收發系統之其他元組件，擬研發「低通濾波器」之規格為：通帶(Passband) 0~4.5 GHz，植入損失(Insertion loss) <1dB，I/O 回波損失 (Return loss) >15 dB，帶拒值(Band rejection)在 5.5 GHz 為 15 dB 並在 6.5 GHz 為 30 dB；而「帶通濾波器」之規格為：通帶 36-40 GHz，植入損失 < 2 dB，I/O 回波損失 > 15 dB，帶拒值在 32.5 GHz 為 40 dB。

三. 研究方法與結果

由基本微波電路之理論可知，λ/4 並接短路截線，可以等效為一個 LC 並聯的共振器，λ/4 串接開路截線，可以等效為一個 LC 串聯的共振器。透過共面波導結構易於串聯與並聯截線的特性，我們可以採取串並接截線之交錯方式，來實現 LC 串並聯共振器組成的帶通濾波器結構。相較於只能實現並接截線的微帶線結構，共面波導結構可以省略截線間的反轉器，進而縮小電路面積。

本研究利用最近發展的串接截線[1],[2]及並接截線[2],[3]，來開發共面波導帶通濾波器。

共面波導 λ/4 並接短路截線佈局圖與模擬及實驗結果如圖一所示，中心頻率設計在 2.4 GHz，由模擬與實驗結果可以看出這種結構具帶通響應。

共面波導 λ/4 串接開路截線佈局圖與模擬及實驗結果如圖二所示，同樣也可以看出這種結構具有帶通響應。

接著利用上述的兩種截線結構，來完成二階與三階共面波導帶通濾波器。

二階共面波導帶通濾波器的佈局如圖三所示，其模擬及實驗結果如圖五所示。本濾波器是一個串/並的結構，其中心頻率設計在 2.4GHz，頻寬也約為 2.4GHz，而頻寬的調整，可以藉由控制串接與並接截線的阻抗來達成，決定阻抗之公式如下:

$$Z_s = \frac{4g_k R_0}{\pi\Delta} \text{，} Z_p = \frac{\pi\Delta R_0}{4g_k}$$

其中 Z_s、Z_p 分別為串接截線與並接截線之特徵阻抗，Δ 為比例頻寬，R_0 為輸入及輸出埠阻抗，g_k 為濾波器低通原型電路之元件值。

三階共面波導帶通濾波器的佈局如圖四所示，其模擬及實驗結果如圖六所示，中心頻率與頻寬與二階濾波器相近，但是濾波器的選擇性與平坦度都比二階的設計要好，濾波器的面積約只佔半個波長，比傳統以二分之一波長共振器設計的三階濾波器，要小了一倍以上。

四.結論

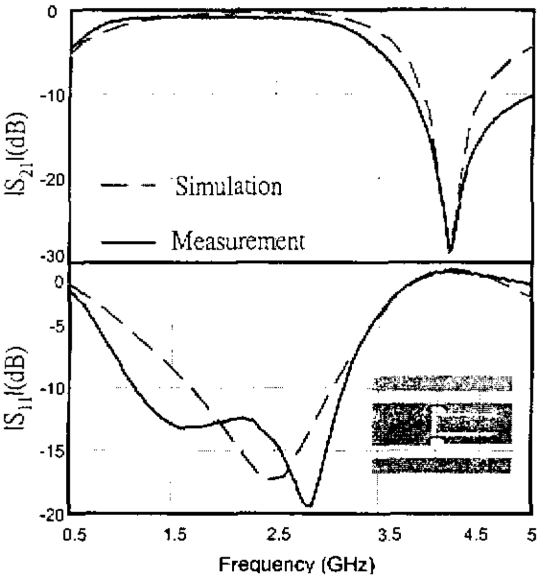
本研究以共面波導 λ/4 開路及短路截線為基礎，已在 2.4GHz 頻段，設計並完成二階與三階共面波導帶通濾波器。這種濾波器具有結構緊密及頻帶寬的特性，適合應用在微波積體電路中。

五. 參考文獻

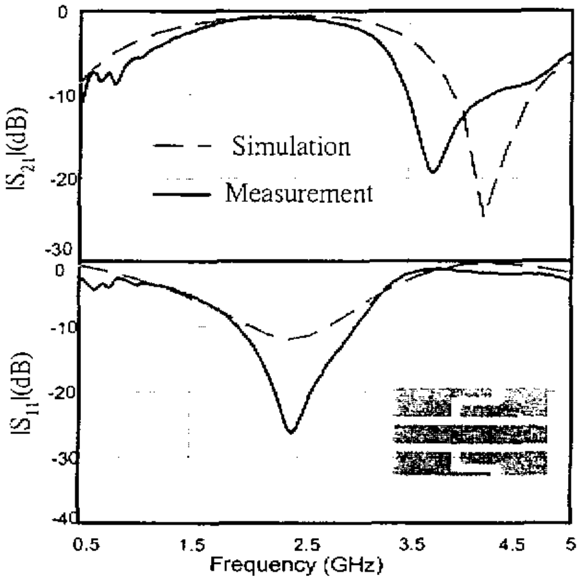
[1] G. E. Ponchak and L. P. B. Katehi, "Open- and short-circuit terminated series stubs in finite-width coplanar waveguide on silicon," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 970-976, June 1997.

[2] K. Hettak, N. Dib, A. F. Sheta, and S. Toutain, "A class of novel uniplanar series resonators and their implementation in original applications," *IEEE Trans. Microwave Theory Tech.*, vol. 46, pp. 1270-1276, Sept. 1998.

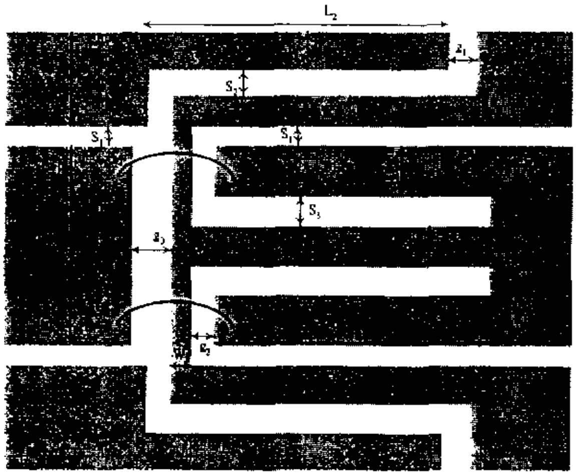
[3] K. Hettak, N. Dib, A. Omar, G. Y. Delisle, M. Stubbs , and S. Toutain, "A useful new class of miniature CPW shunt stubs and its impact on millimeter-wave integrated circuits." *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2340-2349, Dec. 1999.



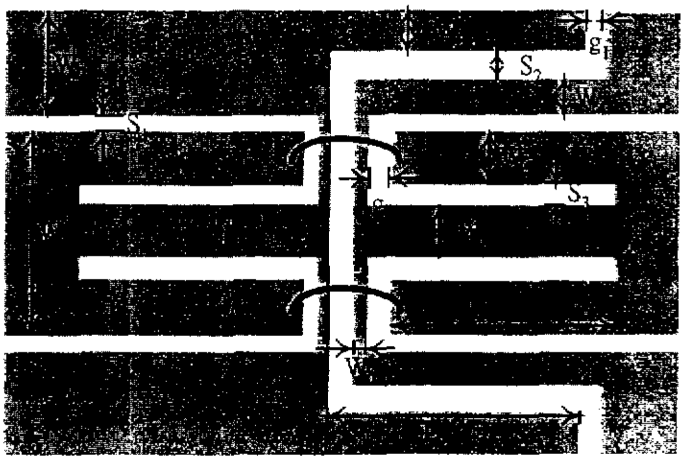
圖一. 共面波導λ/4並接短路截線之模擬與量測。



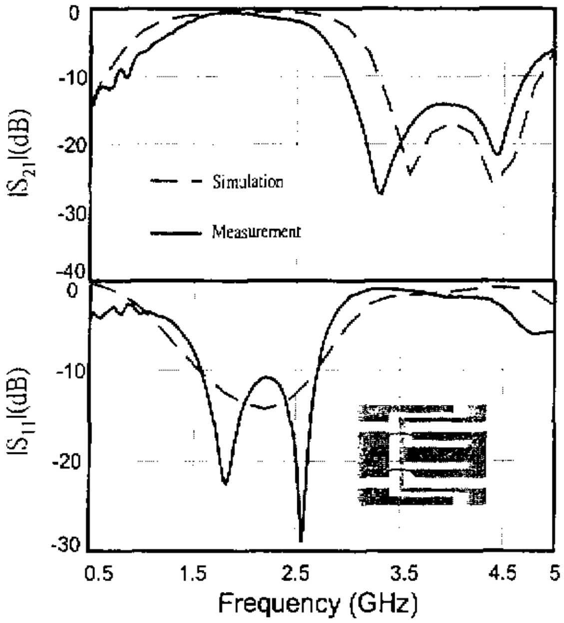
圖二. 共面波導λ/4串接開路截線之模擬與量測。



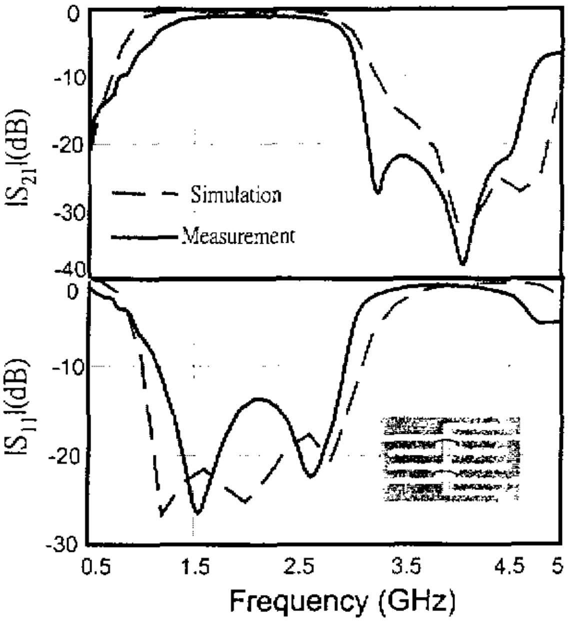
圖三. 共面波導二階帶通濾波器之佈局. W_1=12.2, W_2=6.4, W_3=2.6, W_4=2.4, W_5=4.2, W_6=3, W_7=1, S_1=0.6, S_2=1.4, S_3=0.4, L_1=17.5, L_2=18, g_1=0.5, g_2=0.5, g_3=3 (unit=mm).



圖四. 共面波導三階帶通濾波器之佈局. W_1=10.2, W_2=6.4, W_3=2.2, W_4=2.2, W_5=3.4, W_6=3, W_7=1, S_1=0.6, S_2=2, S_3=0.4, L_1=17.5, L_2=18, g_1=0.5, g_2=0.5(unit=mm).



圖五. 共面波導二階帶通濾波器之模擬與量測.



圖六. 共面波導三階帶通濾波器之模擬與量測.

2002 IEEE MTT-S 國際微波研討會

2002 IEEE MTT-S International Microwave Symposium

2002.6.14

- 報　告　人：台大電機系教授 陳俊雄
- 研討會時間：2002 年 6 月 2 日～ 6 月 7 日
- 研討會地點：美國西亞圖（Seattle，USA）

一. 參加研討會經過

電機電子工程師微波理論與技術學會（The Microwave Theory and Technique Society of the Institute of Electrical and Electronics Engineers, 簡稱 IEEE MTT-S），目前是國際上微波工程界的最大學會，此學會每年舉辦一次國際性研討會，已成為國際微波學界的盛事。

今年 IEEE MTT-S 所舉辦的 2002 年國際微波研討會，在美國西亞圖的 Washington State Convention and Trade Center 舉行，會期由 6 月 2 日至 6 月 7 日共六天，因研討會另與 Radio Frequency Integrated Circuits（RFIC）Symposium 以及 Automatic RF Techniques Group（ARFTG）Conference 一起合辦，全世界微波界的學者、專家、與廠商等均共襄盛舉，參加大會人士超過萬人，可謂盛況空前。

本次研討會的主要活動包括：Plenary Session，61 個 Technical Sessions（含 6 個 Special Sessions），3 個 Interactive Forums，另有 3 個 Tutorials，27 個 Workshops，4 個 Panel Sessions，3 個 Microwave Application and Product Seminars，以及含 600 多個攤位的 Exhibition，聲勢頗為浩大。另外今年適逢 IEEE MTT-S 分會成立 50 週年，因此特別安排 Historical Exhibit 及 Historical Interactive Forum，以為慶祝。

除上述的 Technical Events，IEEE MTT-S 微波學會也安排了 RFIC Symposium Reception（6 月 2 日，1900-2100），Microwave Journal/MTT-S Reception（6 月 3 日，1800-2000），Boat Trip to Tillicum Village（6 月 4 日，1730-2230），Industry-Hosted Cocktail Reception（6 月 5 日，1800-1930），IEEE MTT-S Awards Banquet（6 月 5 日，1930-2200），以及 Student

Awards Banquet（6 月 6 日，1200-1330），使與會人士能互相交談，增進交流。

本大會另一特色為：安排了盛大的 MTT-S Exhibition（6 月 4 日－6 月 6 日，900-1700），此展覽由全世界 600 多家微波及通訊相關公司贊助而成，各廠商均展示了最新發展的軟硬體系統及元組件等，因此對微波及無線通訊技術的發展，提供最佳的展現。

2002 年 IEEE MTT-S 微波學會各種獎章得主如下：

- Microwave Career Award：Ingo Wolff
- Distinguished Service Award：H. John Kuno
- Distinguished Educator Award：Linda P. B. Katehi
- Microwave Pioneer Award：John R. Tucker
- Application Award：Stephen A. Maas
- Microwave Prize（2000 年度最佳論文獎）：Emad Gad，Roni Khazaka, Michel Nakhla, and Richard Griffith，其論文為：A circuit reduction technique for finding the steady state solution of nonlinear circuits, IEEE Trans. MTT-48, pp. 2389-2396（2000）
- N. Walter Cox Award：J. Michael Golio
- Outstanding Yound Engineer Award：Ke Wu
- IEEE USA Harry Diamond Memorial Award：Robert J. Trew

今年 IEEE MTT-S 共推薦 12 位 IEEE Fellows，其大名如下：

John Tilman Barr, Jens Bornemann, Richard John Cameron, Edward L. Griffin, Osami Ishida, Stephen James Nightingale, Zoya Popovic, Ulrich Lother Rohde, David E. Root, James Carson Stewart, Robert Weigel, Dylan Forrest Williams.

另外亦有 13 位 MTT-S 會員，榮獲 2002 年 IEEE Fellows，其姓名如下：

Joachim N. Burghatz, Chi Ho Chan, Christos G Christodoulou, Ramesh Garg, Albin John Gasiewski, Allen W. Glisson, Hiroyoshi Ikuno, Neville Clinton Luhmann, Leda M. Lunardi, Eric Michielssen, Edl Schamiloglu , Staffan Einar Storm, Manfred Kasper Andreas Thumm.

本次研討會共收錄 491 篇論文，而投稿論文高達 886 篇，接受率約 55% ，顯示論文之水準頗高。

本研討會的 Plenary Session（6 月 4 日，800-940）由大會主席 Donn Harvey 主持，並由議程主席 Eric Strid 報告 Technical Program 相關事宜，會中除邀請 IEEE MTT-S 主席 John Barr 致詞外，另邀請 Juha Christensen（Cooperative Vice President , Mobility Group, Microsoft）作 Keynote Address.

此次研討會共推出 61 個 Technical Sessions(含 6 個 Special Sessions)，分 6 組同時進行。本人只能按個人興趣，選擇與毫米波技術、無線通訊技術、以及積體電路相關論文聆聽，並與相關學者、專家研討，雖然時間有限，但對最新研究動態的掌握，未來研究方向的擬定，甚有助益。特別對以下的 Sessions：

- Special session on radio frequency integrated circuits for 3G
- Couplers, dividers, and baluns
- SiGe RFIC process technologies
- Integrated passives for RF and mm-wave applications
- RF MEMS switch design and modeling
- REIC power amplifier technologies
- Application of RF MEMS
- Frequency and phase control circuits
- Microwave and mm-wave sensor applications
- Evolving communication and radar systems
- Transitions, polarizers, and coupling characteristics in LTCC
- New leakage effects on printed circuit transmission lines
- New technologies for communication systems
- Flip-chip techniques and novel application of organic materials in packaging
- Packaging
- Special session on THz technology and applications
- Novel filter structures
- Advanced V-band transceiver technology
- Special session on wide bandgap devices and their application in high power
- W-band transceiver components and applications

- Active, periodic, and planar filters

因與台大目前的研究方向接近，得於現場互相觀摩切磋，感覺收獲頗多。

本人論文（Y.S. Lin and C.H. Chen, Novel lumped-element coplanar waveguide-to-coplanar stripline transitions with low-pass and high-pass characteristics），安排在 6 月 6 日下午 1330-1630 IF-TH Interactive Forum 中宣讀。本文以集總元件方式，應用濾波器設計原理，來發展具有濾波特性之 CPW-CPS 轉接器，因電路面積可大幅縮小，且有轉接及濾波功能，故對單面微波電路技術的發展，頗有助益，而受到多位學者專家的發問與討論，並有學者要求另寄詳盡的研究資料。

綜觀 6 天的研討會，發現美、歐、日科技強國，其研究成果頗為豐碩且先進，也頗能反應該國的研究概況，因此對各國微波及無線通訊發展趨勢的了解，也頗有助益。

二. 與會心得

此次出席國際微波研討會，能與多位學者專家切磋微波及無線通訊領域的相關技術，研討目前與未來的科技發展趨勢，對本人未來研究方向的選定，有直接的幫助。另外因論文的宣讀，使各國學者專家能了解我國微波及無線通訊技術的發展，對科技交流及我國科技形象的提升，也有助益。

三. 建議

我國近年來，由於政府大力支持學術及應用研究，並在相關單位全力推動下，科技實力突發猛進。科技是提升國力的根本，希望政府能長期且大力的支持，期使我國能進入科技強國的行列。

四. 攜回資料

2002 IEEE MTT-S International Microwave Symposium Digest，共三冊 2272 頁。

Novel Lumped-Element Coplanar Waveguide-to-Coplanar Stripline Transitions with Low-Pass and High-Pass Characteristics

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Abstract — **Novel lumped-element coplanar waveguide-to-coplanar stripline transitions are proposed, using the planar lumped-elements to realize the low-pass and high-pass filter responses. Simple equivalent-circuit models are also established, from which the characteristics of various lumped-element transition structures are examined. Specifically, a low-pass lumped-element transition with 3 dB cutoff frequency at 3.2 GHz and a high-pass lumped-element transition with 3 dB cutoff frequency at 1.6 GHz can be achieved.**

I. INTRODUCTION

Coplanar waveguide (CPW) and coplanar stripline (CPS) are widely used in the design of uniplanar MMIC's. To fully utilize the advantages of CPW and CPS, an effective interconnection between them is of crucial importance. Various CPW-to-CPS transitions have been developed and examined [1]-[4], due to their wide range of applications in the implementation of balanced mixers, multipliers, and antenna feeding structures. Most of the transition structures reported have band-pass behaviors [1]-[3]. The wideband transition utilizing a slotline open structure [4] has a low-pass frequency response with a very high 3 dB cutoff at its passband edge, but no explicit design formulas are available to predict its upper passband frequency and also the attenuation at stop band is not good. In practical MMIC design, since the wanted signal is band-limited, a subsequent filter after the transition is usually required to filter out the unwanted spurious responses and harmonics. For instance, the double-balanced mixer in [5] has a wideband transition which is then cascaded with the low-pass/high-pass filters for the IF/RF port so as to increase the port-to-port isolation. If the transition may be designed such that it is inherent with the desired low-pass/high-pass behavior, it will have the advantages of saving one additional filter as well as reducing the circuit area.

In this study, novel lumped-element CPW-to-CPS transitions with third-order low-pass or high-pass frequency response are implemented to provide a compact structure which has the combined functions of transition and filter. The proposed transitions make use of planar lumped-elements to realize the filter prototype. This makes the transition size much smaller than the conventional ones adopting quarter-wavelength transformers. For design purpose, simple equivalent-circuit models based on close-form expressions are also proposed. The design of proposed transitions is then easy through the conventional filter synthesis techniques along with the proposed equivalent-circuit models.

II. LOW-PASS AND HIGH-PASS TRANSITION STRUCTURES

Consider the low-pass CPW-to-CPS transition structure shown in Fig. 1(a). This transition is equivalent to a T-type 3rd-order low-pass filter. Specifically, the two series inductors L_{s1} and L_{s2} in the filter prototype are realized by shorter metal strips; one is on top of the CPW-CPS cross-junction and is series-connected to the CPW center conductor, while the other is on the right side of CPW-CPS cross-junction and is series-connected to the CPS. The shunt capacitor C_p to ground is formed by the interdigital capacitor connected to the left of CPW-CPS cross-junction in a shunt configuration. For suppressing the odd CPW mode excited at the CPW-CPS cross-junction, bondwires at suitable positions are included.

Characterization of the shorter-metal-strip inductance may be done by the quasi-static close-form expressions with the partial-element equivalent-circuit technique [6]. The inductance is obtained once the strip length, width, and thickness are specified. For calculating the capacitance of the interdigital capacitor, the conformal-mapping technique under quasi-static assumption [7] is adopted. The per-unit-length capacitance is first obtained and is then multiplied by the finger length to give the total capacitance. In order to take into account the mode conversion effect at the CPW-CPS cross-junction, a six-port equivalent-circuit model [8] is adopted. In this model, the CPW line is represented by two transmission lines that separately support even CPW mode and odd CPW mode. The odd CPW mode transmission lines are terminated by the bondwire inductances at their corresponding positions. By combining the abovementioned models, one may obtain the equivalent-circuit model for the low-pass

TABLE I

GEOMETRICAL PARAMETERS OF THE CPW-TO-CPS TRANSITIONS FOR FIG. 3 AND FIG. 4. (LENGTH UNITS IN MM)

	Interdigital Capacitor					Inductor		
		finger number	finger length	finger width	gap width		strip length	strip width
Fig. 3	C_p	4	2.6	0.5	0.2	L_{s1}	6	0.2
						L_{s2}	4.4	0.5
Fig. 4	C_{s1}	5	2.8	0.5	0.2	L_p	5.9	0.3
	C_{s2}	4	2.6	0.4	0.2			

transition [Fig. 1(a)] as in Fig. 1(b). This model is based on three assumptions. First, the CPW and CPS sections are modeled as transmission lines. Second, the discontinuity effect of CPW-CPS cross-junction is neglected. Third, the interactions between the lumped-element LC circuit and the transmission lines are not taken into account. Note that all the elements in the equivalent-circuit model are characterized by the close-form expressions, thus the simulation time may be drastically reduced.

By interchanging the metal strip inductor and interdigital capacitor in Fig. 1(a), a high-pass lumped-element transition as shown in Fig. 2(a) can also be built. This transition is equivalent to a T-type 3rd-order high-pass filter, in which the two series capacitors C_{s1} and C_{s2} are realized by interdigital capacitors, and the shunt inductor L_p is formed by the shorter metal strip. The equivalent-circuit model of the high-pass transition is shown in Fig. 2(b).

The design of purposed low-pass and high-pass transitions is easy through the conventional filter synthesis techniques along with the proposed equivalent-circuit models. According to the required specifications on Z_0 and 3dB cutoff frequency, the element values of a 3rd-

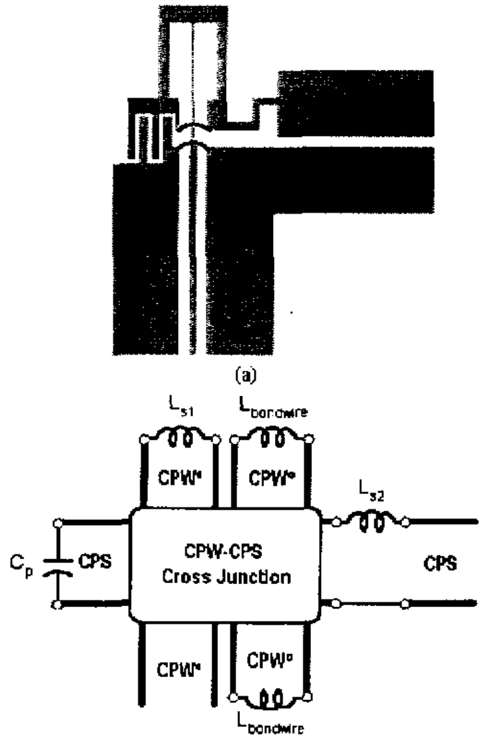

Fig. 1. Lumped-element low-pass CPW-to-CPS transition, (a) layout and (b) equivalent-circuit model.

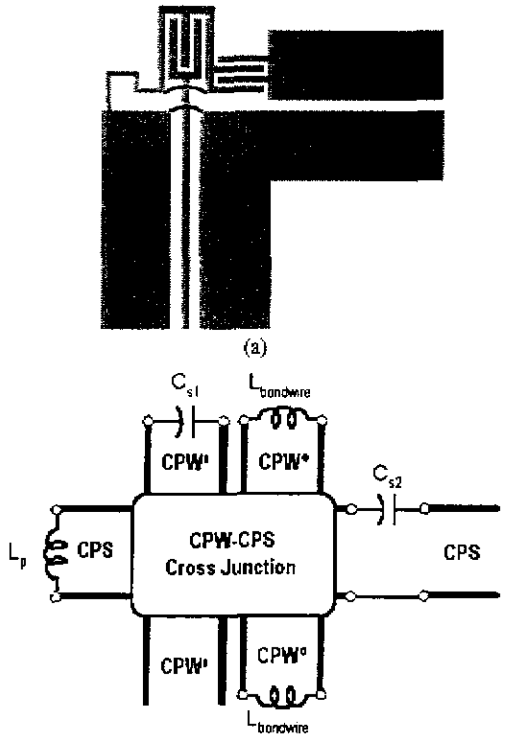

Fig. 2. Lumped-element high-pass CPW-to-CPS transition, (a) layout and (b) equivalent-circuit model.

order low-pass/high-pass filter prototype are first obtained through the filter synthesis formulas. The transition equivalent-circuit model is then constructed, and simulations are made to see whether the element values need to be fine-tuned with the presence of cross-junction model. After the element values are fixed, the geometrical parameters of the interdigital capacitors and metal strip inductors are determined, through the close-form design formulas. The transition prototype may then be built.

III. RESULTS

A back-to-back low-pass lumped-element transition for Fig. 1(a) is fabricated on a FR4 substrate (ε_r = 4.3, tanδ = 0.022, and thickness h = 1.6 mm). The CPW line has a strip width of 0.45 mm, a slot width of 0.6mm, and a finite ground-plane width of 4 mm. The CPS line has a strip width of 4 mm and a slot width of 0.6 mm. Both CPW and CPS lines are designed to possess a characteristic impedance of 100Ω according to the close-form formulas in [9]. The 3 dB cutoff frequency of this transition is designed to be 3.2 GHz. The L and C values are obtained by the filter synthesis formulas for the 3rd-order equal-ripple low-pass filter first. Then with the inclusion of cross-junction model [8], they are fine-tuned in a circuit simulator to give: L_{s1}=6 nH, L_{s2} = 2.93 nH, C_p=0.525 pF. The corresponding geometrical parameters of the interdigital capacitor and metal strip inductors are listed in Table I.

The transition is measured by the HP8510 network analyzer with TRL (Thru-Reflect-Line) calibration to the CPW-CPS junction, and the simulation is based on the equivalent-circuit model [Fig. 1(b)]. The measured and simulated results are shown in. Fig. 3. This transition exhibits a low-pass behavior as expected, and the 3 dB cutoff frequency is at about 2.3 GHz. The measured insertion loss is less than 2 dB below 2 GHz, and the return loss is less than -10dB below 2.3 GHz. The out-band rejection is greater than 20 dB from 3.6 GHz up to 6 GHz. Note that since the transition is measured in a back-to-back configuration with a 20 mm CPS line in between, the measured frequency response and 3dB cutoff frequency is somewhat different from that of a single transition. Good agreement between measured and simulated results is observed. Although there is some discrepancy in the higher frequency range, the equivalent-circuit model (Fig. 1(b)) is still adequate in predicting the transition frequency response. In addition, all the components in the model are characterized by the close-form expressions, thus the simulation time may be largely reduced.

A back-to-back high-pass lumped-element transition for Fig. 2(a) is also fabricated on a FR4 substrate with the same CPW and CPS dimensions as in Fig. 3. The element values are: C_{s1} = 0.655 pF, C_{s2} = 0.454 pF, L_p = 4.79 nH with the designed 3 dB cutoff frequency at 1.6 GHz. The corresponding geometrical parameters of the interdigital capacitors and metal strip inductor are listed in Table I. The measured and simulated results are shown in Fig. 4. This transition exhibits a high-pass behavior as expected, and the 3 dB cutoff frequency is at 1.8 GHz. The measured insertion loss is less than 3.5dB from 1.8 GHz up to 5.3 GHz, and the return loss is less than -9.4dB from 2.18 GHz up to 6 GHz. The attenuation is greater than 20dB below 1.6 GHz. The high frequency insertion loss is not good for this case, a consequence of the back-to-back configuration and the higher power losses of the FR4 substrate. Although there is some discrepancy between measured and simulated results, the equivalent-circuit model is still adequate as an effective design tool.

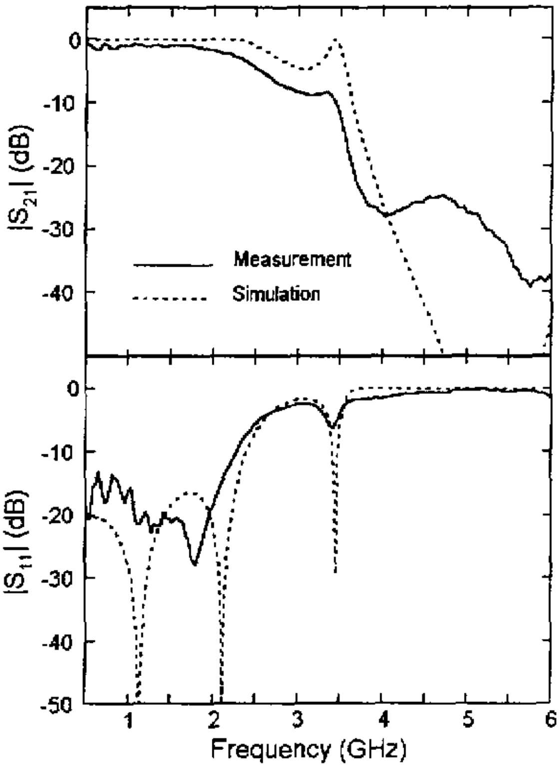

Fig. 3. Measured and simulated results for the back-to-back low-pass transition structures in Fig. 1(a).

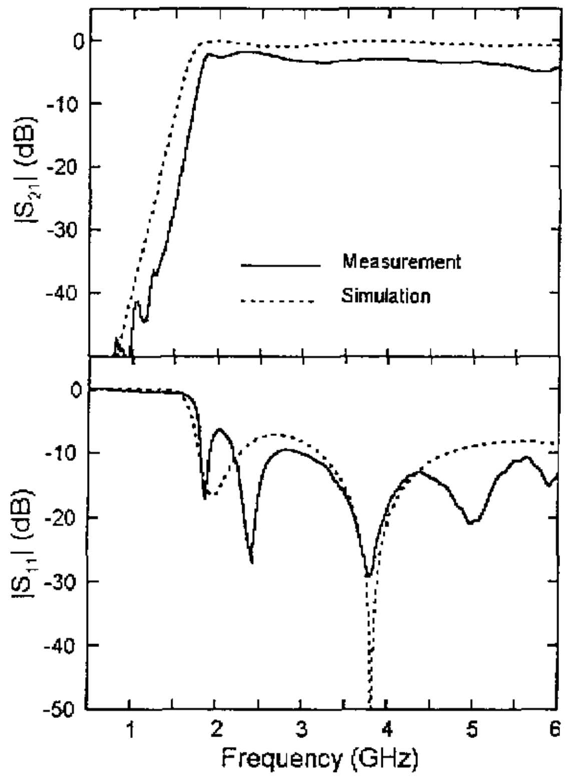

Fig. 4. Measured and simulated results for the back-to-back high-pass transition structures in Fig. 2(a).

IV. CONCLUSIONS

In this study, novel lumped-element CPW-to-CPS transition structures to achieve low-pass and high-pass frequency responses have been proposed and carefully examined. For design and modeling purposes, effective and simple equivalent-circuit models have also been established. The proposed transitions are compact and can provide the combined functions of transitions and filters, thus they are useful in implementing the MMIC components.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Education and National Science Council under Grants 89-F-EA06-2-4 and NSC 90-2219-E-002-003.

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