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台灣光電產業回顧與展望

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摘　要

本文係回顧過去多年來，產、官、學、研各界投入光電產業之心路旅程，列舉具代表性之成功與失敗經驗。並嘗試從台灣經驗中，分析過去成功之關鍵因素與目前面臨之挑戰。同時亦展望未來光電個體與總體產業可能的發展方向。

關鍵詞：光電產業、光學產業、光電材料、光電顯示器、光資訊、光纖通訊、雷射與其他應用

台灣發展光電產業近 20 年，已有舉世注目之成績，成功的經驗近年來已成爲香港、新加坡、韓國，甚至是中國大陸，競相模仿之對象。本文係回顧過去產業的發展歷史，有助於鑑往知來，此乃撰寫之宗旨。

壹、早期的政策思維

過去台灣的經濟發展，歷經以農立國，進而邁入工業化。演進過程中不斷有能人志士，帶領著台灣在驚濤駭浪中前進，奠定了台灣長期經濟發展的基礎。至於過去二十多年來，台灣的經濟發展能突飛猛進的最大功臣，無庸置疑，應是已逝之李國鼎資政，他除了擁有無私無我、一心爲國爲民的高尚情操外，其對於高科技產業的發展，更具高瞻遠矚的眼光。

二十多年前，台灣在電腦與半導體產業已奠下成功基礎之時，李資政便已在思考

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台灣下一世代的高科技產業。在國內外的專家建議下，李資政選定二項新興高科技：一為目前當紅的生技產業，另一則是目前已紅了半邊天的光電產業。目前就單單一項光電個體產業「光電顯示器」，便能與半導體產業平起平坐，成為「兩兆雙星」的一員。而光電產業的廣大範疇內，仍有著無數的明日之星蓄勢待發；事實上，目前人們所看到的光電產業，僅是冰山之一角而已。

在政策方向底定之後，民國七十四年李資政便於行政院下，設立「光電科技執行小組」，由石大成博士擔任執行秘書。同年改隸國科會成為「國科會光電小組」迄今。民國八十二年，國科會光電小組促成「光電科技工業協進會」的成立，將與民間產業相關之推廣業務，移轉光電協進會繼續執行。工研院亦在民國七十九年成立目前光電所的前身「光電與電腦週邊設備發展中心」。中科院早年光電相關之研發工作，主要在「材發中心」進行，近年來該中心亦改名，已將光電二字納入其正式名稱中。

政府除了成立相關的推動與研發單位之外，最重要的政策，便是加強光電人才的培養工作，早在推動之初，李資政便指示教育部，加強光電人才培育工作。早期，實在看不出培養光電人才之效用，因為大部份光電人才畢業之後，大都待在政府相關的研發單位中，少有進入民間光電企業者；其間甚至有不少是投入其他產業者，例如半導體產業。一直到有新興光電公司成立之後，光電人才方有陸續進入民間光電企業之現象產生。

貳、光電個體產業

早年，光電產業之定義較為狹義，稱之為「雷射科技」。從歷史的眼光來看，光電亦屬係興產業。因此，各國的定義均不甚相同，我們的定義範疇是沿襲美日兩國，再參酌台灣現況得來的，實可謂具有「台灣特色」。

台灣光電產業的範疇，初期包括：光學元件與器材、光電半導體、光資訊、光纖通訊、光電檢測、雷射加工等六大子產業。然而隨時空轉變，光電產業的定義範疇也陸續被加以修正，使之更具「台灣特色」。二十年來，將光電半導體改成光電材料，加入雷射醫療。然而，此種分類屬為配合政府政策推動用之分類法，在進行產業研究時，不甚合適。因此於光電協進會負責光電產業研究時期，陸續加以修正，將光電檢測、雷射加工與雷射醫療等，合併稱為雷射與其他應用，將光電顯示器子產業獨立，刪除光學器材。整體而言，目前之定義範疇已經與日本接近相同；無獨有偶，美國亦在近年修正其定義範疇與日本同步。因此近年來台灣光電產業數據比較能進行國際比較；只是我國近年來之統計數據，是不能與過去直接進行比較的。

一、光學

傳統光學產業可說是台灣光電產業之濫觴。早年，台灣光學產業主要產品無外乎：太陽眼鏡、望遠鏡、照相機等；其中太陽眼鏡與照相機，在產量上，都曾經榮登全球榜首。台灣太陽眼鏡之生產重鎮在台南；而照相機則在台中。嚴格來說，由於太陽眼鏡之生產層次較低，對爾後的光電產業發展較無影響力；然而，照相機產業則成爲台灣發展光電產業的基石，如同世界第一的日本光學產業，奠定了世界第一的日本光電產業，其貢獻是一樣的。

地靈人傑的台中會成爲台灣的光學產業重鎮，原因有二：一爲台中天氣乾燥，適合光學產業，二爲早年日本光學大廠的設立。很早年台中便已形成光學產業聚落，大大小小的廠商，有不少都是源自日本光學大廠，尤其是 Canon，例如台灣第一大光學廠亞洲光學賴董事長，早年便是服務於 Canon。目前台灣 Canon 業已逐漸在轉形，由製造轉向設計開發，生產則移至大陸或東南亞；而周邊的台灣光學廠亦如是，只是量產幾乎都在大陸。

台灣光學廠商在過去的二、三十年來，歷經了三次環境大變革，不但沒有消失，反而越來越興旺，其中亞洲光學還曾經成爲股王，如今大立、今國 亦是亦步亦趨。第一次產業變遷，爲傳統相機產業外移，同時造成元件廠商外移；第二次產業變遷，爲掃瞄器零組件的本土化，填補了傳統相機產業外移之剩餘產能，甚至造成部份廠商，大幅擴大產能，然而掃瞄器很快面臨大幅降價的壓力，元件廠商自然難以置身事外；第三次產業變遷，便是數位相機的普及，使得台灣光學廠商柳暗花明又一村，這就是目前之情境。

展望未來幾年，台灣光學廠商還會不斷面臨產業環境大變革，目前可以明顯看到的是：照相手機與投影機的普及。此二項產品台灣廠商應該都不會缺席，自然台灣光學廠亦會在這些新產品中扮演重要角色；由此，亦可呼應前文所述，光學產業乃光電產業的基礎產業。

二、光電半導體

由於光電材料之範疇廣泛，在此僅狹義地述及光電半導體，而光電半導體之範疇又限於發光元件，乃因檢光元件本土廠商投入有限，台灣光電半導體廠商大都投入發光二極體之產銷，只有少數是投入雷射二極體。

台灣廠商投入發光二極體之時點，早於政府推動光電產業，與廠商投入液晶顯示

器之時點差不多。早年，發光二極體廠商大都投入後段封裝，晶粒則自日本進口，規模較大者有光寶、億光等，此一產業聚落大都集中在中和一帶。之後，有鼎元、光磊投入中游，台科投入上游，產業鏈逐步完整。然整體產業還是較集中在低階的封裝產業。此可謂台灣發光二極體產業的草創階段。

一直到超高量度之問世，台灣發光二極體產業開始邁入新的里程碑。國聯光電成立，造成業界不小震撼，其主事者的策略思維，促成晶元的誕生。自此之後，展開了既生瑜何生亮的超高量度發光二極體二雄相爭局面。也因此，使台灣成爲全球第三個擁有超高量度發光二極體產業的國家，同時台灣發光二極體產業版圖亦開始擴張，甚至造就新的戶外看板產業。以上，則是台灣發光二極體產業發展的第二階段，其結局是超高量度發光二極體亦變成無超額利可圖的行業。

日本日亞化學於上世紀末，推出了震撼全球的氮化鎵藍光發光二極體，中村博士此發明對人類的貢獻，實不亞於愛迪生發明燈泡。這也對台灣發光二極體產業產生了極大的啓發作用，除了檯面上的廠商紛紛投入藍光發光二極體的開發外，也促成不少以藍光發光二極體爲主要訴求的第三世代廠商，加入戰局例如：璨圓、廣鎵、元砷、連威等。前年有部份廠商正好趕上防僞潮，適時推出紫外光發光二極體，如：璨圓，營業額暴增。然而，去年手機應用，使得大部份投入藍光發光二極體的廠商都有獲利。也因此，台灣廠商的習性又出現，大肆擴張產能，自然難逃惡性競爭的宿命，2003 年上半年價格大幅下滑，大多數廠商均無利可圖。其下場不僅於此，下半年，日亞已對台灣廠商展開專利訴訟，廠商眞正的夢魘才剛開始。這就是台灣發光二極體產業發展的第三階段，產業競爭變本加厲，不可不謂悲壯。

雖然，藍光發光二極體已邁入惡性競爭階段，很信幸運，發光二極體產業又有新的戰場，從藍光轉向白光。目前白光供不應求，白光之技術障礙比藍光高，專利問題更難避開，對台灣廠商的挑戰，相對於藍光，可說是越來越高。但是，白光之市場則更爲誘人，如能大量使用在背光模組上，其市場遠大於藍光在手機上的應用，會將爲台灣發光二極體產業帶入另一新的紀元；可以預期，台灣廠商必然會前仆後繼，勇往直前的。然而，背光模組之應用並非發光二極體的長期穩定市場，其將隨著液晶顯示器的沒落，而走入歷史。發光二極體產業之眞正價值，在於照明上的應用。相信，不必等到本世紀中葉，所有主要的照明，都將由固態照明當綱。事實上，短期內，便會看到發光二極體大量取代裝飾用或指示用燈泡，汽車應會是第一個大量應用例。

三、液晶顯示器

很多人稱顯示器產業爲「平面顯示器」產業，實有些狹隘，長遠來看，平面顯示器不可能可以呈現所有的三度空間影像，更難有身歷其境之感受；加上，顯示器不全然都是呈現平面狀或只使用光電技術而已；因此，使用光電技術之顯示器，稱之爲「光電顯示器」，應是較爲合適的。

目前光電顯示器產品，大體上可分爲二大支：一、平面顯示器，二、投影顯示器。平面顯示器主要含蓋：液晶顯示器、有機發光二極體、電漿顯示器及其他。投影顯示器則包括：液晶投影顯示器、DLP 投影顯示器、微型投影顯示器及其他。對台灣而言，大部份廠商都是投入較爲成熟之顯示器產品上，如：液晶顯示器、電漿顯示器、有機發光二極體顯示器、液晶投影顯示器、DLP 投影顯示器等。

台灣廠商投入液晶顯示器之時點，大約與發光二極體差不多，相當早期。一路走來，從 TN、STN、TFT 到 LTPS，歷經 20 多年，不可不謂基礎雄厚，這或許是 TFT 液晶顯示器產業能在投入短短的 4-5 年內，便躍居世界第二的原因之一；如果新廠建立一切順利，2004 年台灣 TFT 液晶顯示器產業將會名列世界第一。

台灣發展液晶顯示器可概略分三個階段：TN、STN、TFT。早期有日商及少數台灣廠商如敬業電子、美相等，投入小型 TN 液晶顯示器，大都爲了配合當時的電子產業，主要用於計算機、手錶上，期間長達十多年之久。爾後，碧悠併購美國 Polytronix 公司，1992 年開始投入 STN 液晶顯示器之生產，很幸運，不久遊戲機俄羅斯方塊大流行，讓碧悠的投資很快回本。此一階段很多廠商進入，如南亞、勝華等，接著華映引進日本東芝 STN 廠，台灣液晶顯示器開始進入彩色大面積 STN 時代，目標市場爲筆記型電腦。出乎預料之外，彩色 STN 筆記型電腦市場生命週期不到二年，TFT 液晶顯示器便成爲筆記型電腦之主流配備。台灣也是在 1992 年，開始投入 TFT 液晶顯示器之生產，先後有元太與聯友，然僅止於小尺寸。

由於大面積 TFT 液晶顯示器技術困難度甚高，全球量產技術全掌握在日商手中，日商長期視之爲國寶級技術；加上，台灣在此領域之研究雖然起步很早，但是投入不足，一直無明顯績效。也因此，之後每年均需自日本與韓國大量進口 TFT 液晶顯示器，其進口金額幾乎與進口石油相當，由此也可以解釋：爲何這幾年台灣廠商會如此大幅投資在 TFT 液晶顯示器上；以及其產值數量級，能在短短幾年內，便與發展近 20 年之半導體產業相當。

自 1996 年起，韓國開始大量投入 TFT 液晶顯示器技術與量產。由於日商一直視 TFT 液晶顯示器爲禁臠，因此並無正式技術移轉給韓國，致使韓商開發出不少自有技術，有些技術甚至凌駕日本廠商。這段期間，台灣廠商只能對著大面積 TFT 液晶顯示

器技術，望眼欲穿，因爲要與韓商一樣獨立開發，對企業規模不大的台灣廠商而言，實在是件不可能的任務。不過對台灣廠商而言，倒是多了一處 TFT 液晶顯示器供應來源，因爲正好韓國並無筆記型電腦產業，只能銷售給台灣，台灣正好坐享日、韓自由競爭的好處。

日商與韓商競爭的結果是：兩敗俱傷，漁翁得利。漁翁便是台灣廠商，台灣廠商除了獲得合理價格之外，最大的獲得是日商的技術移轉，此乃台灣廠商夢寐以求的，人算不如天算。日商願將國寶級技術讓售，背後原因有二：一爲，大面積 TFT 液晶顯示器營運，長期虧損，二爲，日本長達十年的經濟不景氣。這二因素使得日商對未來的投資，有了不同於以往之思維：聯台制韓。首先發難者爲日本二線廠三菱，1997 年，三菱將技術移轉給華映，如此一來，三菱不但可獲技轉金，同時亦不需資本支出，便可獲得更多產能；華映則獲得夢寐以求的大面積 TFT 液晶顯示器技術，其費用自然遠低於自行研發，實可謂是雙贏的上上之策。從此日本大廠終於恍然大悟，於是展開技轉台灣廠商之熱潮，同時加上台灣投資人亦不手軟，進而造就今日台灣傲視全球之 TFT 液晶顯示器，當然此事件中，最眼紅者就是韓商。這便是台灣發展液晶顯示器的第三階段，目前方興未艾，預估此一波 TFT 液晶顯示器熱潮，將可延至 2010 年。

四、有機發光二極體顯示器

有機發光二極體顯示器係目前最有機會，接液晶技術棒之顯示器技術，因此自從上世紀末以來，國內有上百家相關廠商躍躍欲試，原因無他，過去台灣 TFT 液晶顯示器起步晚，現今有機發光二極體顯示器才開始萌芽，早起步機會多。但是，有機發光二極體顯示器開發，並不如想像，有些廠商已按兵不動靜觀其變，但是仍有不少廠商依然還在努力中。如今，階段努力有成者有錸寶、東元激光、光磊，此三家被動式有機發光二極體顯示器已能出貨，其成就可排名全球前五名。

台灣投入有機發光二極體顯示器之時空環境，與發展液晶顯示器時期，絕然不同，因此其發展模式亦不同。四、五年來投入廠商，包括：材料、設備與製造等，上、中、下游一起來，加上日漸能掌握 LTPS 液晶顯示器技術，一旦環境成熟，台灣有機發光二極體顯示器產業在全球市場上，必然會是具有不亞於 TFT 液晶顯示器產業的地位，國人應可拭目以待。

五、電漿顯示器

電漿顯示器之研發工作，國內最早投入之廠商應是華映，目前已量產，其技術係

不到五年，全球光碟機產業有了相當變化，投入此產業除了韓國之外，台商也培養出大陸新興民族產業-VCD 影碟機。當年台商將庫存積壓之過時 CD-ROM 光碟機，送往大陸改成 VCD 影碟機，不但刺激出大陸 VCD 影碟機市場，更刺激出大陸 VCD 影碟機產業。沒有幾年功夫，大陸投入 VCD 影碟機之廠商已上千家，絕大部分都非台商，乃大陸本土廠商。每年上千萬台 VCD 影碟機之大陸市場，不但成爲世界最大，也成就了大陸自有技術，建立大陸獨有之 SVCD 規範，自此大陸之影碟機不但紮根，更奠定日後在全球影碟機市場攻城掠地之基石。大陸廠牌大約在三年前，開始推出低價 DVD 影碟機傾銷美國，每年都創新低價，價位幾乎每年都是攔腰一斬，目前已到 49 美元一台，這不但使得台商在 DVD 影碟機幾乎無立足之地，更撼動日商之既有市場。

展望未來，畢竟光碟仍是最便宜的儲存媒體，光碟機仍會朝更高密度，同時是可擦拭的方向發展。而可擦拭的方向正是目前台商避開大陸廠商競爭之利器，例如近來，很多台灣廠商推出 DVD 光碟錄影機，希望搶占傳統錄影機之市場，可預期 DVD 光碟錄影機將會快速普及。而在電腦應用方面，台商則已進入 DVD-R 與 DVD RW 光碟機產品，這都將使台灣光碟機產業進入新紀元。

八、光碟片

台灣發展光碟片之歷史較光碟機晚 2-3 年，第一家投入之廠商爲錸德，其前身爲第一唱片與白金錄音室，由此不難了解錸德之所以投入光碟片，其原因非常單純，那就是光碟片將會取代傳統唱片，也因爲如此，錸德開始產品便是定位在 CD 唱片。CD 唱片廠的本質，僅是個代工廠，其有規模有限，具在地性，並以提供服務爲主要訴求，而不是生產一項能擁有品牌，可行銷全球之產品。也因此，之後投入廠商亦有限，畢竟能掌握唱片行銷管道者有限。當年生產設備與原材料也都是自荷蘭或日本進口，本土廠商幾乎難扮演任何角色。

日本與歐美大廠對光碟片之產品定位，自始便是要開發出足以取代磁性記錄媒體之新產品，也因此目標集中在可擦拭型光碟片。1990 年初期，日本太陽誘電，開發出 CD-R 可擦拭一次型光碟片，由於與理想之可擦拭多次型光碟片，是有段距離，因此，均認爲此乃過渡性產品，並未加以重視。但是硬體光碟機廠商，如 SONY，依然投入 CD-R 光碟機之開發，提供爾後 CD-R 光碟片發展之平台。

錸德便是在此時投入 CD-R 光碟片之生產，而同時技術佼佼者，如巨擘，仍熱衷於磁光型光碟片之開發。在沒有太多競爭者的狀況下，錸德的命運開始轉變，同時也開啓台灣光碟片產業的新紀元。錸德的高毛利，開始吸引衆多的廠商投入，到 1999 年

世紀末，又有 Y2K 危機的推波助瀾，到達巔峰，錸德的每股盈餘超過 10 元。如此高獲利，吸引更多競爭者的瘋狂投入，此刻最高興者，當屬國外設備商，因爲台灣生產線已近千條，以如此的產能，不只是世界第一，也幾乎占全球八、九成左右。

由於進入障礙不高，致使如此一窩蜂的投入，其下場是可預期，CD-R 光碟片單價快速下跌，2002 年單價不到台幣 5 元，所有廠商幾乎都虧錢，CD-R 光碟片瞬間成爲艱困工業。2003 年單價回升，狀況有所改善，然而想再回復原貌，應是緣木求魚，CD-R 光碟片已成爲一般商品，供需決定價位；然而事實上，目前產能依然大於需求，單價會回升是很有意思的。

光碟片產業是否因此成爲傳統產業，答案應是否定的，CD-R 光碟片應屬可擦拭型光碟片產業的第一波。未來可擦拭型光碟片之種類更多，鹿死誰手尚不知，其競爭模式必不同，然不可否認，台商將占舉足輕重之地位，只是台商應多投入研發，否則悲劇將會再現，如：惡性競爭與專利權等。

九、光輸出入裝置

光輸出入裝置產品範疇相當廣泛，然台商投入之大宗產品主要有：掃瞄器與數位相機。掃瞄器之發展歷程與光碟片產業有神似之處，因此在此不再贅述，其乃依循台灣世界第一光電產品之發展八部曲：世界大廠無意投入、台商慧眼獨具、獲利豐厚、一窩蜂投入、流血輸出、產業重傷、市場重整、風光不再。目前掃瞄器在世界市場之佔有率與 CD-R 光碟片一樣，幾乎占全球九成左右，是市場主宰者，然，價格曾觸底之資訊產品，已成爲一般商品，價位由供需決定，昔日風光已隨風而逝，再無超額利潤，除非有新產品問世。

台灣發展數位相機，相較於其他開發中國家是有其利基，因爲台灣曾擁有傳統相機產業加上擁有取像技術基礎。台灣發展數位相機，嚴格說，也有近 15 年之歷史，1989 年，便有歸國學人於新竹科學園區成立一家數位相機公司，然由於生不逢時，公司誕生太早，產業與市場環境均未成熟，不到三年，便消失在科技產業的歷史洪流中，這應可算是台灣發展數位相機的第一階段。

第二階段則是起始於工研院光電所的成立，科專計畫開始投入數位相機之研發。爾後，研究人員投入民間或成立公司量產，加上大環境逐步成形，包括關鍵性零組件的取得，市場成熟等。由於初期，台灣很多專家都將數位相機定位爲資訊週邊設備，因此投入之廠商也大多爲資訊相關廠商，而日商則很明確將之定位爲消費性產品，用來取代傳統相機，也因此投入之廠商涵蓋大部份傳統相機與電器巨人，幾可說是全員

動員。這段期間由於台商仍屬暖身期，加上日本大廠競爭激烈，產品生命週期短暫，取像畫數節節上升，有點類似當年 CD-ROM 光碟機倍速之演進史，只是沒有那般激烈，然而已造成除 SONY 之外，無人獲利。

由於日本大廠大力投入，數位相機取代傳統相機的腳步加速，這也給台灣傳統光學與相機廠商帶來新的契機。目前國內投入之廠商亦是涵蓋大部份傳統相機與資訊廠，然由於缺乏擁有世界知名之品牌，不少仍是以代工爲主。目前，台灣廠商生產之產品也多屬較日商低階之產品；另，關鍵性零組件如變焦鏡頭、CCD 元件等仍得仰仗日商。

除了數位相機廠商給台灣帶來新的契機外，數位相機的衍生應用，特別是手機上使用之取像裝置，其要求品質，目前遠低於數位相機之要求，以台灣廠商目前擁有之技術，相較於數位相機，有更高的掌握度，也因此吸引不少廠商投入手機上使用之取像裝置。近年來，手機的不斷推陳出新，對台灣光電產業的貢獻，除前述之光學鏡頭與影像感測器所組成的取像裝置外，尙有目前需求量大增的 STN 液晶顯示器、以及未來進展至 TFT 液晶顯示器、顯示器用背光模組與 LED 背光光源、按鍵用 LED 光源等。

十、光纖通訊

早年光纖通訊產業是台灣相對較弱個體產業，原因無他，只因爲在電信自由化與設立有線電視之前，台灣市場除國防與國營事業外，大概只有一家客戶，那就是電信局。因此，早年台灣光纖通訊產業係依賴電信局標案而得以生存。主要進口光纖絲，從事光纜之生產，北部爲聯合光纖，南部爲華榮電線電纜，二分天下。陸續有很多追隨者，欲分食此有限的市場，也因此競爭激烈。這應該可算是第一階段的台灣光纖通訊產業。

接著有生產被動元件之廠商設立，產品主要爲連接器、跳接線。這類產品應算是精密機械加工產品，早期利潤不錯，但由於其進入障礙不高，很快廠商便林立。於是牽引產業再向前邁進，進入較高階之光纖耦合器。開始，廠商多半倚靠引進設備與技術，然而不久工研院光電所便開發出相關生產設備與技術，因而開啓不少新創公司。在此階段，由工研院離職員工成立了上詮光纖，自此台灣光纖通訊產業便開始邁入春秋戰國時代，被動元件毛利很快大幅縮水。接著成立的廠商很多便轉戰主動元件，包括：通訊用雷射、收發模組等。

1998-99 年，達康公司當道，頻寬需求瞬間大增，美國光纖通訊產品大賣。造成很

多廠商奮不顧身投入，2000 年達高峰，美國如此，台灣亦若是，最高峰時，台灣光纖通訊廠商高達 70-80 家。2000-2001 年達康公司兵敗如山倒，瞬間，光纖通訊產品乏人問津。也因此，接著 2001-2002 年的骨牌效應，光纖通訊廠商亦關的關，倒的倒，有史以來，最寒冷的冬天終於席捲全球，如今依然存活之廠商，少有獲利者，大都在苦熬，期待 2005 年能有回春的機會。

過去 20 年來，美國光電產業專家都一直認爲，光纖通訊產業乃光電產業中，市場規模最大者，這與台灣光電產業結構是很不相同的，然由此，可以了解光纖通訊產業的重要性。光纖通訊產業終究是會回春，可是眞正會是何時，嚴格來說，無人知曉，就如同 1999 年時的暴起。然而可以肯定，至少要等達康公司回春，要不就是要有新的應用興起。目前已有緩步成長趨勢，成長的力道主要來自新興國家的電信建設，或已開發國家的擴大建設，如：東南亞國家與大陸的一步到位電信建設，日本光纖到家之建設。

據了解，目前台灣光纖通訊相關廠商總數不減反增，已近百家，由此可感受到廠商對光纖通訊產業的期待，同時大家也應樂觀地展望台灣光纖通訊產業的未來發展。

十一、雷射與其他光電應用

就傳統雷射產業來看，過去 20 年來，台灣投入的非常有限。反觀大陸，遠多過於台灣，其原因應是，長年以來，大陸非常重視基礎研究，而台灣則投入光電應用產品的開發。目前傳統雷射應用產品廠商有一些，主要是雷射加工機，績效不錯者有星雲電腦等。

過去台灣在雷射指示器曾在世界市場上獨占鰲頭，也因此爲國內雷射二極體廠商找到新應用出路。可是好景不常，大陸廠商崛起，台商不敵其超低價，兵敗如山倒，目前僅剩一些生產高階產品之廠商存活，如方礎等。

至於光電檢測產品，高階的有雷射干涉儀，低階的有雷射水平儀等，整體而言，仍未成氣候。倒是雷射貼紙，造就出上市級公司，如光群。

參、台灣光電產業成功的關鍵性因素

台灣過去 20 年來在光電產業上的努力，已使台灣名列全球第三，可說是已擁有相當傲人的成績單。回顧過去，嘗試分析其成功的關鍵性因素，大致如下：

1.政府策略性領導與投入：早在 1985 年政策性投入政府資源，可說是，台灣今日

光電產業成功最具關鍵性的因素，亦是政府過去 20 年來最大之成就，嚴格來說，便是提供相較於其他國家，更佳之產業發展環境，並提出政策方針導引政府與民間資源投入方向。

2.海外高級光電人才儲備：人才乃發展工業首要之條件，香港、馬來西亞、新加坡想投入光電產業已多年，然一直未見成效，基本上應是人才總量，未達臨界值。台灣過去早年留美學人有不少是世界級光電專家，由於他們的指導或投入，成爲台灣發展光電產業之種子部隊，功不可沒。

3.系統培育相關人才：正如前文所述，1985 年投入光電產業之政策定案後，李資政交辦的第一項工作便是培訓光電相關人才。教育部每年編列 3000 萬，補助學校建立光電相關實驗室與訓練師資。長期下來，其所培育之初、中、高級人才，大都已成爲今日國內光電產業界重要幹部，甚至是領導人。

4.相關產業已具基礎：台灣擁有一流的資訊與半導體產業，加上具光學產業以及尙可的機械工業基礎，這些都是發展光電工業所不可或缺之條件，也是台灣發展光電工業的優勢。

5.相對充沛資金：光電產業不只是技術密集，也有不少產品是資本密集。以大面積 TFT 液晶顯示器爲例，每條生產線動輒數百億元，台灣已有 7-8 家公司投入，其總投資金額早就是以千億元爲單位。如此龐大的投資，如不是有充沛資金、優良的金融體系與籌資管道，台灣不可能號稱：2004 年台灣 TFT 液晶顯示器將成爲世界第一。

肆、台灣光電產業之隱憂

台灣光電產業在傲人成績單的背後，是有一絲的隱憂的，例如：

1.海外高級人才有限：近年來，由於台灣留學生逐年減少，海外高級光電人才充沛之優勢，已不復存在。

2.光電人才出現斷層：除了海外高級人才有限外，近來，國內各級光電人才已出現嚴重供不應求之現象。由於，資金大量投入光電產業之速度已遠超過人才之培養速度，甚至造成半導體人才流入光電產業之現象。

3.產業大量外移：近年來，台灣傳統產業大量外移中國大陸，其中亦不乏一些毛利低、較成熟之光電產品。此次產業外移，是史無前例，有不少是整個產業聚落集體外移，自然其對台灣經濟的衝擊亦是史無前例的。

4.競爭者崛起：台灣光電產業之起步時間，只比日本晚四年，係第三名起跑者。早年，我們只是個追隨者，緊跟著美、日。然而現在已是後有追兵，韓國與大陸的崛起，都是可敬的競爭者，一位是殺價高手，一位是低價高手。

5.基礎研究不足：過去 10 年來，無論學校或工研院之研究工作，或多或少都以市場爲導向，工研院前瞻性研發比例偏低，大學很多資源投入產學合作。基本上，過去這些政策並無所謂對錯，然而目前產業環境劇變，台灣未來能擁有之光電產業，將會是具有較高技術原創性含量者，因此，如果未來大部份光電產業無法根留台灣，便是過去基礎研究不足問題的浮現。

伍、台灣光電產業未來可能之發展

早年台灣光電產業只是追隨者，20 年後，有些產品已逐漸與世界領導者並駕齊驅。整體除了台灣產業地位提升外，國際大環境亦有很大的變化，尤其是競爭者崛起。我們不能再用過去的發展策略，去迎接新世代的台灣光電產業，正如前文所述，因爲，未來能存活在本土之光電產業，將是知識含量高，具獨特性之產品，會與過去 20 年台灣光電產業結構，有相當大的差別。台灣光電產業未來可能之發展方向爲：

1.二岸分工：產業外移乃大勢之所趨，不是政府能阻擋的，政策上，應依勢利導，做好二岸分工，乃上策也，實不能像　治水。未來，多量少樣置於世界工廠，少量多樣留台灣。台灣成爲營運中心，負責策略規劃、研發與行銷等工作，相信如此二岸分工，台灣之優勢會依然存在，更無產業空洞化之虞。

2.國際化：從本土企業，成爲跨國企業，乃企業國際化的第一步。由於台灣光電產業逐漸有些產品成爲世界第一，如欲長期維持霸業，有必要建立更高的進入障礙與競爭優勢，國際化是不可避免，因爲透過國際化，可取得更多競爭優勢，例如，進用各國優秀人才，或至他國設立研發單位，都是解決台灣本土資源有限之道。

3.創新研發：高科技產業與傳統產業之差異，便在於其技術含量的差異，因此長期投入研發乃發展高科技產業之要件。台灣過去並非單靠技術移轉，而無研發，只是過去研發過於偏重追隨者式的研發工作。未來，台灣本土產業之需求，將會是以具創新性之研發爲主。換言之，未來沒有擁有夠份量之知識財產權保護的產品或技術，將難以在台灣生根。

陸、結　語

多年來，台灣主要的經濟動脈，大都掌握在電子產業手上。電子產業目前係以資訊與半導體產業為「Cash Cow」；至於身為電子產業新生代的光電產業，其所扮演之角色便是「明日之星」。簡言之，光電產業將有機會成為台灣最重要的經濟大動脈，其重要性自然不言而喻。由於台灣資源有限，如何鑑往知來，將有限的資源投入正確的方向，避免惡性競爭，係政府與民間之首要工作。然而，如何借力使力，運用其他國家之資源，亦是不可或缺的工作。唯有如此，方能使台灣光電產業之優勢歷久不衰，維持與先進國家並駕齊驅之地位。

誌　謝

非常感謝華院長提供此機會，將個人過去十八年來，參與台灣光電科技與產業推動工作之經驗與淺見與大家分享。基本上，本文為產業歷史回顧之文章，偏重定性分析，期盼可供產業發展或學術研究策略方向思考用。

由於撰文時間極其有限，未列參考相關文獻，述及年代與統計數字，均仰賴個人記憶，誤差難免，尚請見諒。

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The Review and Prospect of Optoelectronic Industry in Taiwan

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Abstract

In this article I review Taiwan's experience in optoelectronic industry development, including the product, history, key success factor, and weakness, etc. for the past 20 years. The future directions of Taiwan optoelectronic industry is also discussed.

序列連結通訊之超取樣資料復原接收技術

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摘 要

本論文利用有別於傳統時脈萃取（clock extraction）技術的超取樣（oversampling）架構，來解決高速序列傳輸所遭遇之資料復原（data recovery）問題。採用超取樣技術設計一個全數位鎖相迴路（All-Digital Phase-Locked Loop, ADPLL）接收器。此接收器以一個四倍資料取樣器完成對接收位元多重取樣的動作，而平行位元組層級（byte-level）架構則大大減少系統時脈設計的複雜度。多數投票方法與相位對正機制克服傳送接收間所隱含的時脈頻率偏差問題。最後，以平行處理解碼器完成現今高速序列通訊常見之非歸零反向碼（Non-Return-to-Zero Inverted, NRZI）的解碼程序。

建構此規律性架構除了易於以積體電路形式製作外，以標準元件庫爲主（standard-cell-based）的設計流程與複雜式可規劃邏輯元件（Complex Programmable Logic Device, CPLD）的驗證方式亦可知，超取樣架構接收器確實可以增加傳輸資料速度之偏移誤差容忍度（deviation tolerance），來符合未來高速通訊的需求。

關鍵詞：超取樣（Oversampling），資料復原（Data Recovery），鎖相迴路（Phase-Locked Loop），非歸零反向碼（Non-Return-to-Zero Inverted code, NRZI）。

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前 言

序列通訊常用於遠距離連結，但由於信號衰減（attenuation）、抖動（jitter）等等干擾因素皆是隨著傳輸距離和速度之增加而愈見嚴重[1-3]，故通訊過程需要利用額外技術加以彌補這些因素的影響。此外，序列傳輸之傳送器和接收器時脈頻率是彼此獨立的，意即在連結過程中存在著時脈頻率偏差（frequency deviation）的問題[1-4]，亦造成序列裝置在通訊上的困難度增高，如圖 1 所示。

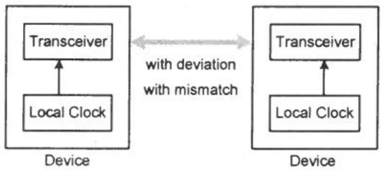

圖 1(a) 序列傳輸所存在之頻率偏差問題

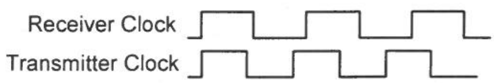

圖 1(b) 頻率偏差示意圖（傳送接收速率不同）

序列傳輸目前存在兩種應用，其一為傳輸器與接收器放置在同一系統中，稱為匯流排（bus）系統，例如電腦。在此架構下，各子區塊（sub-block）利用相同系統時脈作為共同時序的依據，如圖 2 所示，但若在更複雜、更高速的設計或非匯流排系統上，採用此種同步方式會受限於繞線（routing）之延遲。由於接收端採用和傳送端相同的整體時脈，或是接受傳送器經由不同路徑傳遞至接收端之時脈，來對資料作重定時序（retiming）的動作，以達成相位校正的目的。

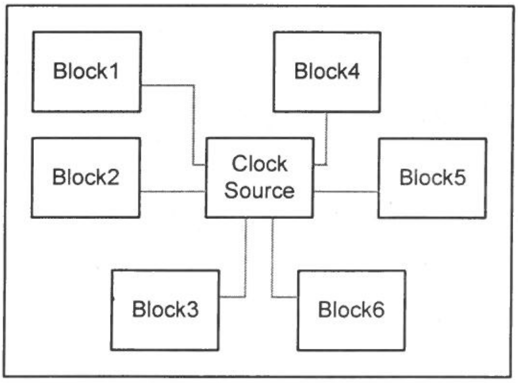

圖 2 匯流排系統時脈分佈

另一種應用情況，亦是最常見的遠距離連結通訊，由於成本考量，資訊傳遞過程並未包含任何外加之時脈機制，且其傳輸速率是根據最大傳輸距離與介面電路的組態而定。爲了完成如此同步工作，將時脈訊息嵌入至所欲傳送的資料之中，而接收端則從輸入資料位元變化中，來萃取出傳送端的時脈資訊。所得到的合成時脈，不僅用來移除接收資料之抖動（jitter）與失真（distortion）效應，更要完成重定時序的動作，以利後續資料處理[5]。爲解決這些問題，序列通訊有兩種資料復原技術，其一是時脈萃取（clock extraction），另一種稱爲超取樣架構（oversampling architecture）[7]。

（I）、序列傳輸之時脈與資料復原技術

利用時脈萃取來達成時脈復原　時脈萃取架構，利用本身時脈對接收信號的內嵌編碼加以轉換與校正，以取出傳送端所隱含的時序資訊。其電路不僅需要從接收資料來復原時脈，更要竭盡所能調整此時脈的時序邊緣以達到取樣資料之最佳時間點[5]。然而，一些非理想因素將會衝擊此時序邊界，造成取樣誤差。圖 3 顯示時脈萃取的取樣時間概念。

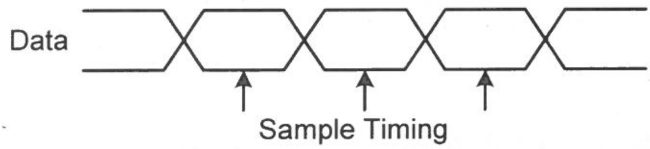

圖 3　時脈萃取之取樣時間

時脈萃取技術可以由延遲鎖定迴路（Delay-Locked Loop, DLL）或鎖相迴路（Phase-Locked Loop, PLL）來實現。其中，鎖相迴路技術不僅可以執行頻率合成、時脈與資料復原、減少時脈歪斜等等工作，更早已被廣泛使用在消費性電子、電腦和通訊領域中[8]，其基本概念如圖 4 所示。延遲鎖定迴路則大部分用在振盪器，用來鎖定或追蹤輸入信號的相位以及頻率，如圖 5 所示[11]。無論是延遲鎖定迴路或是鎖相迴路，其主要工作都在儘可能減少相位誤差，而當其輸入信號和輸出信號誤差非常小或零時，即被稱爲完成工作或是「鎖定」（locked）[12-13]。

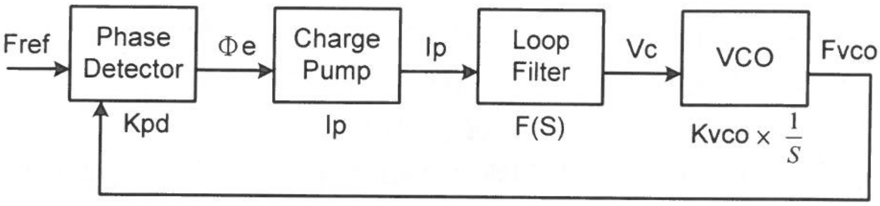

圖 4 鎖相迴路之基本架構圖[11]

鎖相迴路中，電壓控制振盪器（Voltage Controlled Oscillator, VCO）提供系統一個可變的時脈訊息，並與輸入資料相位相互比較，經由回授（feedback）機制，整體系統調整其相位差[8]。鎖定後之動態線性相位模型表示成轉換函數，如式子 1 所示，相位誤差函數亦列於式子 2[11]。其中 Kpd 為相位偵測器增益，單位（V/rad）；Kvco 是電壓控制振盪器增益，單位（Hz/V）；F（S）為濾波器轉移函數。

$$H_{PLL}(S)=\frac{\Theta out(S)}{\Theta ref(S)}=\frac{Kpd\times F(S)\times 2\pi Kvco\times\frac{1}{S}}{1+Kpd\times F(S)\times 2\pi Kvco\times\frac{1}{S}} \qquad (1)$$

$$H_{\Phi error\_PLL}(S)=\frac{\Theta\phi error(S)}{\Theta ref(S)}=\frac{1}{1+Kpd\times F(S)\times 2\pi Kvco\times\frac{1}{S}} \qquad (2)$$

延遲鎖定迴路中，電壓控制延遲線（Voltage Controlled Delay Line, VCDL）直接以延遲輸入數值來減少相位差。其鎖定後之動態線性相位模型表示成轉換函數，如式子 3 所示，相位誤差函數亦列於式子 4[11]。

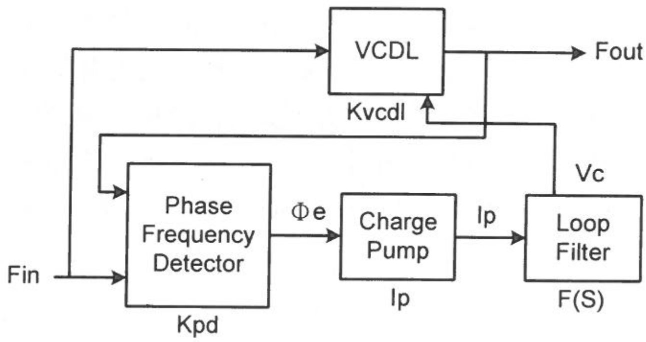

圖 5 延遲鎖定迴路之基本架構[11]

$$H_{DLL}(S)=\frac{\Theta out(S)}{\Theta ref(S)}=\frac{Kpd\times\frac{1}{S}\times 2\pi Kvcdl}{1+Kpd\times\frac{1}{S}\times 2\pi Kvcdl} \tag{3}$$

$$H_{\Phi error\_DLL}(S)=\frac{\Theta\phi error(S)}{\Theta ref(S)}=\frac{1}{1+Kpd\times\frac{1}{S}\times 2\pi Kvcdl} \tag{4}$$

追蹤能力是評估時脈萃取技術的重要指標之一，故在穩定性要求下，鎖相迴路的鎖定時間爲一重要參數。以頻率合成器爲例，當頻道之中心頻率改變時，鎖相迴路需要在有限時間內去建立符合此變化的新頻率，而穩定性與鎖定時間之判斷指標則是觀察新時脈需要多少時間來到達穩定狀況。假若輸入頻率改變得很慢，則在相當短的時間內就可以追蹤得到，但若輸入相位一直和鎖相迴路的頻率/相位保持固定差値，意指，輸入週期性訊號，但其相位卻隨時間不斷產生變化，將會使得時脈萃取系統於有限時間內無法達到穩定狀態，則稱此迴路爲未鎖定（unlocked）情況[8]。

以超取樣架構完成資料復原　超取樣架構和時脈萃取技術有著相當不同的取樣觀點。當時脈萃取傾向在位元區間放置最佳取樣時間點時，超取樣技術則是從接收信號之多重取樣得到額外的取樣訊息[7]，如圖 6 所示。此技術需要產生一個比傳輸速率來得高之任意操作頻率，只要確定此自由時脈能對輸入序列資料有著固定數目的取樣動作，以達到重建時序的目的即可[6-7]，如圖 7 所示。雖然時脈萃取在通訊上已是主要的技術，但從積體電路的觀點來看，超取樣架構是一個較經濟的純數位方式，不僅具備完成高速資料復原之能力，比起時脈萃取技術亦擁有較適合超大型積體電路製造的架構[7]。

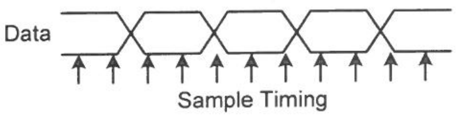

圖 6　超取樣之時序

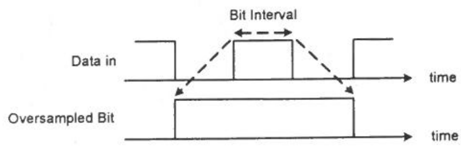

圖 7　利用超取樣技術以重建資料時序[9]

超取樣技術是一個順向操作（forward operation）系統，沒有類似鎖相迴路架構之回授路徑，運行速度並不會受到回授頻寬大小的限制。此外，利用數位觀點完成之相位移動作，不僅可減少雜訊干擾所造成的錯誤，並可引入已經發展相當成熟之數位信

號處理（Digital Signal Processing, DSP）技術，來協助後級電路的運作。

不同於時脈萃取架構一次只復原一個位元的資料，通常，超取樣技術掌握以平行字元（word＝N bits）爲單位之處理寬度。以通用序列資料埠（Universal Serial Bus, USB）第二版規格爲例[14]，若以N＝8（byte-level）而言，可選擇60MHz時脈。由於時脈速率只需位元速率的 N 分之一（八分之一），使得架構中之電壓控制振盪電路（Voltage Controlled Oscillator, VCO）在規格上可以稍微放鬆一點，來增加產品製造的良率。

取樣時序分析　時序分析（timing analysis）主要目的是爲了增加輸入資料的取樣時間邊界（timing margin）[10]，假若控制時脈取樣點在輸入樣本的中間，則理想上可以得到最大之邊界區間，如圖 8 所示[10]。時間邊界與取樣點關係可表示成式子5[10]。Tbit 表示接收位元時間寬度；Tos 表示鎖相迴路或鎖定延遲迴路中由於相位偵測死角（phase detect dead zone）以及在有限迴路頻寬（finite loop bandwidth）所影響之靜態取樣時間點偏移；Tjc 是由於壓控振盪器和相位偵測所造成的時脈抖動，Tjd 是由於傳輸時脈或通道效應形成的資料抖動，不同傳輸器時脈邊緣會造成不同的資料輸出時間，而頻道的內部符號干擾效應（Inter Symbol Interference, ISI）亦會影響資料傳輸之抖動狀況。若再把實際硬體實現問題加入考量，則 Tmargin 必須要比取樣設定時間（setup time）來得大。

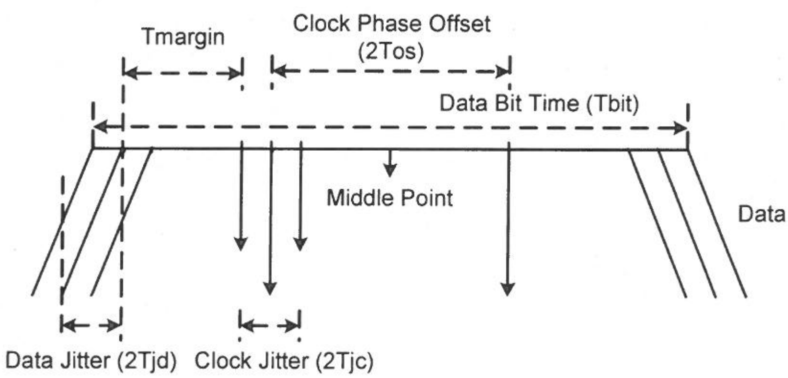

圖 8　取樣時間邊界[10]

$$\text{Tmargin} \geqq \frac{Tbit}{2} - \text{Tos} - \text{Tjc} - \text{Tjd} \tag{5}$$

資料取樣位置也會影響信號雜訊比的大小（Signal to Noise Ratio, SNR）。舉例而言，假設一個振幅爲 a 的三角波輸入，且其含有對於振幅參數標準偏差爲Δ_A的附加高

斯雜訊（Additive White Gaussian Noise, AWGN），如圖 9 所示，詳述其位元錯誤率（Bit Error Rate, BER）對於各式各樣之相位偏差 Δ Φ 以及振幅信號雜訊比的關係[10]。由圖可知，相位偏差將會使得取樣資料振幅下降，相對的，亦會使得信號雜訊比下降。假設取樣位置偏移 $\frac{\pi}{12}$ ，則資料必須增加額外 19-17＝2dB 的信號雜訊比，才能維持資料錯誤率在原來之 10^{-12} 狀況。

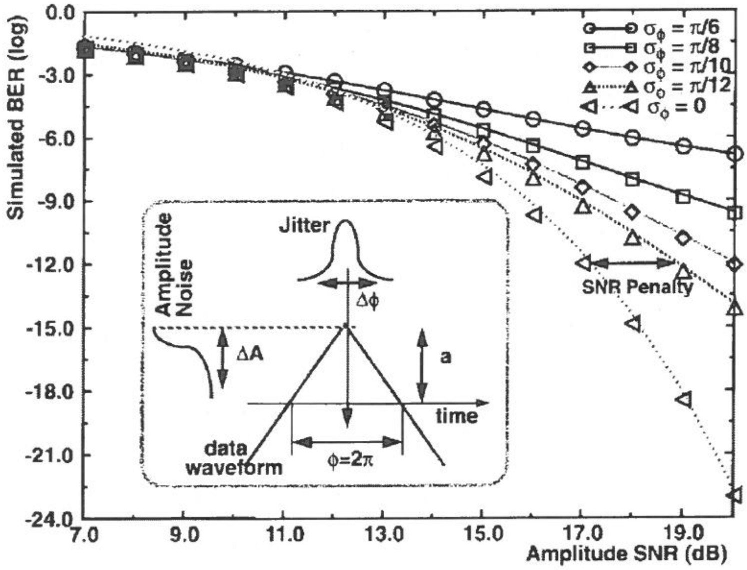

圖 9　在各種相位誤差下，位元錯誤率（BER）對於振幅信號雜訊比（SNR）的關係[10]

（II）、超取樣架構接收器之設計與模擬

整體資料流架構（Data Flow Architecture）　本論文所提出之系統乃利用超取樣技術達到接收與資料復原的動作，其概念如圖 10 所示，主要在給予實體層長距離數位資料連結之高頻寬傳輸與低位元錯誤率（Bit Error Rate, BER）的能力[16]。接收器利用本身時脈將輸入位元作四次超取樣動作，並輔助以相關的資料復原電路將取樣樣本依序還原成傳送器送出之資料，完成整體接收與資料復原的過程。

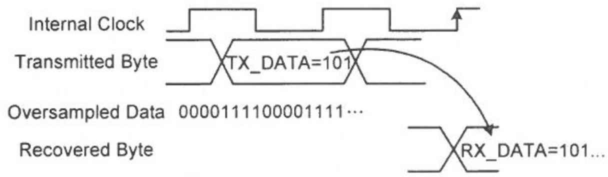

圖 10 超取樣技術完成資料復原[15]

從輸入序列資料串（serial data stream）至輸出以位元組（byte）爲基本單位的平行資料，完整資料流架構圖（data flow architecture）詳細顯示於圖 11[9-10,15]。主要包含將序列型態轉爲平行處理的資料超取樣區塊（data oversampler），連接完整封包的資料片段合併區塊（data frame combiner），爲了掌握輸入資料狀態的邊緣偵測區塊（edge detector），解決相對時脈位置偏差的對正區塊（aligner），多數決定投票區塊（majority voting），處理傳送接收速率不匹配之移動區塊（shifter）以及針對序列編碼處理之平行解碼區塊（parallel processing decoder）。

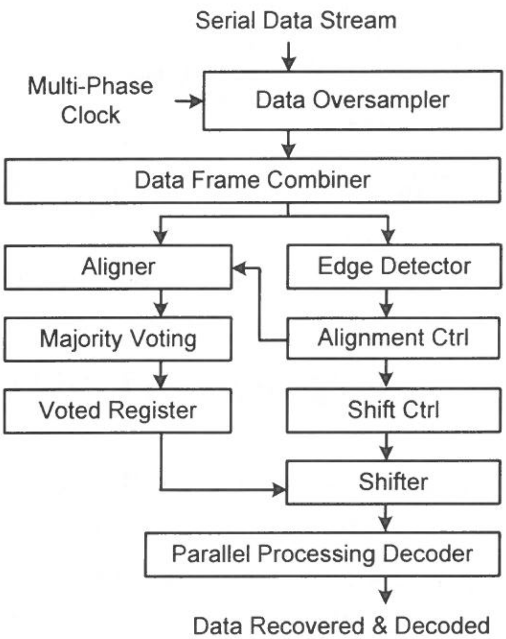

圖 11 接收器完整功能架構圖

超取樣架構之時序修正　接收器超取樣區塊，包含輸入序列資料、多重相位取樣時脈以及樣本時序（timing）之相對關係，如圖 12 所示。

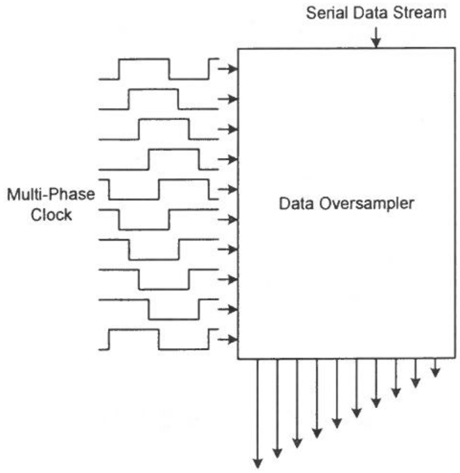

圖 12　**超取樣樣本時序**

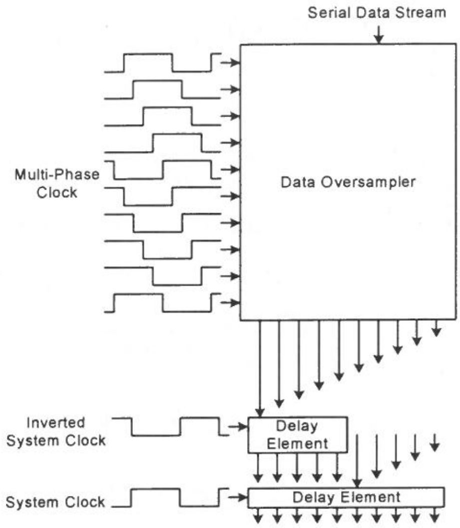

圖 13　**包含時序修正之超取樣區塊架構圖，線條箭頭長短代表樣本產生後所等待之時間**

圖中顯示，由於序列資料轉換爲平行處理之緣故，使得樣本因爲取樣先後而產生不同時間差。圖 12 中依箭頭長短來表示，線條越長代表樣本被取樣產生後經過較長的等待時間，越短則表示由較慢取樣時脈所生成。在龐大的平行處理架構中，如此樣本時間差情形，會使得同一取樣區間內，最早取樣樣本和最遲產生的取樣樣本，在相鄰兩系統時脈週期中，被下一級電路所分別讀取，造成平行資料時序上的錯誤。爲了避免發生此種錯誤，先利用一級負緣觸發儲存元件，對較早產生之前一半樣本作用半個時脈週期的時序延遲，再跟隨一級正緣觸發儲存元件，對所有取樣樣本作用一個完整的時脈延遲，這樣可將取樣樣本修正爲平行處理所需要的資料同步狀態。整體超取樣，包含時序修正區塊，如圖 13 所示。

（III）、接收器各子功能電路描述

1. 資料片段合併區塊（Data Frame Combiner Block）

現今序列連結（serial link）通訊中，傳送的資訊內容被包裝成特定資料封包格式（data packet format），封包格式概念如圖 14 所示。在此接收器架構中，爲了能完整處理各種封包內容，提出以部份位元延遲遞補的技巧，來連接封包資料之各個位元組

（byte）片段（因爲採用位元組架構），以利後級邊緣偵測電路能精確掌握封包內容的變化狀況。

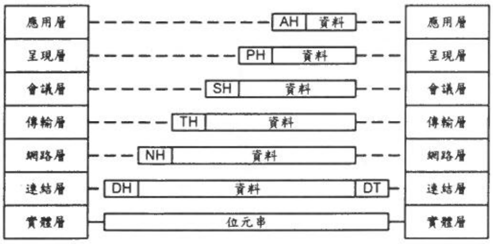

圖 14 資料封包的組成概念

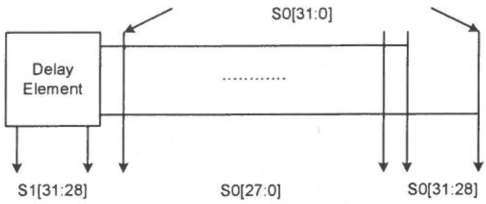

圖 15 資料合併區塊示意圖

遞補技巧採用延遲第 N-1 個時脈之最低權位的四個位元，來加入至第 N 個時脈取樣樣本的最高權位位置，如此形成完整三十六個位元的樣本組。資料片段合併架構圖，如圖 15 所示。符號 S1[31:28]代表經過延遲的第 N-1 個時脈之四個位元樣本，而 S0[31:0] 則表示本時脈所產生之三十二個取樣位元。經過資料片段合併後的完整樣本組，其格式如圖 16 所示。

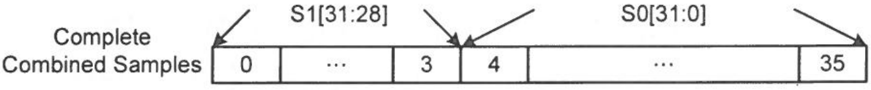

圖 16 合併後之完整樣本格式

2. 邊緣偵測區塊（Edge Detector Block）

此區塊主要功用，在針對取樣樣本內容作偵測動作，找出對應之通訊協定所需要的位元變化種類，並依此產生一組計算結果傳遞給後級電路，來作爲製造控制訊號的依據。在此，爲簡化設計概念，本架構並沒有假設在任何通訊協定之下，僅將區塊設計爲對所有接收訊號內容之 0→1 及 1→0 變化產生反應。邊緣偵測區塊爲一組合邏輯（combinational logic）電路，可對樣本內容作連續、快速的追蹤，並即時產生控制訊號，其邏輯方程列於式子 6。

edge[n] ＝ {(not sample[n]) and（not sample[n+1]） and (sample[n+2]) and (sample[n+3])} or {（sample[n]） and (sample[n+1]) and (not sample[n+2]) and (not sample[n+3])}, n ＝ 0~31 （6）

信號位元 edge[31:0]包含所有即時邊緣訊息，而 sample[0]至 sample[34]則為資料結合後之完整取樣樣本。由於採用四次超取樣架構，故以四個樣本為一組，作逐步的檢查動作。當偵測到 0011 或 1100 樣本時（相對應接收信號為 0→1 或 1→0 變化），邊緣輸出信號顯示為 1。換句話說，當 edge[n]為 1，意指 sample[n+1]、sample[n+2]樣本之間存在 0→1 或 1→0 的變化，更可進一步顯示，sample[n+2]、sample[n+3]、sample[n+4]和 sample[n+5]是由同一個接收位元所產生而來的四個超取樣樣本。

3. 對正控制訊號產生區塊（Alignment Controller Block）

此區塊主要根據樣本內容之切換變化模式，將所接收的邊緣偵測訊號組，經由運算後，產生一組四位元控制信號指標，以表示傳送資料位元和接收時脈間相對位置的關係。後級電路可依此控制訊號的變換狀況，即能以適當操作加以復原所接收之序列資料。控制訊號產生區塊，將三十二位元的邊界偵測結果，經由運算合併成四位元的控制訊號，其邏輯概念如式 7 所示。為了以此四位元信號來描述所有邊界的偵測狀況，故利用邏輯或（or gate）來對各個偵測訊號加以連接，意指，任何一個偵測到 0011 或 1100 的邊緣信號，都會讓控制訊號變成 1。

phase[0]＝edge[0] or edge[4] or edge [8] … or edge[28]

phase[1]＝edge[1] or edge[5] or edge [9] … or edge[29]

phase[2]＝edge[2] or edge[6] or edge [10] … or edge[30]

phase[3]＝edge[3] or edge[7] or edge [11] … or edge[31] （7）

在理想狀況下（傳收資料頻率和接收時脈間沒有相對位置偏移），所產生之控制訊號會將所有出現的 1 合併在同一個控制位元中。為了詳細描述此控制信號在不同情形之變化，假定接收位元為 0010 之簡單例子來加以說明，如圖 17 所示。接收位元 0010，經由超取樣步驟成為 0000 0000 1111 0000，再根據式子 6 所述，轉換成為邊緣訊號（edge signal） 0000 0000 0100 0100，最後利用式子 7 合併成為控制訊號（phase signal） 0100。若在傳收資料頻率和接收器時脈間，存在相對位置偏移的情況，則控制信號會根據偏移位置種類與偏移程度多寡，產生各種不同的位元變化。完整的六種變化類型如圖 18 所示。

Condition	Normal
Received Data	0010
Sampled Bits	0000 0000 1111 0000
Edge Signal	0000 0000 0100 0100
Phase Signal	0100

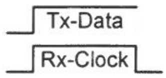

圖 17　在傳送接收間沒有位置偏移之控制訊號情形

圖 18（a）接收時脈比傳送資料慢了（偏移）一個位元，此情形下，超取樣位元比理想狀況向左偏移一個位元位置，所對應之邊緣偵測（edge signal,式子 6）與控制訊號（phase signal,式子 7）亦隨著改變。

圖 18（b）與圖 18（c）各是在接收時脈比傳送資料慢（偏移）兩位元與三位元的情形。超取樣樣本依序向左偏兩個與三個位元位置，根據式子 6 與式子 7 亦可推導出所對應的邊緣偵測與校正控制訊號。

圖 18（d）顯示接收時脈比起傳輸資料頻率快了（偏移）一個位元位置，因此超取樣樣本即提前一個位元位置出現（右移），依據式子 6 與式子 7 可得對應之邊緣偵測與控制訊號，結果顯示於圖 18（e）與圖 18（f）中。

Condition	Slow 1 Bit
Received Data	0010
Sampled Bits	0000 0001 1110 0000
Edge Signal	0000 0000 1000 1000
Phase Signal	1000

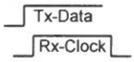

圖 18(a)　接收時脈落後一個位元位置

Condition	Fast 1 Bit
Received Data	0010
Sampled Bits	0000 0000 0111 1000
Edge Signal	0000 0000 0010 0010
Phase Signal	0010

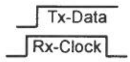

圖 18(b)　接收時脈落後二個位元位置

Condition	Slow 2 Bit
Received Data	0010
Sampled Bits	0000 0011 1100 0000
Edge Signal	0000 0001 0001 0000
Phase Signal	0001

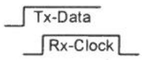

圖 18(b)　接收時脈落後二個位元位置

Condition	Slow 2 Bit
Received Data	0010
Sampled Bits	0000 0011 1100 0000
Edge Signal	0000 0001 0001 0000
Phase Signal	0001

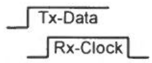

圖 18(e)　接收時脈領先二個位元位置

Condition	Slow 3 Bit
Received Data	0010
Sampled Bits	0000 0111 1000 0000
Edge Signal	0000 0010 0010 0000
Phase Signal	0010

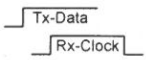

圖 18(c)　接收時脈落後三個位元位置

Condition	Fast 3 Bit
Received Data	0010
Sampled Bits	0000 0000 0001 1110
Edge Signal	0000 0000 0000 1000
Phase Signal	1000

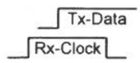

圖 18(f)　接收時脈領先三個位元位置

綜合以上之推導，將所產生的控制訊號變化歸納爲四類（0001，0010，0100，1000），若再根據取樣樣本的移動方式可知，落後一位元所產生的控制狀態等效於領先三位元的情形、落後兩位元之控制模式等效於領先兩位元的情況、落後三位元的控制情形等效於領先一位元的狀態，因此後級對正電路區塊，即可藉由這些控制訊號的變化類型，來對取樣樣本作反向之位元對正動作，以獲得最準確之投票結果。

4.對正區塊（Aligner Block）

根據校正控制訊號的輸入狀態，對正區塊可對合併後之完整樣本加以調整，以消除傳送端頻率與接收端時脈間存在的相對位置偏移效應。由上一節詳細推導結論可知，除理想情形外，每種控制訊號都對應了一種領先狀態與一種落後狀態，其背後所代表之意義即是樣本相對位置的左移（往高位元移動）或右移（往低位元移動）。

舉例而言，若接收控制訊號爲 1000 時，代表取樣位元往高位元偏移了一個位元位置（左移），所以對正區塊必須將完整樣本往低位元移動一個位置（右移），或是將投票區塊視窗往高位元移動一個位元（左移），來補償此種偏移的效應。同理，控制訊號 1000 亦代表位元視窗往低位元偏移了三個位元位置（右移），所以對正區塊必須將完整樣本往高位元移動三個位置（左移），或是將投票區塊視窗往低位元移動三個位元（右移），來補償此種偏移的效應。

5.多數投票區塊（Majority Voting Block）

在此架構中，每個時脈欲還原一個位元組（八個位元）的資料，故可將投票區塊分割爲八個獨立的投票者（voter cell），用來對所有取樣樣本作並行處理（parallel processing）。無論在理想情形或存在相對位置偏差的狀態，區塊中每個投票者所接收之樣本，都以四個爲一組且經由校正區塊依據控制訊號變化所調整過的。由上節推導出來之位置偏移狀態，可將完整樣本與控制信號的四種相對關係，映對於圖 19 中。

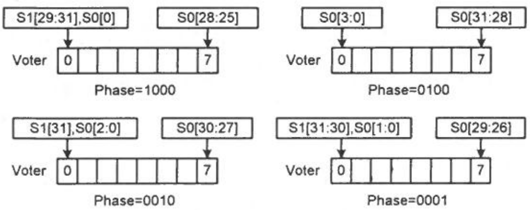

圖 19　完整樣本相對於控制訊號之位置定義

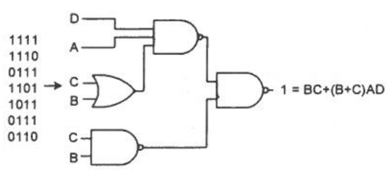

圖 20　單一投票者邏輯圖與投票方式

單一投票者之結果，由四個位元爲一組的樣本內容來決定，採用最簡單的原則，在內容中佔多數的位元就爲輸出信號，詳細概念與邏輯電路顯示於圖 20。其中需要注意的，當四個樣本中有相同數目的 0 與 1 時，本架構定義以樣本中間之兩個位元爲主要的決策依據，呼應超取樣區塊中所討論的邊界位元錯誤問題。此種多數投票方式，不僅提供還原機制較大的正確機率，亦給高速通訊應用上賦予更多還原能力的發展空間。

6. 投票儲存區塊（Voted Register Block）

建構此區塊之主要目的，在儲存多組投票結果以提供給移位區塊，使其可以根據控制訊號之變化種類，來合併出最後完整的位元組資料，更進一步，希望利用各組投票結果在時間上的相依關係，同時解決移位區塊中存在的位元重複（bit duplication）與位元遺失（bit lost）問題。

此區塊硬體架構爲一連串儲存元件所組成的暫存器行列（register file）。其所應具備的大小，與期望處理之接收速率以及傳送接收間頻率誤差有著直接的關係。若希望應用在更高速序列通訊的領域上，或是針對先天頻率誤差有著更寬大之忍耐度，將此簡單且規律的架構加以擴展，即能在規格上達到一定程度的提升，比起時脈萃取技術必須針對要求條件加以重新設計製程參數，具有更大的應用彈性。

7. 移位控制區塊（Shift Controller Block）

移位控制和校正控制的動作機構甚爲相似，不同是此區塊根據校正控制訊號的改變，來觀察傳送端與接收端是否存在頻率偏差（frequency deviation）之狀況，並偵測彼此不匹配程度，以產生移位控制訊號給後級之移位區塊。

8. 移動區塊（Shifter Block）

（1）無頻率偏移狀況

接收移位控制區塊所產生之控制信號，以及三組爲一群的投票暫存檔，開始依據兩個計數器的獨立數值狀況，將三組投票儲存資料作適當的合併處理，完成復原過程之最後步驟。當傳送接收間沒有頻率誤差，移位控制計數器並不會動作，意指每次產生的位元位置必定彼此相等。此種狀況下，前一時脈的資料片段不需要移位，且輸出結果即爲原來的資料片段，如圖 21 所示。位元輸出通式表示爲式子 8，其中 voter 代表投票結果，output 爲完成復原過程之平行輸出資料。

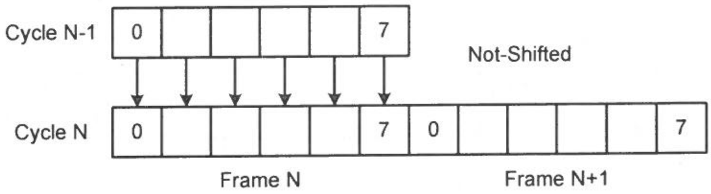

圖 21　沒有頻率誤差的移位區塊輸出狀況

output[n]=voter[n], n=0~7 （8）

（2）存在頻率偏差狀況

假若存在頻率誤差的狀況（傳送接收頻率有些許不同），則每次產生之位元視窗位置必須要利用左移或右移的動作加以調整，以補償先前所提及之相對位移所造成的位元錯誤。

傳送器快於接收器　當傳送器速度持續快於接收器時，會使得控制訊號變化為 0100→0110→0010→0011→0001→1001→1000→1100→0100 （控制位元右移），並且，由所定義之校正方式可知，只有當 1000→1100→0100 （右移計數器動作）狀況發生時，校正作用才將投票者視窗往低位元移動三個位元以修正投票結果。事實上，根據校正控制訊號之推導過程，此相對位元位置是前一時脈視窗位置往高位元移動的效應，故此狀況下，必須將前一時脈的輸出視窗加以左移修正，以得到正確的輸出資料，如圖 22 所示。

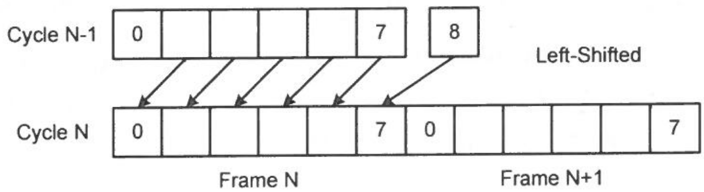

圖 22　傳輸速度快於接收速度的移位區塊輸出狀況

output[n]＝voter[n+1], n=0~7 （9）

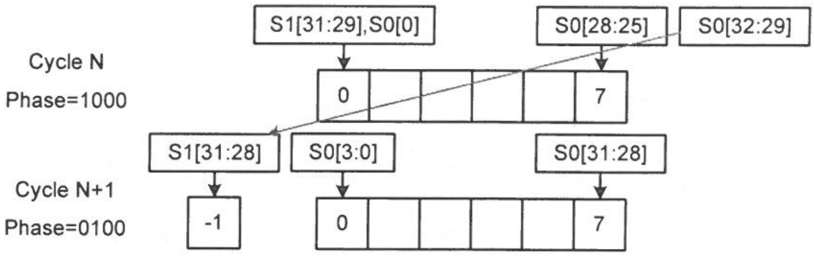

圖 23　位元遺失問題與額外的投票者

承上所述，其輸出通式表示為式子 9，其中 voter[8]為解決相對位置偏移所增加之額外投票者，詳述如後。左移過程會使得高位元投票遺失一個最高位元，而產生溢位（overflow）效應，稱為位元遺失（bit lost）問題。如圖 23 所示，為了不遺失此投票之最高位元結果，採用一個額外的獨立投票者針對 S0[32:29]或 S1[31:28]（因為資料合併緣故，會使得 S0[32:29]與 S1[31:28]相同）來加以處理，以補償此位元遺失的效應（也一併解決校正控制區塊中，以低位元的相對移動代替往高位元移動之位元遺失問題）。

傳送器慢於接收器　若傳送器速度持續慢於接收器，會使得控制訊號變化為 0100→1100→1000→1001→0001→0011→0010→0110→0100（控制位元左移）。且由控制訊號所定義之校正方式可知，只有當 0100→1100→1000 的狀況發生時（左移計數器動作），會讓此時脈相對位元位置為前一個時脈資料往高位元移動的結果，使得輸出視窗右移，造成復原結果一個相對位元的誤差，如圖 24 所示。在此情形下，因為投票視窗往高位元移動的修正動作會造成最高位元和下一時脈之最低投票位元相同（如圖 25 所示，在資料合併區塊的作用下，會使得 S0[31:28]和 S1[31:29]，S0[0]的投票結果相等），稱為位元重複（bit duplication）問題。將此重複位元加以丟棄，以完成資料復原動作。在此，其輸出通式如式子 10 所示。計數 n 由 1 開始，是因為此時脈投票結果的最低位元（n＝0），和前一時脈的最高位元相同。

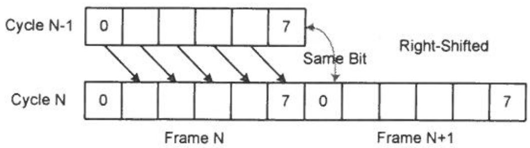

圖 24　傳輸速度慢於接收速度的移位區塊輸出狀況

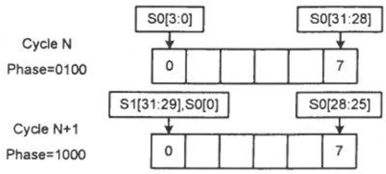

圖 25　位元重複問題示意圖

output[n]=voter[n-1], n=1~7　　　　（10）

9.平行解碼區塊（Parallel Processing Decoder Block）

採用超取樣技術來處理序列通訊的架構中，多相位取樣時脈將序列資料轉爲平行位元，以提供給後級電路加以處理。序列傳輸編碼或解碼若轉爲平行處理，原本所具備的優點也許會成爲需要突破之瓶頸。一般而言，若採用時脈萃取技術來完成資料復原，則搭配隱含時脈的編碼方式（具有自我時序），會使得電路表現有較佳的復原效果；但若採用超取樣技術來完成資料復原，則沒有這方面的考量與顧慮。以下就以不含有傳輸時脈資訊（不具備自我時序）、以及最適合高頻寬傳輸之 NRZI 編碼，來完成平行解碼之架構與動作。

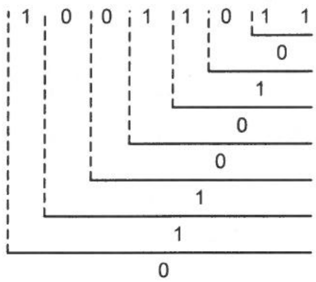

圖 26　平行編碼概念

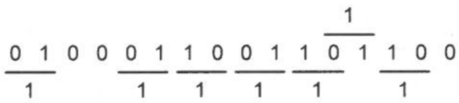

圖 27　平行解碼概念

根據先前所述之序列 NRZI 編碼原則，由目前資料數值來維持前一位元或改變前一位元的狀態，簡單的說，其編碼原則與時間是息息相關的，需要知道先後資料彼此的關係才能進行動作；同樣的，在序列解碼的原則上，亦要針對前後位元的關係加以偵測，並以相反於編碼的原則，來完成解碼的過程。序列型式中，單一正反器即能依循每個時脈的觸發，來替 NRZI 資料進行解碼。

平行解碼或編碼也採用和序列型式相同的編解碼方式。偵測兩兩相鄰樣本間的異同，來作出符合編碼或解碼的位元變化，如圖 26 與圖 27 所示。在硬體製作上，則是希望推導出符合平行架構優點的方式，讓衆多平行位元在一個時脈動作內處理完成，且在越龐大的平行架構之下，越能增加系統操作效率。所推導出之平行編碼方式，其邏輯概念如式 11 所示，平行解碼邏輯則顯示於式 12 中。

NRZI 平行編碼邏輯關係式：

nrzi[n]＝data[-1] xor data[0] xor data[1]… xor data[n-1] xor data[n], n=0~7　（11）

NRZI 平行解碼邏輯關係式：

data[n]＝nrzi[n-1] xor nrzi[n], n=0~7　（12）

上式編號各自代表獨立的平行資料線路，其中需要注意的是，若編號爲-1，則表示此線路是前一時脈之最高位元，經過一時脈週期延遲後的信號。從式（11）可以發現，若其位元位置越高，所需要同時處理的資料線就越多，這是爲了解決平行編碼在時間上的相依關係，所導入類似前瞻進位（look carry ahead）的原則，如此一來，可在龐大的平行處理系統上可以增加編碼的效率。

（IV）. 整體接收器的行為模擬與探討

1.完整接收器之功能

爲了初步模擬接收傳送頻率偏差的狀況，並且驗證所計算之暫存檔案容量是否符合系統需要，在此必須作一些設計參數上之假設，如表 1 所示。模擬結果如圖 28 至圖 30 所示。從圖中可知，此架構在經過七個時脈週期延遲（latency）後（包含平行解碼器），達到接收資料復原的功能。

接收資料速率	500Mbps	位元寬度時間	2nsec
整體系統時脈	62.5MHz	半週期時間	8nsec
等效取樣時脈	2000MHz	取樣時脈相位差	0.5nsec
固定封包長度	10000bit	封包間隔時間	10bit

表 1　接收器模擬參數的設計

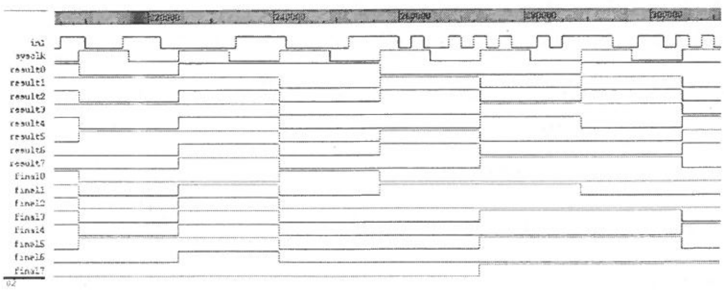

圖 28　傳送與接收間為理想狀態（TX＝RX）

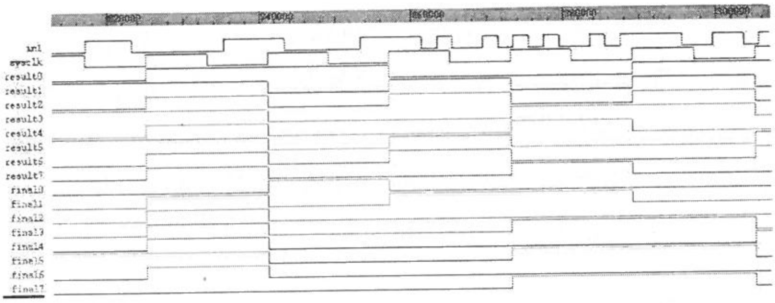

圖 29 傳送器比接收器慢的狀態（TX＜RX）

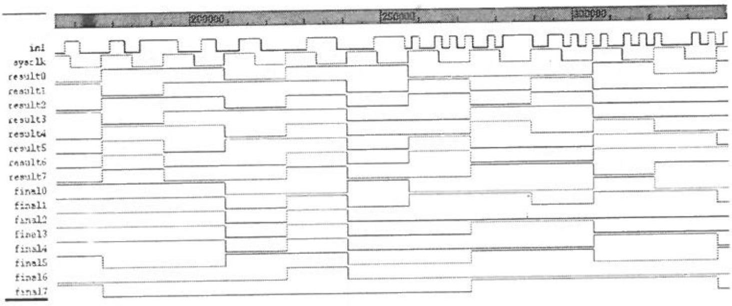

圖 30 傳送器比接收器快的狀態（TX＞RX）

2. 暫存檔案大小與頻率偏移程度之關係

無論是傳送比接收快或慢，假定暫存器都能彌補此種效應的影響，還原出正確之資料結果，則其關係如下所示。

Register Size ＝ Maximum Frequency Deviation × Packet Format Length

假設封包長度爲10000 位元，若頻率偏移爲±500ppm 則暫存器大小至少必須爲 10 位元。

（V）.電路合成與硬體驗證

1. 電路合成環境簡介

本論文中，採用 Synopsys 與 Altera 合作開發的高階邏輯合成（high level logic synthesis）軟體 FPGA Express 3.4 版來將行爲模式（behavior model）的設計轉爲邏輯層電

路（logic level）並給使用者對所欲燒錄之 FPGA/CPLD 晶片作系統最佳化之電路映射（mapping）。圖 31 顯示 FPGA Express 在整體設計流程中所扮演的角色。經過 FPGA Express 高階合成與元件最佳化後，可將所需之電路檔（netlist）轉換成晶片燒錄檔格式（HDL 或 EDIF），輸出給 FPGA/CPLD 的佈局與繞線（Placement and Routing, P&R）軟體，來完成晶片之時序分析與燒錄的工作。如圖 32 所示。

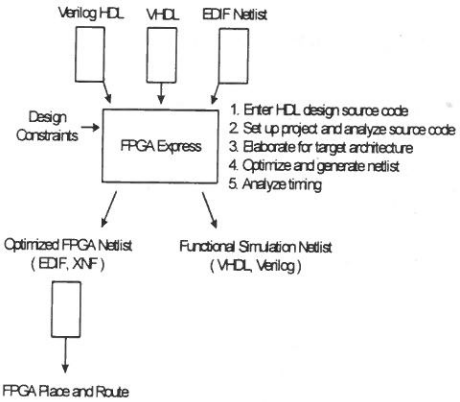

圖 31　FPGA Express 設計流程概觀[17]

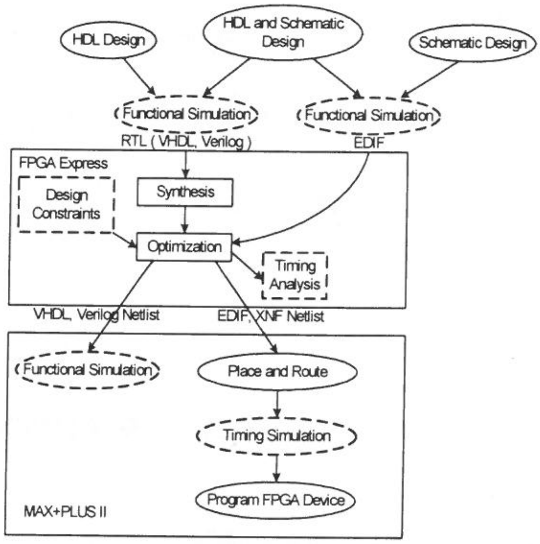

圖 32　整體晶片實現流程[17]

2. 晶片硬體驗證

本篇論文所提出之架構，主要用來克服傳輸頻率不同步或時脈製造不匹配的情形，如此眞實狀況下所遭遇之問題，最佳的驗證方式即爲建立完整平台來模擬其使用環境，檢視晶片在整體運作情形的實際成效。

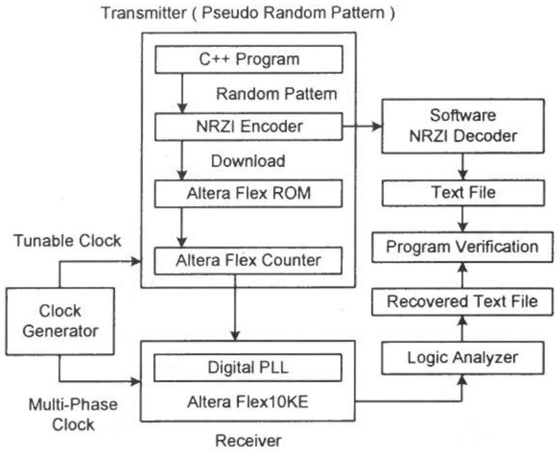

圖 33　完整驗證平台的流程架構

3. 驗證平台和軟體建置

完整驗證平台可概略分爲個人電腦爲主的軟硬體介面、圖樣（pattern）傳送模擬器、硬體晶片接收器三個部分，詳細架構及流程如圖 33 所示。

序列通訊接收器（包含超取樣架構和資料復原電路）完整燒錄於 Altera Flex10KE 系列之複雜式可規劃邏輯元件中（Complex Programmable Logic Device, CPLD），就如同已經下線製造完成的晶片，對其送入不同資料型態和傳輸狀況的訊號，測量輸出數值與預期結果相比較，並重複此過程來完成整體晶片驗證。接收器電路除了接受傳送器送出之信號外，還需要外加系統操作時脈及多相位超取樣時脈。這些時脈是由建構在個人電腦上的時脈產生器（clock generator）所送出，經由硬體廠商所搭配的軟體操控介面，可以輕易調整出所期望之時脈頻率。

使用另一顆 Altera CPLD 晶片來規劃傳送器電路，送出假隨機圖樣（pseudo random pattern）來模擬傳輸之眞實狀況。爲此目的，須結合軟體產生隨機資料的能力，配合 Altera 驗證板及 Max + Plus II 的燒錄功能，方可達成。在此平台架構中，整體傳送器模擬是由個人電腦連接 Altera 驗證板所構成。

平台第三部分，包含建構於個人電腦之量測儀器、軟體操控介面、可程式邏輯元件的燒錄軟體，以及爲了彌補部份不足功能而自行開發的小型程式。硬體量測儀器採用皇晶科技 Acute LA1164P 邏輯分析儀（最大擷取頻率 200MHz，4 個取樣時脈解析度，32 個通道，128KByte 記憶深度）和 Acute PG1050 可程式時脈產生器（最大 200MHz 的時脈產生速率）。

4. 硬體驗證流程及方法

傳送流程分爲三個階段。步驟一是利用自行建置的 C++程式語言產生數組固定長度、隨機內容之資料，並儲存爲燒錄軟體可讀取的檔案格式，作爲模擬傳送封包內容之依據。可供晶片燒錄軟體辨認的隨機檔案型態，可參考附錄說明。步驟二是由 CPLD 燒錄軟體讀取此隨機內容封包檔案，並燒錄至規劃成唯讀記憶體（Read Only Memory, ROM）之 CPLD 晶片中。步驟三則利用規劃成計數器的 CPLD 晶片，循序指向唯讀記憶體的定址位置（address），讀取及送出該記憶體位置儲存的位元內容，用來模擬傳送器連續送出假隨機資料的模式（雖然整個封包內容是隨機狀態，但計數器完成一輪定址動作後，就從頭再一次開始，形成長時間觀察下的規律圖樣，稱之爲假隨機圖樣）。整體傳送器概念如圖 34 所示。

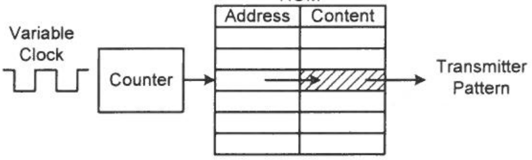

圖 34 整體傳送器模擬概念

如前所述，時脈產生器（clock generator）提供可變的系統時脈給傳送器，依循控制訊號送出隨機資料給接收器；產生器亦提供系統時脈和多重相位取樣時脈給接收器，以對接收位元作超取樣及資料復原的動作。經由復原過程後，利用邏輯分析儀加以量測，並搭配其軟體操控介面擷取偵測結果，來產生復原檔案儲存於電腦之中。同理，傳送器架構若採用軟體 NRZI 編碼器，則編碼結果除了送入唯讀記憶體的燒錄檔外，亦利用和硬體架構相同的軟體 NRZI 解碼器先行解碼存檔，兩個檔案（邏輯分析儀產生檔以及軟體解碼器產生檔）在自行建立的小型程式中，一一比對內容並標示出錯誤的位元位置與個數，如此完成整體驗證流程。

5. 驗證結果

爲了和軟體模擬的結果作一個基本對照，亦將封包容量設定爲 10000 個位元大小（C++程式所產生的隨機圖樣數目與唯讀記憶體容量需要跟隨配合）。除了驗證接收資料是否正確之外，並嘗試改變傳輸器的系統時脈（模擬傳輸器頻率比接收器快或慢

時），不斷重複驗證接收器所能忍受的頻率偏差程度。在此，我們並沒有假設任何位元錯誤率（Bit Error Rate, BER）的標準，以全部資料都完全復原正確之狀況來加以計算。

如圖 35 所示，為傳送器與接收器間擁有頻率偏差的 FPGA/CPLD 驗證情形，經由數位邏輯分析儀所測量出之結果。符號 infast 是代表傳送器頻率較接收器快的情況，而 inslow 是代表傳送器頻率較接收器慢的狀態，in 則表示傳送接收間完全沒有頻率誤差的理想狀況。由圖中所知，序列資料在七個時脈的潛伏時間（latency）後（包含平行解碼器），被同時復原成一個位元組的平行形式資料。

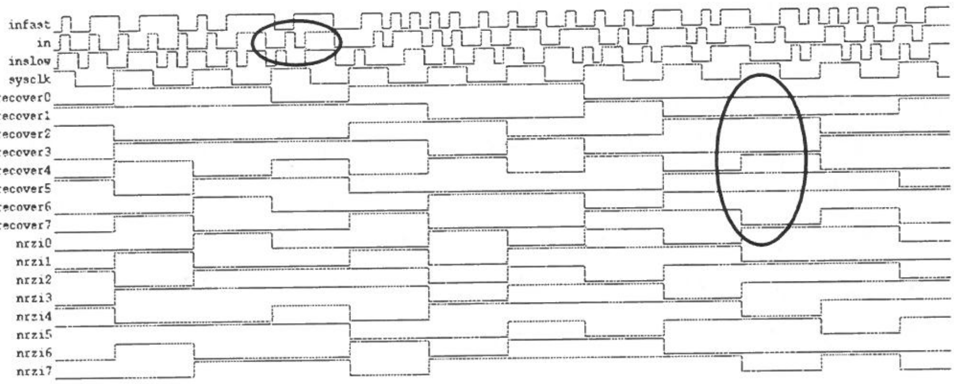

圖 35 當傳送器與接收器擁有頻率偏差情況的邏輯分析儀量測結果

由硬體驗證所測量的結果發現，距離理論分析的 1600ppm 還有一段距離，歸納其中因素包含有：一、所送入之圖樣（pattern）包含比較特殊的例子，如八個連續之 1 或 0。在此種情形下，會使得接收器內部之邊緣偵測區塊展現極致之能力（利用時脈位置偏差，在三十二個取樣樣本中只出現一個切換邊緣），導致些許位元之鎖定失誤。二、FPGA/CPLD 先天速度的限制，使得在此高速操作中（等效取樣時脈 625MHz），即使沒有頻率偏移的狀況下，也會導致取樣錯誤之狀況出現頻繁，超出系統設計所能容忍的範圍與情形。三、在超取樣架構之積體電路設計上，必須要保留系統時間邊界（system-time margin）[16]，意指，理論與實際電路實現上原本就存有誤差空間，只要在容許範圍內就應該被設計者所接受。

(VI).結　論

在本篇論文中，提出了一個嶄新的超取樣架構來實現序列通訊接收器，其不僅可以適用於未來高速的序列連結，更有利於現今成熟的積體電路製造技術。

利用資料流演算法的高階合成觀點，描述整體接收器之功能，不僅減少了繁雜的硬體架構設計，更適用所有特殊應用積體電路（Application-Specific Integrated Circuit, ASIC）的實現方法與 CMOS 製程，對於設計時間與製造成本，亦可大大的降低。

此超取樣架構接收器採用位元組層級的平行處理機制，除了簡化時脈設計時所遭遇的困難外，更加速系統所能處理之資料速度。其中的控制信號產生電路，可以輕易更改設計內容來適應各種不同的通訊協定，而校正電路與移位電路一起克服了序列通訊中頻率不匹配與時脈相對位置誤差的問題。平行處理解碼器則解決了非歸零反向編碼在超取樣架構中的解碼問題。

利用平台驗證的結果，顯示此正向操作（feed-forward）接收器比起回授（feed-back）架構的類比鎖相迴路有著更高的頻率誤差忍耐度（爲現今通用序列埠第二版規格要求的三倍），且其規律性的構造，對於更高速之應用亦相當容易加以延伸和擴展。由硬體的反覆驗證中，檢驗了晶片使用眞實狀況，故可將此設計包裝爲矽智產，重複使用在系統單晶片或嵌入式系統的通訊功能函數中。

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An Oversampling Data Recovery Receiving Technique for Serial Link Communications

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Abstract

This paper investigates an oversampling architecture for high-speed data recovery in serial link communications, which it provides another alternative in addition to the conventional clock / data extraction approach.By taking advantage of the All-Digital Phase-Locked Loop (ADPLL) receiver with the oversampling technique and digital signal algorithms, we can simplify data recovery processes. The receiver comprises a four-time data oversampler to sample received bits, and a parallel byte-level architecture to reduce the complexity of the system clock configuration. According to the communication protocol, the detection of a sampled datum can generate control signals for all of the circuit blocks. The majority voting method and aligner mechanism overcome the clock asynchronous problems. The collective shifter and register file block solve frequency deviation between transmitter and receiver. Finally, adopting parallel processing skill accomplishes NRZI (Non-Return-to-Zero Inverted) decoding procedure which is popular in the state-of-the-art high-speed serial link.

The regular architecture is suitable for the integrated circuit implementation. Moreover, the oversampling receiver does increase the data drift tolerance from the cell-based design flow and the CPLD (Complex Programmable Logic Device) emulation. It conforms to the demand in high-speed communications.

Key Words **:** Oversampling, data recovery, plase-locked loop, NRZI.

Academic achievement and self-concept: Chinese and Japanese adolescents

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Abstract

The present study examined, on the multicultural level, and in the Eastern cultural context, the relationship between academic achievement and self-concept in general and specific domains. Using the multidimensional Tennessee Self-Concept Scale (TSCS, Roid & Fitts, 1988), data from 370 high school students from Taiwan (Republic of China) and Japan indicated that high achieving students had superior views in overall as well as some specific domains of self (physical, moral-ethical, family, identity, self-satisfaction). Mainly for Japanese adolescents, satisfaction with parental relations was positively associated with all aspects of self-concept. The Japanese adolescents were also superior in general as well as some domains of self-concept (physical self, family self, and identity) to the Chinese. Results are discussed in a cross-cultural context taking into account characteristics of the East Asian Confucian societies.

Key Words: academic achievement, self-concept, parental factors, cross-cultural study, Chinese and Japanese adolescents

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INTRODUCTION

Theorists like Erik Erikson (1968) believe that developing a coherent personal identity is a major task of adolescence. Numerous psychological studies have shown that the formation of a stable and positive self-concept is not only one of the major challenges in adolescence but also has widespread and long-lasting effects in many aspects of life (Marcia, 1980; Felson, 1984; Tenner & Herzberger, 1987; Lu & Wu, 1998). Undoubtedly, the school, as a fundamental socialization agent and a focal life domain, has an important influence on adolescents' development of self-concept.

The nature and development of self-concept

Self-concept as a theoretical construct has both numerous synonyms and definitions. Broadly defined, self-concept consists our perceptions of ourselves (Shavelson & Bolus, 1982). According to Burns (1979), self-concept is a psychological entity which includes our feelings, evaluations, and attitudes, as well as descriptive categories of ourselves. In other words, it is the term we use to represent what people know and believe about themselves. This term also implies that at least the conscious part of our self-knowledge is largely coherent and integrated. However, the full stock of self-knowledge may contain gaps, contradictions, inconsistencies, and loose connections (Baumeister, 1999). It could be concluded that self-concept is cognitive generalization about the self (Cross & Markus, 1994). As a psychological construct, self-concept is manifested outwardly by our personality traits and behaviors, and inwardly by our perceptions and feelings of ourselves and the social world. For instance, the quality of self-concept is related to depression (Lu & Wu, 1998) or happiness (Diener, 1984), to behavioral performance such as task effort and persistence (Felson, 1984).

Psychologists have long been interested in the nature and formation of one's self. As one of the most articulate theorists of the self, William James (1890) believed that the self-concept is very much a social experience. In agreement with his emphasis on the social nature of the self, Charles Cooley (1902) introduced the term "looking-glass self" to convey the idea that self-concepts reflect the evaluations of other people around us. George Herbert Mead (1934) and Harry Stack Sullivan (1953) further elaborated this idea into the principle of reflected appraisals, we see ourselves as others see us. Other people are clearly important to the development of our self-concept, and research has shown that parental appraisals as well as peer evaluations are vital for the self views of adolescents (Hoelter, 1984)

However, the self is active and the outcomes of our own actions contribute to our self-concept too (Gekas, 1982). More crucial perhaps is our interpretations of these actions and outcomes. According to the self-perception theory (Bem, 1972), we become aware of ourselves by watching what we do, much as outside observers form judgments of us based on what they see. It can be concluded then both our own action and the views of others contribute to our self-concept. For adolescents, school work is a focal task in their life, hence understandably a major target of others' evaluations of them as well as their own perceptions of themselves. Indeed, the relationship between academic achievement and self-concept has attracted much scientific interest, but the issue is far from conclusive.

Academic achievement and self-concept

Several studies have demonstrated that in adolescents, self-concept might be closely related to academic achievement (Marsh, 1990). Nonetheless, the causality of the relationship is still under debate. Two contrasting views purport different directions of the causal relationship. The self-enhancement theory proposes that students' self-concept is the causal determinant of academic achievement. For instance, in a prospective study, House (1993) found that US college students' self-concept of their overall academic ability was the most powerful predictor of their actual academic performance. However, the opposing skill-development theory argues that self-concept is shaped at least partly by academic achievement. For instance, in a two-wave panel study, 3 cohorts of Norwegian elementary and middle school students were surveyed (Skaalvik & Valas, 1999). Results were consistent with a skill-development model in all cohorts, and no evidence was found to support the self-enhancement model. In the light of conflicting research evidence, it seems plausible to postulate that the relationship between academic achievement and self-concept is a mutual and reciprocal one. Indeed, this reciprocal influence was found among Chilean elementary school children in a recent study (Villarroel, 2001).

Other researchers have looked at the issue of specificity regarding the self-concept and achievement relationship. Most studies have ascertained a low correlation between academic achievement and domain-specific self-concept (Marsh, 1990, 1994; Watkins & Gutierrez, 1990; Marsh & O'Neill, 1984; Kobal & Musek, 2001), but found very little contribution of academic success to other self-concept domains (e.g. the sexual component), and vice versa (Marsh & O'Neill, 1984; Offer et al., 1988; Kobal & Musek, 2001). It seems that academic success is related primarily to the academic or scholastic components of self-concept. However, the puzzling incompatibility between academic achievement and general self-concept may be due to both methodological and theoretical flaws in the extant literature.

Methodologically, in order to systematically examine the relationship between academic success and general self-concept, the measure of latter must include all major categories of the self components. Although the most popular Self-Description Questionnaire (SDQ, Marsh, Smith & Barnes, 1983; Marsh & O'Neill, 1984) purports to measure multidimensional aspects of self-concept, its specificity seriously limits its utility as a measure of overall evaluation (Blascovich & Tomaka, 1991). In addition, its earlier versions are susceptible to response bias and social desirability responding. Thus much of the research has flaws for using the SDQ. As an alternative, the Tennessee Self-Concept Scale (TSCS, Roid & Fitts, 1988) offers a balance between general and specific facets similarly based on a multidimensional view of the self-concept. Particularly, the five categories measured by TSCS, physical self, moral-ethical self, personal self, family self, and social self, are comprehensive and theoretically meaningful. We therefore adopted TSCS to examine the relationship between academic achievement and non-academic aspects of self-concept.

Academic achievement, self-concept, parental factors and culture

The theoretical issue involved in the academic success and general self-concept relationship is related to culture. According to cross-cultural studies of self-concept of adolescents (Robinson, Tayler & Piolat, 1990), the structure of students' self-concept may vary interculturally (from low- to high-achievers amongst different countries). For instance, Robinson and Tayler (1989) founded that Japanese pupils showed the culturally expected signs of modesty on self-concept in a 3-country study. A recent Slovenia-France comparison study (Kobal & Musek, 2001) found significant correlations between academic achievement and various indices of self-concept, which varied in a nationality-dependent fashion. However, no significant differences were found between English and Latvian students (Robinson & Breslav, 2000). It is obvious that cross-cultural studies in this area are still a rarity, and even fewer involved non-Western participants.

It has now been widely recognized that culture has an immense effect on its members' self views, which in turn has significant implications for cognition, emotion, motivation, and subjective well-being (Markus & Kitayama, 1991; Lu et al., 2001). Culture also affects the relationship between academic achievement and self-concept. In the Confucian East Asian societies, most notably the Chinese and Japanese, self is viewed as interdependent with others and intricately embedded in social relations. Achievement is important as a means to preserve and expand the prosperity and vitality of one's family, the most important collective for the Chinese and Japanese (Lu, 2001). Achievement is not only socially oriented (Yu & Yang, 1994), but also regarded as fulfillment of a sacred social duty (Lu, 2001). Markedly different from Western societies, education and academic success have tremendous value for both parents and children in the Chinese and Japanese societies. Social institutions also sanction this emphasis on education and academic success. In both societies, students have to pass a string of entrance exams to move up the educational ladder. As higher education is prerequisite for a privileged social status and affluent life, stress related to entrance exams is phenomenal for parents and students alike (Kao & Lu, 2001). We can thus hypothesize that academic achievement would have a prevailing effect on non-academic aspects of self-concept for both Chinese and Japanese students.

In addition, previous research showed that parental factors were also important to adolescents' self-concept (Hoelter, 1984), and academic performance (Kao & Lu, 2001). For instance, after reviewing extensive Chinese research on the relationship between parental rearing attitudes and various indices of children behaviors, Yang (1986) concluded that positive parental rearing attitudes and behaviors are conducive to children's positive self-concepts, improved self-esteem, enhanced academic performance, better life adjustment in general, and prevention of behavior deviations. Negative parental rearing attitudes and behaviors generally produce the opposite effects on children. A more recent study also found that negative parental factors, such as rejection, inconsistency, and excessive expectations, contributed to Chinese adolescents' trait anxiety, which in turn heightened feelings of stress (Kao & Lu, 2001). As in Confucian societies such as the Chinese and Japanese, parents hold a critical role in their children' socialization, including the shaping and formation of the self (Lin & Wang, 1995), the relative importance of academic achievement and parental factors to adolescents' self-concept is thus an interesting empirical question to explore. The general impression is that with a more prevailing authoritarian family climate in Japan (Markus & Kitayama, 1991), parental factors may be more important to Japanese adolescents' well-being than that of their Chinese counterparts.

Traditionally, the focus of psychology has been on negative states rather than on positive ones. The study of parental factors is no exception, as most of the extant work focuses on negative aspects of the parent-child relationship, such as authoritarian control and rejection. However, recently more attention is being paid to the study of human strengths and optimal functioning. This "positive psychology" is seen as an alternative to the predominant focus on pathology and deficits. Our present enquiry on academic achievement and positive self-concept is in accordance with this perspective. Furthermore, we felt that much of the effects of various parental factors could be captured in a positive construct of psychological quality of the parent-child relationship, supplementing the often negatively phrased constructs of parental attitudes and behaviors. Adolescents' perceived satisfaction of the parent-child relationship was thus used as an overall index in the present study.

To sum, although the relationship between academic achievement and self-concept has been the subject of a number of psychological studies, mostly in the West, some questions are still unresolved. We therefore designed a cross-cultural study to further systematically examine the relationship in a non-Western cultural context. The main thrust of the present study was to examine, on the multicultural level, and in the Eastern cultural context, the association between academic achievement and non-academic aspects of self-concept in general and specific domains. Specifically, our hypotheses were: (1) Differences in the levels of academic achievement in adolescents would be reflected in both general and specific components of self-concept. Specifically, for both Chinese and Japanese adolescents, high-achievers would have more superior overall and specific self-concept than low-achievers.

(2) Chinese and Japanese adolescents would differ in various components of self-concept, though we did not have sufficient grounds to make specific predictions and treated the issue as an empirical exploration.

(3) The relative importance of academic achievement and parental factors to adolescents' self-concept would differ across cultures. Specifically, parental factors would be more important to Japanese adolescents' self-concept than that of their Chinese counterparts.

METHODS

Subjects

A total of 370 high school students (162 males, 208 females) from Taiwan (Republic of China) and Japan took part in the study. They were in the final year of high school and facing an impending university entrance exam, the most important qualifying exam in their lives. The Taiwanese sample (153 participants) was drawn from one high school in a northern county, and the Japanese sample (217 participants) from a central county. They were selected on the grounds of comparable educational programs, school prestige, and similar age (17-18 years).

Measurements and variables

1. Self-concept. Tennessee Self-Concept Scale (TSCS, Roid & Fitts, 1988) was applied as a measure of self-concept. TSCS is designed to be simple, widely applicable, and multidimensional. It is intended for use with adolescents aged 12 and over. The scale can produce a total score and 5 categorical scores: physical self, moral-ethical self, personal self, family self, and social self. Three additional scores: behavior, self-satisfaction, and identity are also produced. TSCS is one of the most popular self-concept scales, and validational support is present (Blascovich & Tomaka, 1991). The special reason for choosing TSCS is the availability of its Chinese and Japanese versions, and its frequent use with Chinese students (Wang, 1991; Chen, 1995).

2. Academic achievement. School marks were used as the basis to quantify academic achievement. In the realm of the school scenario, school marks remain the predominant determinants of the subjective interpretation of academic success. Thus, for our purposes, school marks are more relevant and appropriate indicators of academic achievement as related to self-concept.

However, the operationalization of school marks were different for the Taiwanese and Japanese samples to reflect the different educational systems and practice in the two countries. In Taiwan, a long-standing practice exists to sort students into different classes according to their school marks. Research has shown that students in "special (gifted) classes" and "ordinary classes" were markedly different in academic motivation, academic performance, exam stress, and anxiety (Wang, 1991; Kao & Lu, 2001). Thus, class labeling does reflect students' actual academic performance and other school-related factors. We had two special classes and two ordinary classes in our Taiwanese sample. Students of the former were grouped as high-achievers (coded "2"), and those of the latter as low-achievers (coded "1").

In Japan, a different conversion exists. Since 1960s the "reference score" was introduced and has been used to judge the likelihood of students' entry to universities. The reference score represents the standing of a particular student in a group, calculated based on the standardized z score in a nation-wide mock exam. In Japan, the reference score corresponds to the levels of university prestige. A reference score above 50 usually enables a student to enter prestigious national universities, and a score below 50 means entering private universities at best. Thus in our Japanese sample, those with a reference score of 50 and above were grouped as high-achievers (coded "2"), and the rest as low-achievers (coded "1").

3. Parental factors. Adolescents' perceived satisfaction of the parent-child relationship was used as an overall index in the present study. This was rated on a 5-point scale, ranging from "very satisfied" (5) to "very dissatisfied" (1).

Some general demographic information (e.g. age, gender, socio-economic variables) was collected too.

Procedure and statistical treatment of data

The collection of data took place in one high school in Miaoli (Taiwan), and one high school in Hyogo (Japan). The participants completed the entire questionnaire battery (in the appropriate language) in class. The data were then analyzed with SPSS 10.0.

Results

As the operationalization of academic achievement was different in our Taiwanese and Japanese samples, data were first analyzed mono-culturally. This treatment of the data enabled us to systematically examine the relationship between academic achievement and various aspects of self-concept *within* the distinct social and educational context of each country. Later, data on self-concept were contrasted between Taiwan and Japan for a direct comparison.

Academic achievement and self-concept

Independent sample t tests were conducted to explore differences in self-concept between high- and low- achievers in Taiwan (N=79 and 74). Three significant results were found, indicating that high-achievers were superior in physical self, moral-ethical self, and self-identity to low-achievers (see Table 1). Similar t tests were conducted with the Japanese data, to explore differences in self-concept between high- and low- achievers (N=78 and 41). Five significant results were found, indicating that high achievers were superior in family self, moral-ethical self, self-satisfaction, self-identity, and overall self-concept (also see Table 1). These results were generally consistent with our first hypothesis that for both Chinese and Japanese adolescents, high academic achievement was associated with a more positive self-concept, specifically with those aspects seemingly unrelated to academic ability.

Table 1. Differences in self-concept between high- and low-achievers in Taiwan and Japan.

Self-concept	Groups	Chinese	t	Japanese	t
Physical self	**H**	37.09		37.93	
	L	36.00	2.01*	37.05	.65
Moral-ethical self	**H**	38.46		38.46	
	L	37.28	2.07*	34.76	3.27**
Personal self	**H**	33.76		34.47	
	L	34.57	-1.61	33.54	.76
Family self	**H**	35.32		38.79	
	L	35.08	.46	35.55	2.17*
Social self	**H**	35.63		36.37	
	L	35.99	-.72	33.93	1.65
Identity	**H**	59.91		64.94	
	L	57.70	3.20**	60.98	2.00*
Self-satisfaction	**H**	58.72		59.30	
	L	59.57	-1.08	54.79	2.04*
Behavior	**H**	61.62		61.66	
	L	61.65	-.04	59.18	1.57
Total	**H**	180.25		183.90	
	L	178.92	.86	173.83	2.02*

*p<.05 **p<.01

Relative importance of academic achievement and parental factors to self-concept

Pearson correlation analysis was conducted to explore the relationship between perceived parental satisfaction and self-concept for the Chinese and Japanese students separately. There was only one significant correlation (self-identity) for the Chinese adolescents, but all correlations were significant for the Japanese sample (see Table 2). Taken as a whole, these results suggested that a satisfying parental relationship is associated with a positive general self view as well as positive views in specific aspects of the self, more pronounced perhaps for the Japanese students.

Table 2. Pearson correlation between self-concept and parental satisfaction.

Self-concept	Parental satisfaction	
	Chinese	Japanese
Physical self	.05	.15*
Moral-ethical self	.03	.18*
Personal self	.02	.26***
Family self	.11	.38***
Social self	.06	.19**
Identity	.15*	.28***
Self-satisfaction	.01	.31***
Behavior	.02	.25***
Total	.05	.30***

*p<.05 **p<.01 p<.001***

In order to further explore the relative unique contribution of academic achievement and parental satisfaction to self-concept, stepwise method was used in a series of regression analysis. Academic achievement (dummy coded) and parental satisfaction were independent variables, and various aspects of self-concept (9 in all as listed in Tables 1 & 2) were dependent variables. For the Chinese sample, in all nine regression models, academic achievement predicted physical self ($\beta=.16$, $p<.05$), moral-ethical self ($\beta=.17$, $p<.05$), and self-identity ($\beta=.25$, $p<.01$). Parental satisfaction however, did not add significant contributions to self-concept over and above academic achievement.

For Japanese students, in all nine regression models, academic achievement predicted moral-ethical self ($\beta=.32$, $p<.05$), family-self ($\beta=.29$, $p<.05$), self-identity ($\beta=.33$, $p<.05$), and overall self-concept (β=.40, p<.01). Parental satisfaction predicted family self (β=.48, p<.001), personal self (β=.39, p<.01), social self (β=.35, p<.01), self-identity (β=.31, p<.01), self-satisfaction (β=.48, p<.001), and overall self-concept (β=.40, p<.001). Taken as a whole, our results suggested that academic achievement was more important than parental factors to self-concept of the Chinese students, whereas the two were equally important to the Japanese students. Our third hypothesis was thus generally supported.

Self-concept: Chinese vs. Japanese

A direct comparison between the Chinese and Japanese samples on self-concept was conducted using independent sample t tests. Results showed that Japanese students exceeded Chinese in some domains of self-concept: family self (37.97 vs. 35.20, t=5.00, p<.001), physical self (37.90 vs. 36.56, t=2.56, p<.01), self-identity (64.85 vs. 58.84, t=7.86, p<.001), and overall self-concept (183.71 vs. 179.61, t=2.17, p<.01). The two samples were not different though in their perceived parental satisfaction. Our second hypothesis regarding possible cultural differences in adolescents self-concept was generally supported, with results showing a superior pattern of Japanese students over their Chinese counterparts.

DISCUSSIONS

In the present study, we hypothesized that high academic achievement would be associated with a more positive self-concept, specifically with those aspects seemingly unrelated to academic ability. Our data from both the Chinese and Japanese adolescents generally supported this hypothesis. These results were also concordant with previous observations that gifted and high-achieving Chinese students had higher achievement motivation, better self-concept, lower exam anxiety (Wang, 1991), as well as lower trait anxiety, and perceived lower entrance exam stress (Kao & Lu, 2001), than their average counterparts.

The fact that both Chinese and Japanese high-achievers possessed a more positive moral-ethical self–concept, and a clearer sense of overall self-identity underlines the strong cultural sanction and moral values attached to educational success in Confucian societies (Yu & Yang, 1994). Virtue is the central theme of the Confucian world view, and morality is the necessary condition for human happiness (Lu, 2001). For scholars and social elite, the selfcompletion of moral and ethical ideas (i.e. virtue) should be aspired as the highest state of being and their primary achievement goal. For ordinary people of the mass, family is the center of everyday existence, as one is conceived as only a link in the family lineage and a continuation of one's ancestors. Therefore, success through intellectual labor and passing exams is traditionally the most prominent way to acquire respectable social status and subsequent wealth for the family. In traditional and modern Confucian societies, state-organized and certified exams (e.g. university entrance exams) have been regarded as fair competitions with equal opportunities for all walks of life. For adolescents of modern Taiwan and Japan, core traditional values (e.g. education and family values) still hold strong (Lu & Kao, 2002). It is thus understandable that academic success is seen as a moral-ethical achievement, as well as a contribution to the family glory. Academic success also helps to strength the self-identity of a useful, good person and promotes self-satisfaction in general. This is exactly what we found in the present study.

We also hypothesized that parental factors would be important to adolescents' self-concept along with academic achievement. However, the relative importance of the two may vary across cultures, with parental factors being more important to Japanese adolescents' self-concept than that of their Chinese counterparts. This hypothesis was generally supported. We found that a satisfying parent-child relationship from the adolescents' perspective was associated with a superior self-concept across the board in the Japanese sample. The perceived satisfaction towards parents was also associated with a superior self-identity in the Chinese sample. Regression analyses further confirmed that while academic achievement was important for both the Chinese and Japanese adolescents, parental factors had unique incremental power in predicting Japanese students' positive self-concept.

These findings are concordant with previous research on parental rearing attitudes. Parish and McCluskey (1992) found that students' self-concept was associated with the caring parenting style. Many studies with Chinese students have also found a consistent pattern: parents' confidence in, caring, acceptance, and encouragement of their children is advantageous to the development of self-concept (Li, 1988; Lu, 1980; Chen, 1981). Our present findings are also complimentary to previous observations that negative parenting attitudes (e.g. rejection) were conducive to students' anxiety and exam stress (Kao & Lu, 2001). On the other hand, positive and harmonious family relationships contribute to personal well-being across cultures (Lu et al., 2001). Thus our current findings have clarified that positive parental factors are related to adolescents' self-concept development.

With regard to possible cultural differences in adolescents' self-concept, we found that the Japanese adolescents to be more successful in overall as well as certain domains of self-concept. As both the Chinese and Japanese students reported similar levels of parental satisfaction and were drawn from schools of comparable local prestige, the discrepancies in self-concept cannot be attributed to either academic achievement or parental factors. However, sample bias may be part of the reason. The Japanese students were residing in a metropolitan city in the most developed and prosperous central region of the country. The Chinese students in contrast, were residing in a relatively remote, agriculture-based county. Therefore, the national differences in self-concept found here may be reminiscent of the urban-rural or socio-economic status-related differences within a single country (Wylie, 1979; Song & Hattie, 1984). Due caution should be exercised in interpreting these results.

It is also possible though that the results obtained in our study reflect to some extent the cross-national personality differences, notably the differences in modesty and self-presentation. Traditionally, both Chinese and Japanese youngsters are socialized to be modest and restrained, especially in self-presentational styles (Markus & Kitayama, 1991). However, the popular young culture is changing fast in both societies following societal modernization and cultural invasions from the West. There is evidence that a traditional interdependent view of self is now coexisting with a modern (Western) independent view of self in East Asian countries (Lu & Kao, 2002; Lu et al., 2001), especially among the educated young urban population (Sinba & Tripathi, 1994). Nonetheless, the Japanese adolescents seem to be leading the popular culture of self-expression at every front in the Asian region, and Taiwanese adolescents are eager to follow the steps (Ju & Lu, 2000). Thus the superiority of the Japanese self-concept may reflect their power position in the young pop culture in East Asia.

CONCLUSIONS

Using a cross-cultural design, and a multidimensional measure of non-academic self-concept, we were able to discern several significant findings regarding adolescent Chinese and Japanese students.

1. High achieving students had superior views in overall as well as some specific domains of self, notably physical self, moral-ethical self, family self, self-identity, and self-satisfaction. Therefore, our first hypothesis was confirmed that differences in the levels of academic achievement in adolescents would reflect in their self-concept.

2. Mainly for Japanese adolescents, satisfaction with parental relations was associated with all aspects of self-concept in a positive manner. Therefore, the theoretical proposition of self-concept being a social experience has received empirical support, in the context of adolescents' familial relationships.

3. While academic achievement was important to self-concept of both the Chinese and Japanese adolescents, parental satisfaction was also important to the Japanese, with a significant incremental power. Therefore, our third hypothesis was confirmed that academic achievement and parental factors would have different relative importance to self-concept across cultures.

4. The Japanese adolescents were superior in general as well as some domains of self-concept, notably physical self, family self, and self-identity to the Chinese. Therefore, our second hypothesis was confirmed that nationality would influence various components of self-concept.

In general, our study has contributed to the existing literature with cross-cultural data outside the usual Western world of psychological research. Our findings with both Chinese and Japanese adolescents have also unequivocally clarified that academic achievement is indeed associated with a wide range of self-concept domains, not least those academic-related ones. It is fair to generalize further that in all cultures that strongly emphasize education and vocational achievement, academic success should be of great importance to adolescents' views of self. These contributions underline the value of cross-cultural studies, especially those sensitive to cultural milieus other than the Western world. In addition, parental factors are strongly implicated in the development of Chinese and Japanese adolescents' self-concept, which deserve more concerted research in the future. Finally, the possible nationality bias in self-concept is an important area too for future research.

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學業成就與自我概念：台灣與日本青少年的比較研究

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摘　要

本研究在文化比較的層次上，探討東亞文化圈內青少年的學業成就與其整體及特定自我概念間的關係。研究者對 370 位台灣及日本的高中生施測「多向度田納西自我概念量表」，並收集其學業成就資料。結果發現：學業成就高的學生其整體及某些特定面向（身體、道德、家庭、認同、及自我滿意）的自我概念較優。對日本青少年而言，親子關係的滿意度與各方面的自我概念均有正相關。相較於台灣學生，日本學生在整體及某些特定面向（身體、家庭、及認同）的自我概念較優。研究者在跨文化比較及東亞儒家文化圈的雙層脈絡中討論了研究結果的可能意涵。

關鍵詞：學業成就，自我概念，親子關係，跨文化比較，台灣與日本青少年

Current-Mode Biquad Using Two $CFCCII_p$s

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Abstract

A novel configuration using two pairs of four-terminal p-type active current Conveyors ($CFCCII_p$), three/four grounded resistors and three/four grounded capacitors is presented. The proposed network offers the following advantages: (i) realization of current-mode lowpass, highpass, bandpass, notch and allpass filtering from the same configuration; (ii) minimum active elements; (iii) low passive sensitivity; (iv) without current tracking errors; and (v) use of only grounded passive elements which is suitable for integrated circuit implementation.. Experimental results are included to certify the theoretical prediction.

Key Words： four-terminal p-type active current conveyor, sensitivity

I. INTRODUCTION

Current mode current conveyor based filters can offer wider signal bandwidths, greater linearity and larger dynamic ranges of operation [1-2]. Hence, a number of universal current-mode biquads using second-generation current conveyors were proposed [3~11]. Recently, Gunes and Anday presented a multifunction biquadratic filter using three pairs of four-terminal p-type active current conveyors ($CFCCII_p$), two grounded resistors and two grounded capacitors. However, all-pass response cannot be obtained in the design[12]. Chang

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and Tu then proposed two universal active filters with current gain, one of which has three inputs and a single output and the other of which has a single input and three outputs, using four $CFCCII_ps$, two grounded capacitors and two/four resistors. However, the required number of $CFCCII_p$ for universal filter was quite large[13].

In this paper, a new current-mode using two $CFCCII_ps$, three/four grounded resistors and three/four grounded capacitors is presented. The circuit can realize highpass, lowpass, bandpass, notch and allpass filters from the same configuration. The major goal is to reduce the number of the required active components — $CFCCII_ps$. In comparison with the recent filters proposed by Gunes and Anday(1996) and the other one proposed by Chang and Tu (1998), the new proposed filter offers the following extra advantages: use of only grounded capacitors and grounded resistors, low passive sensitivity, and without current tracking errors. Experimental results which confirm the theoretical analysis are obtained.

II.CIRCUIT DESCRIPTION

The proposed filter circuit based on and employing only two $CFCCII_ps$ is shown in Fig.1. Using standard notation, the port relations of a $CFCCII_p$ shown in Fig.2 can be characterized by $i_z = i_x$, $v_x = v_y$, $i_y=0$ and $i_0 = i_x$. From a routine analysis, the transfer function of the Fig. 1 can be derived as

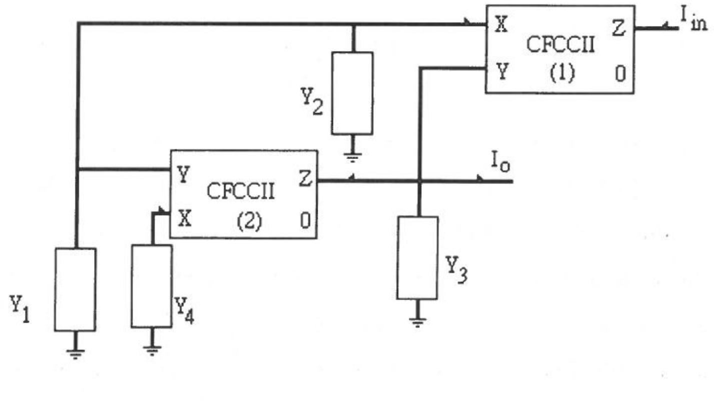


Fig.1. Current-mode filters using two only $CFCCII_ps$

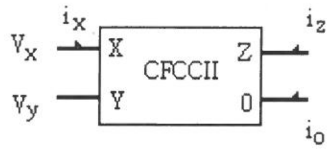


Fig.2. The port relations of a CFCCII$_p$ can be characterized by $i_z = i_x$, $v_x = v_y$, $i_y = 0$ and $i_0 = i_x$.

$$\frac{I_o}{I_{in}} = \frac{Y_3 - Y_4}{Y_1 + Y_2} \tag{1}$$

where $Y_1 - Y_4$ are admittances. If $Y_2 = Y_3$ and $Y_4 = 2Y_1$, equation (1) will be

$$\frac{I_o}{I_{in}} = \frac{Y_2 - 2Y_1}{Y_1 + Y_2} \tag{2}$$

If the admittances are chosen as $Y_2 = sC_2 + (1/R_2)$ and $Y_1 = 1/(R_1 + \frac{1}{sC_1})$, equation (2) will be

$$\frac{I_o}{I_{in}} = \frac{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 - 2C_1R_2) + 1}{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \tag{3}$$

Hence, if $C_1R_1 + C_2R_2 = 2C_1R_2$, a second-order notch filter as shown in Fig. 3 can be realized. If $2(C_1R_1 + C_2R_2) = C_1R_2$, a second-order allpass filter as shown in Fig. 3 can be also achieved. Furthermore, if $Y_3 = 0$ (open-circuited), $Y_4 = Y_1 = sC_1$ and $Y_2 = G_2$, equation

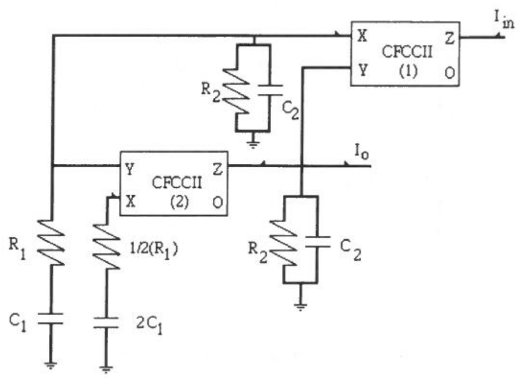


Fig.3. A current–mode second-order notch/allpass filter

(1) can be expressed as

$$\frac{I_o}{I_{in}} = \frac{-sC_1}{sC_1 + G_2} \qquad (5)$$

Thus, a highpass filter shown in Fig.4 can be obtained. If $Y_3 = 0$ (open-circuited), $Y_1 = sC_1$ and $Y_4 = Y_2 = G_2$, equation (1) can be written as

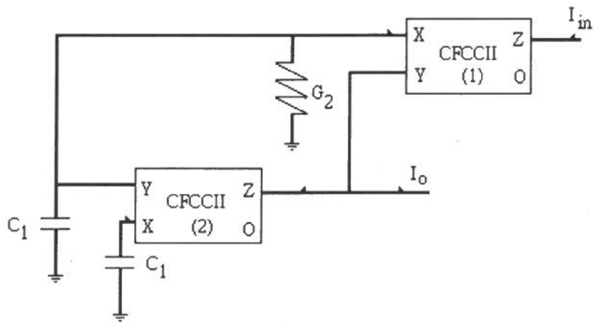


Fig.4. A current–mode highpass filter

$$\frac{I_o}{I_{in}} = \frac{-G_2}{sC_1 + G_2} \qquad (6)$$

Thus, a lowpass filter shown in Fig.5 can be obtained.

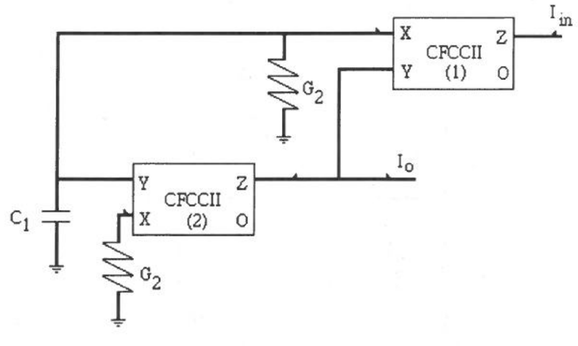


Fig.5. A current–mode lowpass filter

To realize a bandpass filter, the admittances in Fig. 1 might be chosen as follows:

$Y_3 = 0$ (open-circuited), $Y_4 = Y_1 = 1/ (R_1 + 1/sC_1)$ and $Y_2 = sC_2 + (1/R_2)$. Equation (1) can be expressed as

$$\frac{I_o}{I_{in}} = \frac{-sC_1R_2}{s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 + C_1R_2) + 1} \tag{4}$$

Thus, a second-order bandpass filter shown in Fig. 6 can be obtained. From the mentioned above, we can see that the proposed circuit provides the following advantage: minimum active components and use of only grounded capacitors. The comparison between this paper and the recent ones〔12~13〕〔Gunes and Anday (1996) and Chang and Tu (1998)〕 is shown in the table 1.

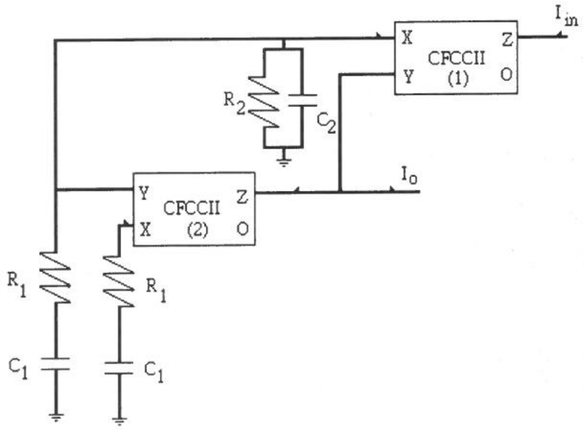


Fig.6. A current–mode second-order bandpass filter

Number of $CFCCII_p$ components

Paper \ Filter	Lowpass	Highpass	bandpass	notch	allpass
Gunes and Anday(1996)	3	3	3	3	X
Chang and Tu (1998)	4	4	4	4	4
Yin	2	2	2	2	2

Table1. Comparison of the active components

From the above table, we can see that the required number of active components is indeed reduced.

III. SENSITIVITY

The resonance angular frequency ω_o and the quality factor ϑ of the current-mode band-pass filter can be expressed as

$$\omega_o = \frac{1}{(C_1C_2R_1R_2)^{1/2}} \text{ and } \vartheta = \frac{(C_1C_2R_1R_2)^{1/2}}{C_1R_1 + C_2R_2 + C_1R_2}$$

By relating a sensitivity parameter F to the element of variation X_i

$$S_{X_i}^{F} = \frac{X_i}{F}\frac{dF}{dX_i}$$

The passive sensitivities are given by

$$S_{C_1}^{\vartheta} = \frac{1}{2}[1 - \frac{R_1 + R_2}{\Delta(C_2R_1R_2)}]$$

$$S_{C_2}^{\vartheta} = \frac{1}{2}[1 - \frac{R_2}{\Delta(C_1R_1R_2)}]$$

$$S_{R_1}^{\vartheta} = \frac{1}{2}[1 - \frac{C_1}{\Delta(C_1C_2R_2)}]$$

$$S_{R_2}^{\vartheta} = \frac{1}{2}[1 - \frac{C_1 + C_2}{\Delta(C_1C_2R_1)}]$$

$$S_{R_1}^{\omega_o} = S_{R_2}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = -1/2$$

where $\Delta = (C_1R_1+C_2R_2+C_1R_2)$. All the passive sensitivities are quite small.

Taking into account the non-ideal $CFCCII_p$, namely $i_z = \alpha i_x$ and $v_x = \beta v_y$, where $\alpha = 1-\varepsilon_1$ and ε_1 ($\varepsilon_1 << 1$) denotes the current tracking error of a $CFCCII_p$, and where $\beta = 1-\varepsilon_2$ and ε_2 ($\varepsilon_2 << 1$) denotes the voltage tracking error. The transfer function of the proposed network shown in Fig. 1 can be expressed as

$$\frac{I_o}{I_{in}} = \frac{Y_3 - \alpha_2 Y_4}{\alpha_1 (Y_1 + Y_2)} \tag{7}$$

The equations of the proposed notch, allpass, bandpass, highpass and lowpass filters with two non-ideal $CFCCII_p$s are given by the following:

(1) notch/allpass: $$\frac{I_o}{I_{in}} = \frac{s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 - 2\alpha_2 C_1 R_2) + 1}{\alpha_1 [s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 + C_1 R_2) + 1]} \tag{8}$$

(2) bandpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 s C_1 R_2}{\alpha_1 [s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 + C_1 R_2) + 1]} \tag{9}$$

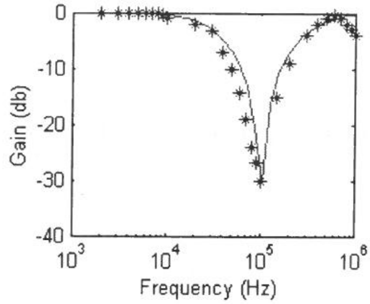
(3) highpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 s C_1}{\alpha_1 (s C_1 + G_2)} \tag{10}$$

(4) lowpass: $$\frac{I_o}{I_{in}} = \frac{-\alpha_2 G_2}{\alpha_1 (s C_1 + G_2)} \tag{11}$$

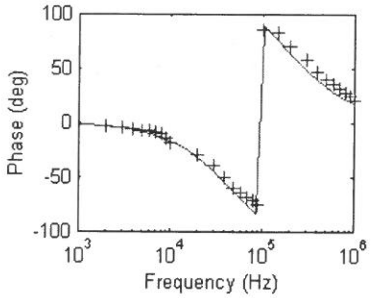
where α_1 and α_2 are non-ideal factors for $CFCCII_p$ (1) and $CFCCII_p$ (2), respectively. The resultant current-mode filters will be insensitive to the current tracking error of the $CFCCII_p$s.

IV. EXPERIMENTAL RESULTS

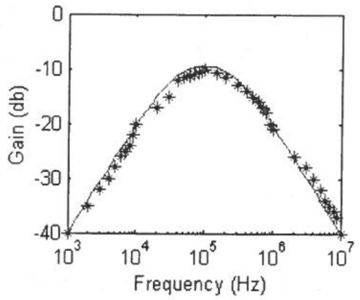
To verify the theoretical prediction of the proposed circuit, a notch and a bandpass filter prototypes have been realized with discrete components. The experimental and simulation network in Fig. 3 and Fig.6 were built with $C_1 = C_2 = 1nF$ and $R_1 = R_2 = 10k\Omega$, and Fig. 4 and Fig.5 were built with $C_1 = 1nF$ and $G_2 = 10^{-4}(\Omega)^{-1}$. The $CFCCII_p$ can be constructed by the AD844, because the AD844 has the same properties. The Matlab has carried out a simulation of the ideal curves of the proposed filters. The experimental results above were measured using the Hewlett Packard network/spectrum analyzer 4195A. Figure 7 shows the experimental results. The theoretical analysis correlates with the measured results with few errors which were due to the use of passive elements. However, the experimental results as shown still confirm with the results of the theoretical analysis.


Gain (db)
0
-10
-20
-30
-40
Frequency (Hz)

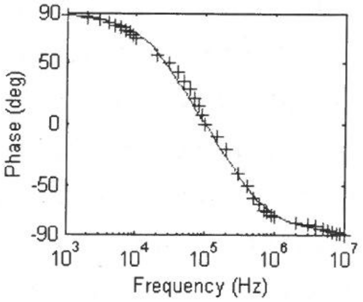
(a)


Phase (deg)
100
50
0
-50
-100
Frequency (Hz)

(b)


Gain (db)
0
-10
-20
-30
-40
Frequency (Hz)

(c)


Phase (deg)
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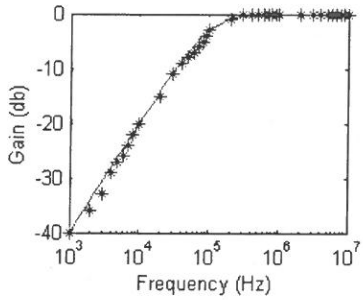
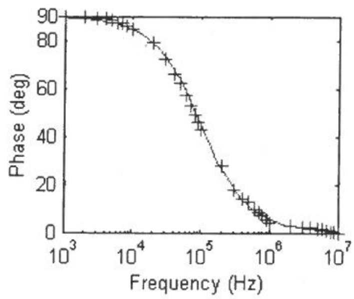
50
0
-50
-90
Frequency (Hz)

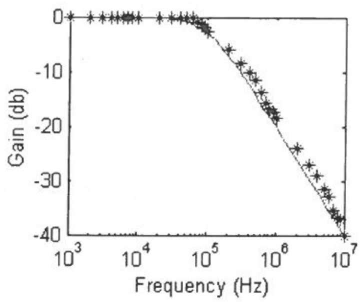
(d)


Gain (db)
0
-10
-20
-30
-40
Frequency (Hz)

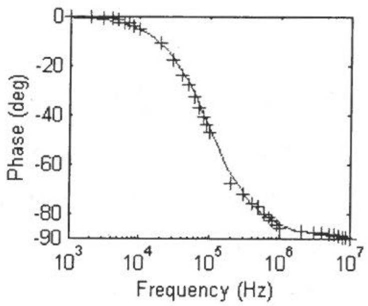
(e)


Phase (deg)
90
80
60
40
20
0
Frequency (Hz)

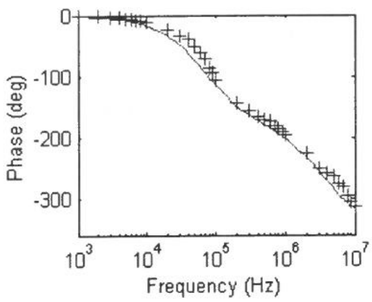
(f)


Gain (db)
0
-10
-20
-30
-40
Frequency (Hz)

(g)


Phase (deg)
0
-20
-40
-60
-80
-90
Frequency (Hz)

(h)



(i)

Fig.7. (a): Notch filter gain response; (b): Notch filter phase response
(c): bandpass filter gain response; (d): bandpass filter phase response
(e):Highpass filter gain response; (f): Highpass filter phase response
(g): Lowpass filter gain response; (h): Lowpass filter phase response
(i): Allpass filter phase response
***: experimental result for gain; +: experimental result for phase; —: ideal curve**

V. CONCLUSION

In 1996, Gunes and Anday presented a multifunction biquadratic filter which can realize highpass, lowpass, bandpass and notch filter functions and contain three $CFCCII_p$s, two grounded resistors and two grounded capacitors. However, all-pass response cannot be obtained in the design. In 1998, Chang and Tu proposed two universal active filters using four $CFCCII_p$s , two grounded capacitors and two/four resistors. However, the required number of $CFCCII_p$ for this two universal filters were quite large. In this paper, the author has proposed a new universal filter circuit which can realize the allpass filter transfer function in addition to highpass, lowpass, bandpass and notch filter transfer functions. The proposed circuit employs only two $CFCCII_p$s, three/four grounded resistors and three/four grounded capacitors. Moreover, this proposed circuit employs only grounded capacitors and grounded resistors ideal for integration circuit implementation, is insensitive to the current tracking errors of the $CFCCII_p$, and has low passive sensitivities characteristics. The required number of active components is indeed reduced. Two experimental results confirmed the theoretical analysis. The results will be useful in analogue signal processing applications.

VI. ACKNOWLEDGEMENT

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使用兩個四端 P 型主動電流傳輸器合成二階電流式濾波器

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摘　要

本論文主要目的是：僅使用二個四端 P 型主動電流傳輸器與被動元件電阻和電容，即設計出含帶通、全通、帶拒、低通與高通五種濾波功能，之新結構電流式濾波器。這些新結構電流式濾波器具有如下優點：〔1〕從品質因素與中心頻率之靈敏度分析中得知，不僅其主動靈敏度等於零，甚至於被動靈敏度也很低。因此，這些新結構電流式濾波器不存在電流之軌跡誤差問題。〔2〕其使用之被動元件之電容接地，這種電路結構，適合於合成積體電路。〔3〕此合成電路是目前使用四端 P 型主動電流傳輸器數量最少，而且能合成出帶通、全通、帶拒、低通與高通五種濾波功能的電路。最後爲了證明理論的正確性，我們對這些濾波器作了模擬與實體實驗。實驗所測量出的數據與理想的模擬理論曲線相符合。因此，可證明出本論文以兩個四端 P 型主動電流傳輸器所合成出電流轉移方式之濾波器正確無誤。

串聯系統 U 型故障函數估計式之研究

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輔仁大學數學系

摘 要

本文主要探討串聯系統 U 型故障函數之估計。主要討論直接由系統壽命估計及間接由組成零件估計兩種估計方法，結果發現，由近似變異數的觀點比較不論是估計故障函數或估計其參數，間接估計法均優於直接估計法。因此，當故障函數未知時，估計故障函數之參數即可。

關鍵字：U 型故障函數，串聯系統

1. 簡 介

工業產品可由兩個或兩個以上的組件組合而成的，而組合的方式包括串聯（series）或並聯（parallel）。對於一個純串聯系統只要其中任何一個組成零件故障便會導致整個系統故障，所以用以串聯之零件數愈多，該組合產品故障的機會就愈大。如鏈條（chains），高壓電池（high-voltage multi-cell batteries），廉價的電腦系統（inexpensive computer systems），和裝飾在樹上所使用的低伏特燈泡（low-voltage bulbs）等產品均屬之。至於一個純並聯系統則當該系統的所有組成零件全數故障時整個系統才失效，如汽車的前燈（automobile headlights），樓梯間的緊急照明燈（emergency lighting），放映機上方支援的燈（overhead projectors with backup bulb）等都屬於並聯系統產品。而汽車的煞車系統（automobile brake system）則同時具有串聯及並聯之設計（參[5]）。

本文將考慮由兩個組件串聯而成的產品之故障率，至於由多個組件串聯而成的產

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品的處理方式均可被簡化成兩組件的情形。一般言之，產品故障率是未知的，本文將討論直接由系統產品壽命來估計該類產品之故障率及透過產品組件之個別壽命間接來估計產品故障率等兩種情形。

第二節我們將要討論U型故障函數（hazard function）的估計。第三節爲結論。

2. U型故障函數之直接與間接估計式

2.1 U型故障函數

令 $\lambda(u)$ 爲一非負函數，定義 $\Lambda(t)=\int_0^t \lambda(u)du$ 且 $\Lambda(0)=0, \Lambda(\infty)=\infty$ 。假設某產品之壽命 T 的機率密度函數（pdf）f_T 及累積分佈函數（cdf）F_T 分別爲 $f_T(t)=\lambda(t)e^{-\Lambda(t)}$ 及 $F_T(t)=1-e^{-\Lambda(t)}$ 則其故障函數（瞬間失效函數，hazardfunction）爲 $h_T(t)=\dfrac{f_T(t)}{1-F_T(t)}=\lambda(t)$ ，且 $F(t)=1-e^{-\int_0^t h(u)du}=1-R(t)$ ，$f(t)=h(t)e^{-\int_0^t h(u)du}$ ，其中 $R(t)=1-F(t)$ 係產品之可靠度函數。

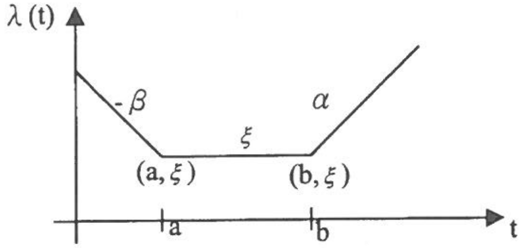
對於一個U型故障函數（hazard function）$\lambda(t)=\lambda_1(t)I_{[0,a]}(t)+\lambda_2(t)I_{[a,b]}(t)+\lambda_3(t)I_{[b,\infty)}(t)$，其密度函數 $f_T(t)=\lambda(t)e^{-\Lambda(t)}$

$$
=\begin{cases}
\lambda_1(t)e^{-\int_0^t \lambda_1(u)du} & \overset{\Delta}{=} f_1(t) \text{ 若 } t\in[0,a] \\
\lambda_2(t)e^{-[\int_0^a \lambda_1(u)du+\int_a^t \lambda_2(u)du]} & \overset{\Delta}{=} f_2(t) \text{ 若 } t\in[a,b], \\
\lambda_3(t)e^{-[\int_0^a \lambda_1(u)du+\int_a^b \lambda_2(u)du+\int_b^t \lambda_3(u)du]} & \overset{\Delta}{=} f_3(t) \text{ 若 } t\in[b,\infty)
\end{cases}
$$

其中 a，b 爲常數。爲了能討論含有夭折期（Infant Mortality）、隨機故障期（Random Failures）及損耗期（Wear out Failures）之類似浴缸曲線（bathtub curve）及兼顧計算的方便性，故本文考慮 $\lambda_1(t)=-\beta t+\xi+a\beta$ （$\because \lambda_1(t)-\xi=\beta(a-t)$ $\therefore \lambda_1(t)=\beta a-\beta t+\xi$ ），$\lambda_2(t)=\xi$ ，$\lambda_3(t)=\alpha t+\xi-b\alpha$ （$\because \lambda_3(t)-\xi=\alpha(t-b)$ $\therefore \lambda_3(t)=\alpha t-\alpha b+\xi$ ），$\alpha,\beta,\xi>0$ 的情形。令 $\mathbf{\Theta}=(\beta,\xi,\alpha)$ 爲參數向量（如圖一所示）。在此情形下壽命T的機率密度函數（p.d.f）f_T 爲

$$
f(t\mid\mathbf{\Theta})=(-\beta t+\xi+a\beta)e^{-\int_0^t(-\beta u+\xi+a\beta)du}I_{[0,a]}(t)+\xi e^{-[\int_0^a(-\beta u+\xi+a\beta)du+\int_a^t \xi du]}I_{[a,b]}(t)
$$

$$
+(\alpha t+\xi-b\alpha)e^{-[\int_0^a(-\beta u+\xi+a\beta)du+\int_a^b \xi du+\int_b^t(\alpha u+\xi-b\alpha)du]}I_{[b,\infty)}(t) \text{ ---------- （模型 I ）}
$$



圖一

當故障函數 $\lambda(t)$ 未知時，考慮下列估計式：

$$\hat{\lambda}(t)=\begin{cases}\hat{\lambda}_1(t)=-\hat{\beta}_n(t-a)+\hat{\xi}_n & 若\ t\in[0,a]\\ \hat{\lambda}_2(t)=\hat{\xi}_n & 若\ t\in[a,b]\\ \hat{\lambda}_3(t)=\hat{\alpha}_n(t-b)+\hat{\xi}_n & 若\ t\in[b,\infty)\end{cases},$$

其中 $\hat{\Theta}_n=(\hat{\beta}_n,\hat{\xi}_n,\hat{\alpha}_n)$ 爲 $\Theta=(\beta,\xi,\alpha)$ 的最大概似估計式（Maximum Likelihood Estimator，MLE）。根據 Serfling[5] $\hat{\Theta}_n$、$\hat{\beta}_n$、$\hat{\xi}_n$、$\hat{\alpha}_n$ 分別爲 Θ、β、ξ、α 的近似有效估計式（asymptotically efficient estimator），而且

$$\begin{aligned}&\sqrt{n}(\hat{\Theta}_n-\Theta)\xrightarrow[n\to\infty]{}N((0,0,0),I^{-1}(\Theta))\\ &\sqrt{n}(\hat{\beta}_n-\beta)\xrightarrow[n\to\infty]{}N(0,[I^{-1}(\Theta)]_{11})\\ &\sqrt{n}(\hat{\xi}_n-\xi)\xrightarrow[n\to\infty]{}N(0,[I^{-1}(\Theta)]_{22})\\ &\sqrt{n}(\hat{\alpha}_n-\alpha)\xrightarrow[n\to\infty]{}N(0,[I^{-1}(\Theta)]_{33})\end{aligned},$$

其中 $I(\Theta)$ 爲壽命 T 之機率密度函數 $f_T(t\mid\Theta)$ 的 Fisher Information matrix，
定義爲

$$I(\Theta)=\begin{pmatrix}-E_\Theta(\frac{\partial^2}{\partial\beta^2}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\beta\partial\xi}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\beta\partial\alpha}\log f_T(t\mid\Theta))\\ -E_\Theta(\frac{\partial^2}{\partial\xi\partial\beta}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\xi^2}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\xi\partial\alpha}\log f_T(t\mid\Theta))\\ -E_\Theta(\frac{\partial^2}{\partial\alpha\partial\beta}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\alpha\partial\xi}\log f_T(t\mid\Theta)) & -E_\Theta(\frac{\partial^2}{\partial\alpha^2}\log f_T(t\mid\Theta))\end{pmatrix}。$$

在模型 I 之下，$I(\boldsymbol{\Theta}) \stackrel{\Delta}{=} \begin{pmatrix} A & D & 0 \\ D & B & E \\ 0 & E & C \end{pmatrix}$，其中

$$A=\frac{1}{\beta^{2}}(1-e^{-\frac{1}{2}\beta a^{2}-a\xi})-\frac{2\xi}{\beta^{2}\sqrt{\beta}}e^{-\frac{1}{2}\beta a^{2}-\frac{\xi^{2}}{2\beta}-a\xi}\int_{\frac{\xi}{\sqrt{\beta}}}^{\frac{\xi+a\beta}{\sqrt{\beta}}}e^{\frac{w^{2}}{2}}dw+\frac{\xi^{2}}{\beta^{3}}e^{-\frac{1}{2}\beta a^{2}-\frac{\xi^{2}}{2\beta}-a\xi}\int_{\frac{\xi}{\sqrt{\beta}}}^{\frac{\xi+a\beta}{\sqrt{\beta}}}\frac{1}{w}e^{\frac{w^{2}}{2}}dw\ ,$$

$$B=\frac{1}{\beta}e^{-\frac{1}{2}\beta a^{2}-\frac{\xi^{2}}{2\beta}-a\xi}\int_{\frac{\xi}{\sqrt{\beta}}}^{\frac{\xi+a\beta}{\sqrt{\beta}}}\frac{1}{w}e^{\frac{w^{2}}{2}}dw+\frac{1}{\xi^{2}}e^{-\frac{1}{2}\beta a^{2}}(e^{-\xi a}-e^{-\xi b})+\frac{1}{\alpha}e^{\frac{\xi^{2}}{2\alpha}-b\xi-\frac{1}{2}\beta a^{2}}\int_{\frac{\xi}{\sqrt{\alpha}}}^{\infty}\frac{1}{w}e^{-\frac{w^{2}}{2}}dw\ ,$$

$$C=\frac{1}{\alpha^{2}}e^{-b\xi-\frac{1}{2}\beta a^{2}}-\frac{2\xi\sqrt{2\pi}}{\alpha^{2}\sqrt{\alpha}}e^{\frac{\xi^{2}}{2\alpha}-b\xi-\frac{1}{2}\beta a^{2}}(1-\Phi(\frac{\xi}{\sqrt{\alpha}}))+\frac{\xi^{2}}{\alpha^{3}}e^{\frac{\xi^{2}}{2\alpha}-b\xi-\frac{1}{2}\beta a^{2}}\int_{\frac{\xi}{\sqrt{\alpha}}}^{\infty}\frac{1}{w}e^{-\frac{w^{2}}{2}}dw\ ,$$

$$D=\frac{1}{\beta\sqrt{\beta}}e^{-\frac{1}{2}\beta a^{2}-\frac{\xi^{2}}{2\beta}-a\xi}\int_{\frac{\xi}{\sqrt{\beta}}}^{\frac{\xi+a\beta}{\sqrt{\beta}}}e^{\frac{w^{2}}{2}}dw-\frac{\xi}{\beta^{2}}e^{-\frac{1}{2}\beta a^{2}-\frac{\xi^{2}}{2\beta}-a\xi}\int_{\frac{\xi}{\sqrt{\beta}}}^{\frac{\xi+a\beta}{\sqrt{\beta}}}\frac{1}{w}e^{\frac{w^{2}}{2}}dw\ ,$$

$$E=\frac{\sqrt{2\pi}}{\alpha\sqrt{\alpha}}e^{\frac{\xi^{2}}{2\alpha}-b\xi-\frac{1}{2}\beta a^{2}}(1-\Phi(\frac{\xi}{\sqrt{\alpha}}))-\frac{\xi}{\alpha^{2}}e^{\frac{\xi^{2}}{2\alpha}-b\xi-\frac{1}{2}\beta a^{2}}\int_{\frac{\xi}{\sqrt{\alpha}}}^{\infty}\frac{1}{w}e^{-\frac{w^{2}}{2}}dw\ ,$$

且 $I^{-1}(\boldsymbol{\Theta})=\dfrac{1}{ABC-CD^{2}-AE^{2}}\begin{pmatrix} BC-E^{2} & -CD & DE \\ -CD & AC & -AE \\ DE & -AE & AB-D^{2} \end{pmatrix}$。

此時近似共變異矩陣 $I^{-1}(\boldsymbol{\Theta})$ 之跡（trace）爲 $trace(I^{-1}(\boldsymbol{\Theta}))=\dfrac{BC-E^{2}+AC+AB-D^{2}}{ABC-CD^{2}-AE^{2}}$ 。

2.2 由具 U 型故障函數之二組件串聯之產品的參數估計式

令 S 代表一個由獨立且分別具有故障函數 λ^{X} 及 λ^{Y} 之二組件 X、Y 串聯而成的組合產品。假設 X 及 Y 壽命分別爲 T_X 及 T_Y，則產品 S 之壽命 $T_S=\min\{T_X，T_Y\}$。且產品壽命 T_S 之故障函數 λ^{S} 爲 $\lambda^{S}=\lambda^{X}+\lambda^{Y}$。

假設 T_X，T_Y 分別具有 U 型故障函數 $\lambda_X(t)=\lambda_1^X(t)I_{[0,a]}(t)+\lambda_2^X(t)I_{[a,b]}(t)+\lambda_3^X(t)I_{[b,\infty)}(t)$，$\lambda_Y(t)=\lambda_1^Y(t)I_{[0,a]}(t)+\lambda_2^Y(t)I_{[a,b]}(t)+\lambda_3^Y(t)I_{[b,\infty)}(t)$，其中 $\lambda_1^X(t)=-\beta_X t+\xi_X+a\beta_X$，$\lambda_2^X(t)=\xi_X$，

$\lambda_3^X(t)=\alpha_X t+\xi_X-b\alpha_X$，$\lambda_1^Y(t)=-\beta_Y t+\xi_Y+a\beta_Y$，$\lambda_2^Y(t)=\xi_Y$，$\lambda_3^Y(t)=\alpha_Y t+\xi_Y-b\alpha_Y$，且 a、b、c、d 爲常數，則$T_X$與$T_Y$之分佈函數分別爲

$$f_T^X(t)=\begin{cases}\lambda_1^X(t)e^{-\int_0^t \lambda_1^X(u)du} & 若\ t\in[0,a]\\ \lambda_2^X(t)e^{-[\int_0^a \lambda_1^X(u)du+\int_a^t \lambda_2^X(u)du]} & 若\ t\in[a,b]\\ \lambda_3^X(t)e^{-[\int_0^a \lambda_1^X(u)du+\int_a^b \lambda_2^X(u)du+\int_b^t \lambda_3^X(u)du]} & 若\ t\in[b,\infty)\end{cases},$$

及

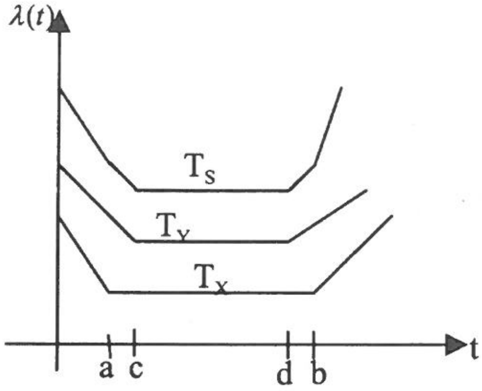
$$f_T^Y(t)=\begin{cases}\lambda_1^Y(t)e^{-\int_0^t \lambda_1^Y(u)du} & 若\ t\in[0,c]\\ \lambda_2^Y(t)e^{-[\int_0^c \lambda_1^Y(u)du+\int_c^t \lambda_2^Y(u)du]} & 若\ t\in[c,d]\\ \lambda_3^Y(t)e^{-[\int_0^c \lambda_1^Y(u)du+\int_c^d \lambda_2^Y(u)du+\int_d^t \lambda_3^Y(u)du]} & 若\ t\in[d,\infty)\end{cases}。$$

此時組合產品 S 之故障函數及壽命密度函數分別爲 $\lambda^S(t)=\lambda^X(t)+\lambda^Y(t)$ 及 $f_T^S(t)=\lambda^S(t)e^{-\int_0^t \lambda^S(u)du}$。當參數$\beta_X$、$\xi_X$、$\alpha_X$、$\beta_Y$、$\xi_Y$、$\alpha_Y$未知時，組合產品 S 之故障函數$\lambda^S$亦未知。此時我們可直接由組合產品壽命來估計$\lambda^S$或間接透過二組件 X、Y 之壽命來估計$\lambda^S$。前者先估計系統參數$\beta_S$、$\xi_S$、$\alpha_S$，再利用參數估計式來估計故障函數$\lambda^S$（稱此法爲直接估計法）；後者則是先估計零件參數$\beta_X$、$\xi_X$、$\alpha_X$、$\beta_Y$、$\xi_Y$、$\alpha_Y$，再利用這六個參數估計式來估計故障函數$\lambda^S$（稱此法爲間接估計法）。令$\mathbf{\Theta}_S$、$\mathbf{\Theta}_X$、$\mathbf{\Theta}_Y$分別代表組合產品壽命$T_S$和零組件壽命$T_X$、$T_Y$之參數向量，i.e. $\mathbf{\Theta}_S=(\beta_S,\xi_S,\alpha_S)$，$\mathbf{\Theta}_X=(\beta_X,\xi_X,\alpha_X)$，$\mathbf{\Theta}_Y=(\beta_Y,\xi_Y,\alpha_Y)$。

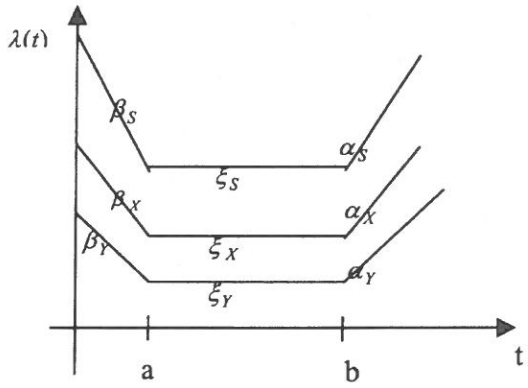
假設$\hat{\mathbf{\Theta}}_S$、$\hat{\mathbf{\Theta}}_X$、$\hat{\mathbf{\Theta}}_Y$分別爲$\mathbf{\Theta}_S$、$\mathbf{\Theta}_X$、$\mathbf{\Theta}_Y$之最大概似估計式（MLE），則

$$\begin{aligned}\sqrt{n}(\hat{\mathbf{\Theta}}_S-\mathbf{\Theta}_S)&\xrightarrow[n\to\infty]{}N((0,0,0),I^{-1}(\mathbf{\Theta}_S))\\ \sqrt{n}(\hat{\mathbf{\Theta}}_X-\mathbf{\Theta}_X)&\xrightarrow[n\to\infty]{}N((0,0,0),I^{-1}(\mathbf{\Theta}_X)),\\ \sqrt{n}(\hat{\mathbf{\Theta}}_Y-\mathbf{\Theta}_Y)&\xrightarrow[n\to\infty]{}N((0,0,0),I^{-1}(\mathbf{\Theta}_Y))\end{aligned}$$

由圖二可看出，當$a\neq c$且$b\neq d$時因參數空間維度不同將產生比較上的困難，因此以下我們僅就$a=c$且$b=d$的情形討論（如圖三所示）。此時系統壽命T_S之密度函數爲：



圖二



圖三

$$f_T^S(t) = \lambda^S(t) e^{-\int_0^t \lambda^S(u)\,du}$$

$$= \begin{cases} \lambda_1^S(t) e^{-\int_0^t \lambda_1^S(u)\,du} & \text{若} \quad t \in [0, a] \\ \lambda_2^S(t) e^{-[\int_0^a \lambda_1^S(u)\,du + \int_a^t \lambda_2^S(u)\,du]} & \text{若} \quad t \in [a, b] \\ \lambda_3^S(t) e^{-[\int_0^a \lambda_1^S(u)\,du + \int_a^b \lambda_2^S(u)\,du + \int_b^t \lambda_3^S(u)\,du]} & \text{若} \quad t \in [b, \infty) \end{cases},$$

其中

$$\begin{cases} \lambda_1^S(t) = \beta_S t + \xi_S - a\beta_S = (\beta_X + \beta_Y)t + (\xi_X + \xi_Y) - a(\beta_X + \beta_Y) & \text{若 } t \in [0,a] \\ \lambda_2^S(t) = \xi_S = \xi_X + \xi_Y & \text{若 } t \in [a,b] \\ \lambda_3^S(t) = \alpha_S t + \xi_S - b\alpha_S = (\alpha_X + \alpha_Y)t + (\xi_X + \xi_Y) - b(\alpha_X + \alpha_Y) & \text{若 } t \in [b,\infty) \end{cases}。$$

令 $\hat{\Theta}^d$ 及 $\hat{\Theta}^I$ 分別代表 Θ_S 向量之直接及間接估計式。則根據最大概似估計式之不變性（invariance property），

$$\sqrt{n}(\hat{\Theta}^d - \Theta_S) \xrightarrow[n\to\infty]{} N((0,0,0), I_d^{-1}(\Theta))$$

$$\sqrt{n}(\hat{\Theta}^I - \Theta_S) \xrightarrow[n\to\infty]{} N((0,0,0), I_I^{-1}(\Theta))$$

其中 $I_d^{-1}(\Theta) = I^{-1}(\Theta_S)$，$I_I^{-1}(\Theta) = I^{-1}(\Theta_X) + I^{-1}(\Theta_Y)$（參[3]）。

令 Fisher information matrix $I(\Theta_J) \stackrel{\Delta}{=} \begin{pmatrix} A_J & D_J & 0 \\ D_J & B_J & E_J \\ 0 & E_J & C_J \end{pmatrix}$，其中 J 可為 X、Y 或 S，且

$$\left.\begin{aligned}
A_J &= \frac{1}{\beta_J^{\ 2}}(1-e^{-\frac{1}{2}\beta_J a^2-a\xi_J}) - \frac{2\xi_J}{\beta_J^{\ 2}\sqrt{\beta_J}} e^{-\frac{1}{2}\beta_J a^2-\frac{\xi_J^2}{2\beta_J}-a\xi_J} \int_{\frac{\xi_J}{\sqrt{\beta_J}}}^{\frac{\xi_J+a\beta_J}{\sqrt{\beta_J}}} e^{\frac{w^2}{2}} dw + \frac{\xi_J^{\ 2}}{\beta_J^{\ 3}} e^{-\frac{1}{2}\beta_J a^2-\frac{\xi_J^2}{2\beta_J}-a\xi_J} \int_{\frac{\xi_J}{\sqrt{\beta_J}}}^{\frac{\xi_J+a\beta_J}{\sqrt{\beta_J}}} \frac{1}{w} e^{\frac{w^2}{2}} dw \\
B_J &= \frac{1}{\beta_J} e^{-\frac{1}{2}\beta_J a^2-\frac{\xi_J^2}{2\beta_J}-a\xi_J} \int_{\frac{\xi_J}{\sqrt{\beta_J}}}^{\frac{\xi_J+a\beta_J}{\sqrt{\beta_J}}} \frac{1}{w} e^{\frac{w^2}{2}} dw + \frac{1}{\xi_J^{\ 2}} e^{-\frac{1}{2}\beta_J a^2} (e^{-\xi_J a} - e^{-\xi_J b}) + \frac{1}{\alpha_J} e^{\frac{\xi_J^2}{2\alpha_J}-b\xi_J-\frac{1}{2}\beta_J a^2} \int_{\frac{\xi_J}{\sqrt{\alpha_J}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw \\
C_J &= \frac{1}{\alpha_J^{\ 2}} e^{-b\xi_J-\frac{1}{2}\beta_J a^2} - \frac{2\xi_J\sqrt{2\pi}}{\alpha_J^{\ 2}\sqrt{\alpha_J}} e^{\frac{\xi_J^2}{2\alpha_J}-b\xi_J-\frac{1}{2}\beta_J a^2} (1-\Phi(\frac{\xi_J}{\sqrt{\alpha_J}})) + \frac{\xi_J^{\ 2}}{\alpha_J^{\ 3}} e^{\frac{\xi_J^2}{2\alpha_J}-b\xi_J-\frac{1}{2}\beta_J a^2} \int_{\frac{\xi_J}{\sqrt{\alpha_J}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw \\
D_J &= \frac{1}{\beta_J\sqrt{\beta_J}} e^{-\frac{1}{2}\beta_J a^2-\frac{\xi_J^2}{2\beta_J}-a\xi_J} \int_{\frac{\xi_J}{\sqrt{\beta_J}}}^{\frac{\xi_J+a\beta_J}{\sqrt{\beta_J}}} e^{\frac{w^2}{2}} dw - \frac{\xi_J}{\beta_J^{\ 2}} e^{-\frac{1}{2}\beta_J a^2-\frac{\xi_J^2}{2\beta_J}-a\xi_J} \int_{\frac{\xi_J}{\sqrt{\beta_J}}}^{\frac{\xi_J+a\beta_J}{\sqrt{\beta_J}}} \frac{1}{w} e^{\frac{w^2}{2}} dw \\
E_J &= \frac{\sqrt{2\pi}}{\alpha_J\sqrt{\alpha_J}} e^{\frac{\xi_J^2}{2\alpha_J}-b\xi_J-\frac{1}{2}\beta_J a^2} (1-\Phi(\frac{\xi_J}{\sqrt{\alpha_J}})) - \frac{\xi_J}{\alpha_J^{\ 2}} e^{\frac{\xi_J^2}{2\alpha_J}-b\xi_J-\frac{1}{2}\beta_J a^2} \int_{\frac{\xi_J}{\sqrt{\alpha_J}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw
\end{aligned}\right\} \quad (1)$$

則 $I^{-1}(\mathbf{\Theta}_J) = \dfrac{1}{A_J B_J C_J - C_J D_J^{\ 2} - A_J E_J^{\ 2}} \begin{pmatrix} B_J C_J - E_J^{\ 2} & -C_J D_J & D_J E_J \\ -C_J D_J & A_J C_J & -A_J E_J \\ D_J E_J & -A_J E_J & A_J B_J - D_J^{\ 2} \end{pmatrix}$，

因此

$$trace(I^{-1}(\mathbf{\Theta}_X)) = \frac{B_X C_X - E_X^{\ 2} + A_X C_X + A_X B_X - D_X^{\ 2}}{A_X B_X C_X - C_X D_X^{\ 2} - A_X E_X^{\ 2}} \ ,$$

$$trace(I^{-1}(\mathbf{\Theta}_Y)) = \frac{B_Y C_Y - E_Y^{\ 2} + A_Y C_Y + A_Y B_Y - D_Y^{\ 2}}{A_Y B_Y C_Y - C_Y D_Y^{\ 2} - A_Y E_Y^{\ 2}} \ 。$$

$$trace(I^{-1}(\mathbf{\Theta}_S)) = \frac{B_S C_S - E_S^{\ 2} + A_S C_S + A_S B_S - D_S^{\ 2}}{A_S B_S C_S - C_S D_S^{\ 2} - A_S E_S^{\ 2}} \ 。$$

（一）$\mathbf{\Theta}_S$ 之直接估計式 $\hat{\mathbf{\Theta}}^d$

$\mathbf{\Theta}_S$ 之直接估計式 $\hat{\mathbf{\Theta}}^d$ 的近似共變異矩陣之跡爲

$$trace(I_d^{-1}(\mathbf{\Theta})) = trace(I^{-1}(\mathbf{\Theta}_S)) = \frac{B_S C_S - E_S^{\ 2} + A_S C_S + A_S B_S - D_S^{\ 2}}{A_S B_S C_S - C_S D_S^{\ 2} - A_S E_S^{\ 2}}$$

$$=\{(\frac{1}{\beta_s}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_s^{\ 2}}e^{-\frac{1}{2}\beta_S a^2}(e^{-\xi_S a}-e^{-\xi_S b})+\frac{1}{\alpha_s}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_s^{\ 2}}e^{-b\xi_S-\frac{1}{2}\beta_S a^2}-\frac{2\xi_s\sqrt{2\pi}}{\alpha_s^{\ 2}\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))+\frac{\xi_s^{\ 2}}{\alpha_s^{\ 3}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{\sqrt{2\pi}}{\alpha_s\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))-\frac{\xi_s}{\alpha_s^{\ 2}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)^2$$

$$+(\frac{1}{\beta_s^{\ 2}}(1-e^{-\frac{1}{2}\beta_S a^2-a\xi_S})-\frac{2\xi_s}{\beta_s^{\ 2}\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw+\frac{\xi_s^{\ 2}}{\beta_s^{\ 3}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_s^{\ 2}}e^{-b\xi_S-\frac{1}{2}\beta_S a^2}-\frac{2\xi_s\sqrt{2\pi}}{\alpha_s^{\ 2}\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))+\frac{\xi_s^{\ 2}}{\alpha_s^{\ 3}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$+(\frac{1}{\beta_s^{\ 2}}(1-e^{-\frac{1}{2}\beta_S a^2-a\xi_S})-\frac{2\xi_s}{\beta_s^{\ 2}\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw+\frac{\xi_s^{\ 2}}{\beta_s^{\ 3}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_s}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_s^{\ 2}}e^{-\frac{1}{2}\beta_S a^2}(e^{-\xi_S a}-e^{-\xi_S b})+\frac{1}{\alpha_s}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{1}{\beta_s\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw-\frac{\xi_s}{\beta_s^{\ 2}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)^2\}$$

$$\times\{(\frac{1}{\beta_s^{\ 2}}(1-e^{-\frac{1}{2}\beta_S a^2-a\xi_S})-\frac{2\xi_s}{\beta_s^{\ 2}\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw+\frac{\xi_s^{\ 2}}{\beta_s^{\ 3}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_s}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_s^{\ 2}}e^{-\frac{1}{2}\beta_S a^2}(e^{-\xi_S a}-e^{-\xi_S b})+\frac{1}{\alpha_s}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_s^{\ 2}}e^{-b\xi_S-\frac{1}{2}\beta_S a^2}-\frac{2\xi_s\sqrt{2\pi}}{\alpha_s^{\ 2}\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))+\frac{\xi_s^{\ 2}}{\alpha_s^{\ 3}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{1}{\alpha_s^{\ 2}}e^{-b\xi_S-\frac{1}{2}\beta_S a^2}-\frac{2\xi_s\sqrt{2\pi}}{\alpha_s^{\ 2}\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))+\frac{\xi_s^{\ 2}}{\alpha_s^{\ 3}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_s\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw-\frac{\xi_s}{\beta_s^{\ 2}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)^2$$

$$-(\frac{1}{\beta_s^{\ 2}}(1-e^{-\frac{1}{2}\beta_S a^2-a\xi_S})-\frac{2\xi_s}{\beta_s^{\ 2}\sqrt{\beta_s}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}e^{\frac{w^2}{2}}dw+\frac{\xi_s^{\ 2}}{\beta_s^{\ 3}}e^{-\frac{1}{2}\beta_S a^2-\frac{\xi_S^2}{2\beta_S}-a\xi_S}\int_{\frac{\xi_S}{\sqrt{\beta_S}}}^{\frac{\xi_S+a\beta_S}{\sqrt{\beta_S}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{\sqrt{2\pi}}{\alpha_s\sqrt{\alpha_s}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}(1-\Phi(\frac{\xi_s}{\sqrt{\alpha_s}}))-\frac{\xi_s}{\alpha_s^{\ 2}}e^{\frac{\xi_S^2}{2\alpha_S}-b\xi_S-\frac{1}{2}\beta_S a^2}\int_{\frac{\xi_S}{\sqrt{\alpha_S}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)^2\}^{-1}\text{ 。}$$

（二）$\boldsymbol{\Theta}_s$ 的間接估計式 $\hat{\boldsymbol{\Theta}}^I$

因 X 與 Y 分別代表二獨立之組件，故 $\boldsymbol{\Theta}_s$ 之間接估計式 $\hat{\boldsymbol{\Theta}}^I$ 的近似共變異矩陣之跡爲 $trace(I_I^{-1}(\boldsymbol{\Theta})) = trace(I^{-1}(\boldsymbol{\Theta}_X)) + trace(I^{-1}(\boldsymbol{\Theta}_Y))$

$$= \{(\frac{1}{\beta_X} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw + \frac{1}{\xi_X^2} e^{-\frac{1}{2}\beta_X a^2} (e^{-\xi_X a} - e^{-\xi_X b}) + \frac{1}{\alpha_X} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\alpha_X^2} e^{-b\xi_X-\frac{1}{2}\beta_X a^2} - \frac{2\xi_X\sqrt{2\pi}}{\alpha_X^2\sqrt{\alpha_X}} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} (1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}})) + \frac{\xi_X^2}{\alpha_X^3} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$-(\frac{\sqrt{2\pi}}{\alpha_X\sqrt{\alpha_X}} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} (1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}})) - \frac{\xi_X}{\alpha_X^2} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)^2$$

$$+(\frac{1}{\beta_X^2}(1-e^{-\frac{1}{2}\beta_X a^2-a\xi_X}) - \frac{2\xi_X}{\beta_X^2\sqrt{\beta_X}} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} e^{\frac{w^2}{2}} dw + \frac{\xi_X^2}{\beta_X^3} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\alpha_X^2} e^{-b\xi_X-\frac{1}{2}\beta_X a^2} - \frac{2\xi_X\sqrt{2\pi}}{\alpha_X^2\sqrt{\alpha_X}} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} (1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}})) + \frac{\xi_X^2}{\alpha_X^3} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$+(\frac{1}{\beta_X^2}(1-e^{-\frac{1}{2}\beta_X a^2-a\xi_X}) - \frac{2\xi_X}{\beta_X^2\sqrt{\beta_X}} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} e^{\frac{w^2}{2}} dw + \frac{\xi_X^2}{\beta_X^3} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\beta_X} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw + \frac{1}{\xi_X^2} e^{-\frac{1}{2}\beta_X a^2} (e^{-\xi_X a} - e^{-\xi_X b}) + \frac{1}{\alpha_X} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$-(\frac{1}{\beta_X\sqrt{\beta_X}} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} e^{\frac{w^2}{2}} dw - \frac{\xi_X}{\beta_X^2} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw)^2\}$$

$$\times\{(\frac{1}{\beta_X^2}(1-e^{-\frac{1}{2}\beta_X a^2-a\xi_X}) - \frac{2\xi_X}{\beta_X^2\sqrt{\beta_X}} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} e^{\frac{w^2}{2}} dw + \frac{\xi_X^2}{\beta_X^3} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\beta_X} e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X} \int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}} \frac{1}{w} e^{\frac{w^2}{2}} dw + \frac{1}{\xi_X^2} e^{-\frac{1}{2}\beta_X a^2} (e^{-\xi_X a} - e^{-\xi_X b}) + \frac{1}{\alpha_X} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\alpha_X^2} e^{-b\xi_X-\frac{1}{2}\beta_X a^2} - \frac{2\xi_X\sqrt{2\pi}}{\alpha_X^2\sqrt{\alpha_X}} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} (1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}})) + \frac{\xi_X^2}{\alpha_X^3} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$-(\frac{1}{\alpha_X^2} e^{-b\xi_X-\frac{1}{2}\beta_X a^2} - \frac{2\xi_X\sqrt{2\pi}}{\alpha_X^2\sqrt{\alpha_X}} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} (1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}})) + \frac{\xi_X^2}{\alpha_X^3} e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2} \int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty} \frac{1}{w} e^{-\frac{w^2}{2}} dw)$$

$$\times(\frac{1}{\beta_X\sqrt{\beta_X}}e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X}\int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}}e^{\frac{w^2}{2}}dw-\frac{\xi_X}{\beta_X^2}e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X}\int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)^2$$

$$-(\frac{1}{\beta_X^2}(1-e^{-\frac{1}{2}\beta_X a^2-a\xi_X})-\frac{2\xi_X}{\beta_X^2\sqrt{\beta_X}}e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X}\int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}}e^{\frac{w^2}{2}}dw+\frac{\xi_X^2}{\beta_X^3}e^{-\frac{1}{2}\beta_X a^2-\frac{\xi_X^2}{2\beta_X}-a\xi_X}\int_{\frac{\xi_X}{\sqrt{\beta_X}}}^{\frac{\xi_X+a\beta_X}{\sqrt{\beta_X}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{\sqrt{2\pi}}{\alpha_X\sqrt{\alpha_X}}e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2}(1-\Phi(\frac{\xi_X}{\sqrt{\alpha_X}}))-\frac{\xi_X}{\alpha_X^2}e^{\frac{\xi_X^2}{2\alpha_X}-b\xi_X-\frac{1}{2}\beta_X a^2}\int_{\frac{\xi_X}{\sqrt{\alpha_X}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)^2\}^{-1}$$

$$+\{(\frac{1}{\beta_Y}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_Y^2}e^{-\frac{1}{2}\beta_Y a^2}(e^{-\xi_Y a}-e^{-\xi_Y b})+\frac{1}{\alpha_Y}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_Y^2}e^{-b\xi_Y-\frac{1}{2}\beta_Y a^2}-\frac{2\xi_Y\sqrt{2\pi}}{\alpha_Y^2\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))+\frac{\xi_Y^2}{\alpha_Y^3}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{\sqrt{2\pi}}{\alpha_Y\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))-\frac{\xi_Y}{\alpha_Y^2}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)^2$$

$$+(\frac{1}{\beta_Y^2}(1-e^{-\frac{1}{2}\beta_Y a^2-a\xi_Y})-\frac{2\xi_Y}{\beta_Y^2\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw+\frac{\xi_Y^2}{\beta_Y^3}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_Y^2}e^{-b\xi_Y-\frac{1}{2}\beta_Y a^2}-\frac{2\xi_Y\sqrt{2\pi}}{\alpha_Y^2\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))+\frac{\xi_Y^2}{\alpha_Y^3}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$+(\frac{1}{\beta_Y^2}(1-e^{-\frac{1}{2}\beta_Y a^2-a\xi_Y})-\frac{2\xi_Y}{\beta_Y^2\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw+\frac{\xi_Y^2}{\beta_Y^3}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_Y}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_Y^2}e^{-\frac{1}{2}\beta_Y a^2}(e^{-\xi_Y a}-e^{-\xi_Y b})+\frac{1}{\alpha_Y}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{1}{\beta_Y\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw-\frac{\xi_Y}{\beta_Y^2}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)^2\}$$

$$\times\{(\frac{1}{\beta_Y^2}(1-e^{-\frac{1}{2}\beta_Y a^2-a\xi_Y})-\frac{2\xi_Y}{\beta_Y^2\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw+\frac{\xi_Y^2}{\beta_Y^3}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_Y}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw+\frac{1}{\xi_Y^2}e^{-\frac{1}{2}\beta_Y a^2}(e^{-\xi_Y a}-e^{-\xi_Y b})+\frac{1}{\alpha_Y}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\alpha_Y^2}e^{-b\xi_Y-\frac{1}{2}\beta_Y a^2}-\frac{2\xi_Y\sqrt{2\pi}}{\alpha_Y^2\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))+\frac{\xi_Y^2}{\alpha_Y^3}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$-(\frac{1}{\alpha_Y^2}e^{-b\xi_Y-\frac{1}{2}\beta_Y a^2}-\frac{2\xi_Y\sqrt{2\pi}}{\alpha_Y^2\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))+\frac{\xi_Y^2}{\alpha_Y^3}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)$$

$$\times(\frac{1}{\beta_Y\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw-\frac{\xi_Y}{\beta_Y^2}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)^2$$

$$-(\frac{1}{\beta_Y^2}(1-e^{-\frac{1}{2}\beta_Y a^2-a\xi_Y})-\frac{2\xi_Y}{\beta_Y^2\sqrt{\beta_Y}}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}e^{\frac{w^2}{2}}dw+\frac{\xi_Y^2}{\beta_Y^3}e^{-\frac{1}{2}\beta_Y a^2-\frac{\xi_Y^2}{2\beta_Y}-a\xi_Y}\int_{\frac{\xi_Y}{\sqrt{\beta_Y}}}^{\frac{\xi_Y+a\beta_Y}{\sqrt{\beta_Y}}}\frac{1}{w}e^{\frac{w^2}{2}}dw)$$

$$\times(\frac{\sqrt{2\pi}}{\alpha_Y\sqrt{\alpha_Y}}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}(1-\Phi(\frac{\xi_Y}{\sqrt{\alpha_Y}}))-\frac{\xi_Y}{\alpha_Y^2}e^{\frac{\xi_Y^2}{2\alpha_Y}-b\xi_Y-\frac{1}{2}\beta_Y a^2}\int_{\frac{\xi_Y}{\sqrt{\alpha_Y}}}^{\infty}\frac{1}{w}e^{-\frac{w^2}{2}}dw)^2\}^{-1}。$$

2.2.1 參數 Θ_S 之直接與間接估計式之近似共變異矩陣之比較

首先考慮當 $\beta_Y = k\beta_X$，$\xi_Y = k\xi_X$，$\alpha_Y = k\alpha_X$，$k > 0$，此時 $\beta_S = (1+k)\beta_X$，$\xi_S = (1+k)\xi_X$，$\alpha_S = (1+k)\alpha_X$，因此 $I^{-1}(\Theta_S) = (1+k)^2 I^{-1}(\Theta_X)$，$I^{-1}(\Theta_Y) = k^2 I^{-1}(\Theta_X)$。且 $\hat{\Theta}^d$ 的近似變異數總和 $trace(I_d^{-1}(\Theta)) = trace(I^{-1}(\Theta_S)) = (1+k)^2 trace(I^{-1}(\Theta_X))$，$\hat{\Theta}^I$ 的近似變異數總和 $trace(I_I^{-1}(\Theta)) = trace(I^{-1}(\Theta_X) + I^{-1}(\Theta_Y)) = (1+k^2) trace(I^{-1}(\Theta_X))$。

因為 $k > 0$，$trace(I_d^{-1}(\Theta)) > trace(I_I^{-1}(\Theta))$。因此由近似變異數總和的準則看來，參數之間接估計優於參數之直接估計。

在此種特殊情形之下，我們亦可比較參數之直接估計與間接估計之廣義參數變異數（generalized parameter variance），即 $I^{-1}(\Theta)$ 矩陣之行列式值。$\hat{\Theta}^d$ 及 $\hat{\Theta}^I$ 之廣義參數變異數分別為

$\det(I_d^{-1}(\Theta)) = \det(I^{-1}(\Theta_S)) = (\det(I(\Theta_S))^{-1} = (1+k)^6 \det(I^{-1}(\Theta_X))$ 及

$\det(I_I^{-1}(\Theta)) = \det(I^{-1}(\Theta_X) + I^{-1}(\Theta_Y)) = (1+k^2)^3 \det(I^{-1}(\Theta_X))$。

因為 $k>0$，$\det(I_d^{-1}(\Theta)) > \det(I_I^{-1}(\Theta))$。即當比較的準則為廣義參數變異數時，間接估計式 $\hat{\Theta}^I$ 仍然優於直接估計式 $\hat{\Theta}^d$。

至於一般情形，由 $trace(I_d^{-1}(\Theta))$ 及 $trace(I_I^{-1}(\Theta))$ 之定義看來，直接用分析法來比較 Θ_S 之直接估計式與間接估計式的近似共變異矩陣之跡幾乎不可能。因此以下我們以數值方法來討論之。考慮參數（a,b）=（1, 3）、（1, 10）、（1, 20）、（2, 4）、（2, 12），β_X = 0.1, 0.5、ξ_X = 0.1, 0.3, 0.5、α_X = 0.1, 0.5，β_Y = 0.1, 0.9、ξ_Y = 0.1, 0.5, 0.9、α_Y = 0.1, 0.9。此外，除了比較跡，我們亦考慮參數之直接估計式與間接估計式之相對差異，其中

$$相對差異 = \frac{trace(I_d^{-1}(\Theta)) - trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))} \times 100\%。$$

詳細數值計算結果置於附錄一至附錄五。由表中數據我們發現（1）不論是直接估計或是間接估計，在所有 a，b 的預設值之處，改變 β 、ξ 、α 三個參數中的任何一

個而其他兩個固定時，參數之直接與間接估計式之近似變異數總和會隨著參數值之增加而變大。尤其當ξ 改變而β 、α固定時，參數之直接與間接估計式之近似變異數總和的變化均最大。也就是在 U 型故障曲線中，不論各段時間的長短如何（i.e.不論 a 與 b 值如何），比起改變夭折期的參數 β 或是損耗期的參數α ，隨機故障期參數 ξ 的變化，將使得參數估計式之近似變異數總和改變最大。（2）在折點 a 固定的情形下，若ξ或α的值大於等於 0.5 時，參數之直接估計式及間接估計式之近似變異數總和均會隨著 a 與 b 之差距的增加而變大。（3）當 a 與 b 的差距維持固定（i.e. b-a 固定）時，若ξ及α的值均大於等於 0.5 ，則參數之直接估計式及間接估計式之近似變異數總和均會隨著 a 值的增大而愈大；換言之，在夭折期的時間固定時（i.e. a 固定），若隨機故障期的時間長度愈長（i.e. b-a 愈大），則參數之直接估計式及間接估計式之近似變異數總和會愈大；當隨機故障期的時間一定時（i.e. b-a 固定），若夭折期的期間愈長（i.e. a 愈大），則參數之直接估計式及間接估計式之近似變異數總和會愈大，即不論哪一時期時間變長，均會使參數變異數總和變大。我們亦觀察到參數之直接估計式之近似變異數總和大於參數之間接估計式之近似變異數總和，尤其當隨機故障期的時間愈長（i.e. b-a 愈大）時，其差異就愈明顯。

以上是針對直接估計與間接估計做個別的比較，接下來，我們要比較直接估計與間接估計之間的相對差異，根據附錄中之數據我們會發現，當 a 的值大於 1 時，不論 b 值爲多少，參數β 、ξ 、α中之任一參數增加時，其相對差異亦會隨著增加，如附錄五中，在 a=2，b=12 時，當β_X 、ξ_X、α_X 、β_Y 、ξ_Y均爲 0.1，α_Y由 0.1 變爲 0.9 時，相對差異由 63%變爲 78%；β_X 、ξ_X、α_X 、β_Y 、α_Y均爲 0.1，ξ_Y由 0.1 變爲 0.9 時，相對差異由 63%變爲 94%；β_X 、ξ_X 、α_X 、ξ_Y、α_Y均爲 0.1，β_Y由 0.1 變爲 0.9 時，相對差異由 63%變爲 67%；β_X 、ξ_X、β_Y 、ξ_Y、α_Y均爲 0.1，α_X由 0.1 變爲 0.5 時，相對差異由 63%變爲 78%；β_X 、α_X 、β_Y 、ξ_Y、α_Y均爲 0.1，ξ_X由 0.1 變爲 0.5 時，相對差異由 63%變爲 92%；ξ_X 、α_X 、β_Y 、ξ_Y、α_Y均爲 0.1，β_X由 0.1 變爲 0.5 時，相對差異由 63%變爲 64%；但當 a=1 的情況下，若 a 與 b 的距離小於等於 5（i.e.$b-a\le 5$）的情況下，則參數β 、ξ 、α中之任一參數增加時，其相對差異亦會隨著增加，如附錄一中，在 a=1，b=3 時，當β_X 、ξ_X 、α_X 、β_Y 、ξ_Y均爲 0.1，α_Y由 0.1 變爲 0.9 時，相對差異由 12.7%變爲 26.98%；β_X 、ξ_X 、α_X 、β_Y 、α_Y均爲 0.1，ξ_Y由 0.1 變爲 0.9 時，相對差異由 12.7%變爲 20.55%；β_X 、ξ_X 、α_X 、ξ_Y、α_Y均爲 0.1，β_Y由 0.1 變爲 0.9 時，相對差異由 12.7%變爲 13.87%；β_X 、ξ_X 、β_Y 、ξ_Y、α_Y均爲 0.1，α_X由 0.1 變爲 0.5 時，相對差異由 12.7%變爲 21.56%；β_X 、α_X 、β_Y 、ξ_Y、α_Y均爲 0.1，ξ_X由 0.1 變爲

0.5 時，相對差異由 12.7%變爲 19.31%；ξ_X、α_X、β_Y、ξ_Y、α_Y 均爲 0.1，β_X 由 0.1 變爲 0.5 時，相對差異由 12.7%變爲 13.65%；但若 a 與 b 的距離大於 5（i.e. $b-a>5$）時，參數 ξ 、α 不變，β 變大時，相對差異會變小，如附錄二中，在 a=1，b=10 的情況下，當 β_X、ξ_X、α_X、ξ_Y、α_Y 均爲 0.1，β_Y 由 0.1 變爲 0.9 時，相對差異由 22.0%變爲 18.3%；不過，其參數之直接估計式之近似變異數還是會大於參數之直接估計式之近似變異數。綜合以上觀察得知，由參數估計式之近似變異數的觀點來看，參數之間接估計式優於直接估計式，這與前面我們所討論的特殊情形的結果一致。

總而言之，不論是參數的直接估計法或是間接估計法，在夭折期或隨機故障期時，若隨機故障期所維持的時間（i.e. b-a）相較於夭折期所維持的時間長，則 U 型故障函數之參數估計式之近似變異數總和會愈大。即參數估計式之變異數總和，主要因隨機故障期時間的長短而不同，時間愈長變異數總和愈大。此外，參數之直接估計式之近似變異數總和大於參數之間接估計式之近似變異數總和。

2.3 U 型故障函數之直接估計與間接估計式之比較

$$\text{U型故障函數}\lambda^S(t)=(-\beta_S(t-a)+\xi_S)I_{[0,a]}(t)+\xi_S I_{[a,b]}(t)+(\alpha_S(t-b)+\xi_S)I_{[b,\infty)}(t)$$
$$\stackrel{\Delta}{=}g(\beta_S,\xi_S,\alpha_S)，$$

因實際壽命 t 一定會落在某一時間區段之中，$\frac{\partial g}{\partial\beta_S},\frac{\partial g}{\partial\xi_S},\frac{\partial g}{\partial\alpha_S}$ 不全爲零，故

$$\sqrt{n}(g(\hat{\Theta}_S)-g(\Theta_S))\sim AN(0,\Sigma_S)$$

$$\sqrt{n}(g(\hat{\Theta}_X)-g(\Theta_X))\sim AN(0,\Sigma_X)$$

$$\sqrt{n}(g(\hat{\Theta}_Y)-g(\Theta_Y))\sim AN(0,\Sigma_Y)，$$

其中

$$\Sigma_S=(\frac{\partial g}{\partial\beta_S},\frac{\partial g}{\partial\xi_S},\frac{\partial g}{\partial\alpha_S})\ I^{-1}(\Theta_S)\begin{pmatrix}\frac{\partial g}{\partial\beta_S}\\ \frac{\partial g}{\partial\xi_S}\\ \frac{\partial g}{\partial\alpha_S}\end{pmatrix}$$

$$=\begin{cases}\dfrac{(B_SC_S-E_S^{\,2})(t-a)^2+2(t-a)C_SD_S+A_SC_S}{A_SB_SC_S-C_SD_S^{\,2}-A_SE_S^{\,2}} & \text{若} t\in[0,a]\\ \dfrac{A_SC_S}{A_SB_SC_S-C_SD_S^{\,2}-A_SE_S^{\,2}} & \text{若} t\in[a,b]\\ \dfrac{(A_SB_S-D_S^{\,2})(t-b)^2-2(t-b)A_SE_S+A_SC_S}{A_SB_SC_S-C_SD_S^{\,2}-A_SE_S^{\,2}} & \text{若} t\in[b,\infty)\end{cases}\ ;$$

$$\Sigma_X=\left(\frac{\partial g}{\partial\beta_X},\frac{\partial g}{\partial\xi_X},\frac{\partial g}{\partial\alpha_X}\right)I^{-1}(\mathbf{\Theta}_X)\begin{pmatrix}\dfrac{\partial g}{\partial\beta_X}\\ \dfrac{\partial g}{\partial\xi_X}\\ \dfrac{\partial g}{\partial\alpha_X}\end{pmatrix}$$

$$=\begin{cases}\dfrac{(B_XC_X-E_X^{\,2})(t-a)^2+2(t-a)C_XD_X+A_XC_X}{A_XB_XC_X-C_XD_X^{\,2}-A_XE_X^{\,2}} & \text{若} t\in[0,a]\\ \dfrac{A_XC_X}{A_XB_XC_X-C_XD_X^{\,2}-A_XE_X^{\,2}} & \text{若} t\in[a,b]\\ \dfrac{(A_XB_X-D_X^{\,2})(t-b)^2-2(t-b)A_XE_X+A_XC_X}{A_XB_XC_X-C_XD_X^{\,2}-A_XE_X^{\,2}} & \text{若} t\in[b,\infty)\end{cases}\ ;$$

$$\Sigma_Y=\left(\frac{\partial g}{\partial\beta_Y},\frac{\partial g}{\partial\xi_Y},\frac{\partial g}{\partial\alpha_Y}\right)I^{-1}(\mathbf{\Theta}_Y)\begin{pmatrix}\dfrac{\partial g}{\partial\beta_Y}\\ \dfrac{\partial g}{\partial\xi_Y}\\ \dfrac{\partial g}{\partial\alpha_Y}\end{pmatrix}$$

$$=\begin{cases}\dfrac{(B_YC_Y-E_Y^{\,2})(t-a)^2+2(t-a)C_YD_Y+A_YC_Y}{A_YB_YC_Y-C_YD_Y^{\,2}-A_YE_Y^{\,2}} & \text{若} t\in[0,a]\\ \dfrac{A_YC_Y}{A_YB_YC_Y-C_YD_Y^{\,2}-A_YE_Y^{\,2}} & \text{若} t\in[a,b]\\ \dfrac{(A_YB_Y-D_Y^{\,2})(t-b)^2-2(t-b)A_YE_Y+A_YC_Y}{A_YB_YC_Y-C_YD_Y^{\,2}-A_YE_Y^{\,2}} & \text{若} t\in[b,\infty)\end{cases}\ ,$$

其中 A_X、B_X、C_X、D_X、E_X、A_Y、B_Y、C_Y、D_Y、E_Y、A_S、B_S、C_S、D_S、E_S的定義參式子（1）。（參 Serfling（1980），Corollary and Remarks B（p124））。

令 $\frac{1}{n}\Sigma_d$ 及 $\frac{1}{n}\Sigma_I$ 分別代表故障函數之直接估計式與間接估計式之近似變異數，則 $\Sigma_d = \Sigma_S$，$\Sigma_I = \Sigma_X + \Sigma_Y$ 。

（一）故障函數之直接估計之近似變異數爲

$$\Sigma_d = \Sigma_S = \begin{cases} \dfrac{(B_S C_S - E_S^2)(t-a)^2 + 2(t-a)C_S D_S + A_S C_S}{A_S B_S C_S - C_S D_S^2 - A_S E_S^2} & 若 t \in [0,a] \\ \dfrac{A_S C_S}{A_S B_S C_S - C_S D_S^2 - A_S E_S^2} & 若 t \in [a,b] \\ \dfrac{(A_S B_S - D_S^2)(t-b)^2 - 2(t-b)A_S E_S + A_S C_S}{A_S B_S C_S - C_S D_S^2 - A_S E_S^2} & 若 t \in [b,\infty) \end{cases} 。$$

（二）故障函數之間接估計之近似變異數爲

$$\Sigma_I = \Sigma_X + \Sigma_Y$$

$$= \begin{cases} \dfrac{(B_X C_X - E_X^2)(t-a)^2 + 2(t-a)C_X D_X + A_X C_X}{A_X B_X C_X - C_X D_X^2 - A_X E_X^2} + \dfrac{(B_Y C_Y - E_Y^2)(t-a)^2 + 2(t-a)C_Y D_Y + A_Y C_Y}{A_Y B_Y C_Y - C_Y D_Y^2 - A_Y E_Y^2} & 若 t \in [0,a] \\ \dfrac{A_X C_X}{A_X B_X C_X - C_X D_X^2 - A_X E_X^2} + \dfrac{A_Y C_Y}{A_Y B_Y C_Y - C_Y D_Y^2 - A_Y E_Y^2} & 若 t \in [a,b] \\ \dfrac{(A_X B_X - D_X^2)(t-b)^2 - 2(t-b)A_X E_X + A_X C_X}{A_X B_X C_X - C_X D_X^2 - A_X E_X^2} + \dfrac{(A_Y B_Y - D_Y^2)(t-b)^2 - 2(t-b)A_Y E_Y + A_Y C_Y}{A_Y B_Y C_Y - C_Y D_Y^2 - A_Y E_Y^2} & 若 t \in [b,\infty) \end{cases}$$

故障函數之直接估計式與間接估計式之近似變異數。詳列於附錄六。由數值結果我們發現，當 t 落在損耗期時其故障函數之近似變異數最大，而 t 落在隨機故障期時其故障函數之近似共變異矩陣之值最小，同時，不論 t 落在哪一時期，故障函數之直接估計式之近似變異數都大於故障函數之間接估計式之近似變異數，如附錄六中，當 β_X=0.1、ξ_X=0.1、α_X=0.1、β_Y=0.1、ξ_Y=0.1、α_Y=0.9 時，在夭折期的故障函數之直接估計式之近似變異數爲 0.2876，間接估計式之近似變異數爲 0.2729；在隨機故障期的故障函數之直接估計式之近似變異數爲 0.0519，間接估計式之近似變異數爲 0.024；在損耗期的故障函數之直接估計式之近似變異數爲 104.39，間接估計式之近似變異數爲 4.2432。

綜合 2.2 及 2.3 ，不論是估計故障函數之近似變異數，或是估故障函數之參數估計式之近似變異數，其結果均是直接估計式的近似變異數大於間接估計式的近似變異數；也就是說間接估計的方法優於直接估計。由以上分析更發現不論是估計故障函數

之近似共變異數或是估計故障函數之參數估計式之近似變異數，比較直接與間接估計式所得結論相同。因此，對於有關故障函數之估計問題，我們建議只要討論故障函數之參數估計即可。

3.結　論

由第二節之結果得知不論是估計故障函數或估計其參數，由近似變異數的觀點看來間接估計法均優於直接估計法。因此，當故障函數未知時，我們可直接比較故障函數之參數之估計式即可。由本文的討論得知間接估計法優於直接估計法，故對於串聯系統 U 型故障函數的估計，我們建議採用組合零件的個別資料間接的估計即可。

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附 錄

附錄一：折點 a=1、b=3 時 U 型故障曲線之參數的直接與間接估計式之近似變異數總和

a=1 b=3	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	相對差異 $= \frac{trace(I_d^{-1}(\Theta)) - trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))} \times 100\%$
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.1$	1.3834	1.5850	12.7%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.9$	2.5377	3.4760	27.0%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.5\ \alpha_Y=0.9$	7.4167	10.4400	29.0%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.9\ \alpha_Y=0.1$	9.7137	12.2300	20.6%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.9\ \xi_Y=0.1\ \alpha_Y=0.1$	3.6657	4.2560	13.9%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.1$	1.7487	2.2290	21.6%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.9$	2.9030	5.3510	45.7%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.5\ \alpha_Y=0.9$	7.7820	15.9200	51.1%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.9\ \alpha_Y=0.1$	10.0790	16.9900	40.7%
$\beta_X=0.1\ \xi_X=0.1\ \alpha_X=0.5$ $\beta_Y=0.9\ \xi_Y=0.1\ \alpha_Y=0.1$	4.0310	5.2250	22.8%
$\beta_X=0.1\ \xi_X=0.3\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.1$	3.1547	4.1330	23.7%
$\beta_X=0.1\ \xi_X=0.3\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.9$	4.3090	9.4570	54.4%
$\beta_X=0.1\ \xi_X=0.3\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.5\ \alpha_Y=0.9$	9.1880	26.3200	65.1%
$\beta_X=0.1\ \xi_X=0.3\ \alpha_X=0.5$ $\beta_Y=0.1\ \xi_Y=0.9\ \alpha_Y=0.1$	11.4850	25.9800	55.8%
$\beta_X=0.1\ \xi_X=0.3\ \alpha_X=0.5$ $\beta_Y=0.9\ \xi_Y=0.1\ \alpha_Y=0.1$	5.4370	8.0120	32.1%
$\beta_X=0.1\ \xi_X=0.5\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.1$	4.1917	5.1950	19.3%
$\beta_X=0.1\ \xi_X=0.5\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.9$	5.3460	10.4400	48.8%
$\beta_X=0.1\ \xi_X=0.5\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.5\ \alpha_Y=0.9$	10.2250	27.2300	62.5%
$\beta_X=0.1\ \xi_X=0.5\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.9\ \alpha_Y=0.1$	12.5220	25.2800	50.5%
$\beta_X=0.1\ \xi_X=0.5\ \alpha_X=0.1$ $\beta_Y=0.9\ \xi_Y=0.1\ \alpha_Y=0.1$	6.4740	9.4990	31.8%
$\beta_X=0.5\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.1$	2.4427	2.8290	13.7%
$\beta_X=0.5\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.1\ \alpha_Y=0.9$	3.5970	5.1440	30.1%
$\beta_X=0.5\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.5\ \alpha_Y=0.9$	8.4760	13.6200	37.8%
$\beta_X=0.5\ \xi_X=0.1\ \alpha_X=0.1$ $\beta_Y=0.1\ \xi_Y=0.9\ \alpha_Y=0.1$	10.7730	15.7100	31.4%
$\beta_1=0.5\ \xi_1=0.1\ \alpha_1=0.1$ $\beta_2=0.9\ \xi_2=0.1\ \alpha_2=0.1$	4.7250	5.9020	19.9%

附錄二：折點 a=1、b=10 時 U 型故障曲線之參數的直接與間接估計式之近似變異數總和

a=1 b=10	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	相對差異 $=\frac{trace(I_d^{-1}(\Theta))-trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))}\times 100\%$
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.259	1.61	22.0%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	3.495	8.99	61.1%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	105.430	352.44	70.1%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	55.823	564.92	90.1%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	3.496	4.28	18.3%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.924	4.02	52.2%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	4.159	16.55	74.9%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	106.094	713.09	85.1%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	56.487	5625.50	99.0%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	4.160	7.87	47.2%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	6.717	20.23	66.8%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	8.953	106.32	91.6%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	110.888	4898.50	97.7%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	61.281	39716.00	99.8%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	8.954	31.99	72.0%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	4.767	15.97	70.1%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	7.003	352.44	98.0%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	108.938	16668.00	99.3%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	59.331	28763.00	99.8%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	7.004	25.53	72.6%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	2.294	2.85	19. 5%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	4.529	11.86	61.8%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	106.464	431.31	75.3%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	56.857	690.76	91.8%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	4.530	5.93	23.6%

附錄三：折點 a=1、b=20 時 U 型故障曲線之參數的直接與間接估計式之近似變異數總和

a=1 b=20	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	相對差異 $=\frac{trace(I_d^{-1}(\Theta))-trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))}\times 100\%$
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.32	3.33	60.5%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	7.38	57.80	87.2%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	15077.66	140280.00	89.3%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	377830.66	12194000.00	96.9%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	3.56	6.83	47.8%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	3.11	21.10	85.2%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	9.18	113.60	91.9%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	15079.46	285760	94.7%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	377832.46	123660000	99.7%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	5.36	33.34	83.9%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	91.46	960.15	90.5%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	97.53	5658.70	98.3%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	15167.81	14579000	99.9%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	377920.81	6461200000	100%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	93.71	1434.20	93.5%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	145.14	4570.10	96.8%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	151.20	140280	99.9%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	15221.48	366890000	100%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	377974.48	34562000000	100%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	147.38	6819.40	97.8%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	2.35	4.94	52.4%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	8.42	71.47	88.2%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	15078.70	171340	91.2%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	377831.70	14894000	97.5%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	4.60	9.05	49.1%

附錄四：折點 a=2、b=4 時 U 型故障曲線之參數的直接與間接估計式之近似變異數總和

a=2 b=4	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	相對差異 $=\frac{trace(I_d^{-1}(\Theta))-trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))}\times 100\%$
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.3972	0.6215	36.1%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	1.8456	3.6740	49.8%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	7.7356	15.8500	51.2%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	6.3556	11.6400	45.4%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	1.7556	3.3000	46.8%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.8393	1.6370	48.7%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	2.2877	6.7560	66.1%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	8.1777	29.2700	72.1%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	6.7977	28.8700	76.5%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	2.1977	8.3420	73.7%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.7246	3.5150	50.9%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	3.1730	14.1600	77.6%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	9.0630	60.3900	85.0%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	7.6830	57.1900	86.6%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	3.0830	17.3200	82.2%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.7366	3.1730	45.3%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	3.1850	15.8500	79.9%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	9.0750	66.1800	86.3%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	7.6950	36.1600	78.7%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	3.0950	15.2000	79.6%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.8939	1.5620	42.8%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	2.3423	8.3630	72.0%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	8.2323	35.3500	76.7%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	6.8523	25.6300	73.3%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	2.2523	6.5350	65.5%

附錄五：折點 a=2、b=12 時 U 型故障曲線之參數的直接與間接估計式之近似變異數總和

a=2 b=12	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta)$	相對差異 $=\frac{trace(I_d^{-1}(\Theta))-trace(I_I^{-1}(\Theta))}{trace(I_d^{-1}(\Theta))}\times 100\%$
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.35	0.93	63%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	3.52	15.79	78%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	322.30	1560.90	79%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	333.54	5531.40	94%
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	1.61	4.84	67%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	1.29	5.78	78%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	4.46	31.00	86%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	323.24	3177.20	90%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	334.48	56006.00	99%
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	2.55	28.85	91%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	10.07	53.76	81%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	13.24	312.33	96%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	332.02	32705.00	99%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	343.26	590730.00	100%
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	11.33	266.11	96%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	4.47	53.16	92%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	7.64	1560.90	100%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	8.59	5531.40	100%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	337.66	637990.00	100%
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	5.73	262.73	98%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.81	2.25	64%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	3.98	35.31	89%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	322.76	3474.00	91%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	334.00	12310.00	97%
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	2.07	9.98	79%

附錄六：a=1、b=30 U 型故障函數之直接與間接估計式之近似變異數

a=1 b=30	t=0.5		t=10.5		t=30.5	
	$trace(I_d^{-1}(\Theta))$	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	$trace(I_I^{-1}(\Theta))$	$trace(I_d^{-1}(\Theta))$	$trace(I_I^{-1}(\Theta))$
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.2876	0.2728	0.0519	0.0239	3.7719E+00	1.2017E-01
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	0.2876	0.2729	0.0519	0.0240	1.0439E+02	4.2432E+00
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	0.7241	0.6616	0.6229	0.3933	1.4148E+07	5.5927E+05
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	1.3411	1.2028	2.2866	1.6496	6.7150E+10	7.6538E+08
β_X=0.1 ξ_X=0.1 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	0.8912	0.8190	0.0784	0.0300	5.6282E+00	1.4992E-01
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.2876	0.2729	0.0519	0.0239	3.6597E+01	1.3425E+00
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	0.2876	0.2729	0.0519	0.0240	2.0747E+02	5.4656E+00
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	0.7241	0.6616	0.6229	0.3934	2.8821E+07	5.5927E+05
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	1.3411	1.2028	2.2866	1.6497	6.8095E+11	7.6538E+08
β_X=0.1 ξ_X=0.1 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	0.8912	0.8190	0.0784	0.0300	5.4598E+01	1.3723E+00
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.4890	0.4530	0.2398	0.1307	1.3069E+04	4.4801E+02
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	0.4890	0.4530	0.2398	0.1308	7.7201E+04	4.5213E+02
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	1.0036	0.8417	1.2748	0.5002	1.0865E+10	5.5972E+05
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	1.7536	1.3829	3.7691	1.7565	2.6290E+14	7.6538E+08
β_X=0.1 ξ_X=0.3 α_X=0.5 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	1.1660	0.9991	0.3649	0.1368	1.9497E+04	4.4804E+02
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.7241	0.6616	0.6229	0.3933	4.6046E+05	5.2431E+03
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	0.7241	0.6616	0.6229	0.3934	1.4148E+07	5.2472E+03
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	1.3411	1.0504	2.2866	0.7628	2.0203E+12	5.6451E+05
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	2.2624	1.5916	5.8558	2.0191	1.0391E+16	7.6539E+08
β_X=0.1 ξ_X=0.5 α_X=0.1 β_Y=0.9 ξ_Y=0.1 α_Y=0.1	1.4835	1.2078	0.9513	0.3994	6.8692E+05	5.2431E+03
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.1	0.5671	0.5248	0.0639	0.0266	4.6076E+00	1.3359E-01
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.1 α_Y=0.9	0.5671	0.5248	0.0639	0.0267	1.2751E+02	4.2566E+00
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.5 α_Y=0.9	1.0777	0.9136	0.7714	0.3961	1.7280E+07	5.5927E+05
β_X=0.5 ξ_X=0.1 α_X=0.1 β_Y=0.1 ξ_Y=0.9 α_Y=0.1	1.7991	1.4548	2.8335	1.6524	8.2017E+10	7.6538E+08
β_1=0.5 ξ_1=0.1 α_1=0.1 β_2=0.9 ξ_2=0.1 α_2=0.1	1.2657	1.0710	0.0961	0.0327	6.8746E+00	1.6334E-01

A Study on the Direct and Indirect Estimators of U-Type Hazard Function in a Series System

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Abstract

In this paper, we compare the direct and indirect estimators of a U-type hazard function in a series system. It turns out that the indirect estimator is better than the direct estimator.

Titanium Dioxides Film Improved by Cosputtering Materials with Ion Beam Sputtering

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Abstract

Cosputtering of titanium dioxide films with aluminum (Al), fuse silicon (SiO_2) and silicon (Si) is investigated. Their optical properties, surface morphology and structure show better than pure titanium oxide. In general, the extinction coefficient and surface roughness of the cosputtered films are smaller than the pure TiO_2 film. Also, the microstructure of the cosputtered films are improved to an amorphous structure even though post-baked up to 450℃.

Key Words： Cosputtering, ion-beam sputtering, amorphous structure.

INTRODUCTION

The fabrication of high quality optical coatings with low scattering and low absorption losses has recently become significant. Among those coatings, titanium dioxide (TiO_2) has been studied extensively, since it has a high refractive index and transparent range in the visi-

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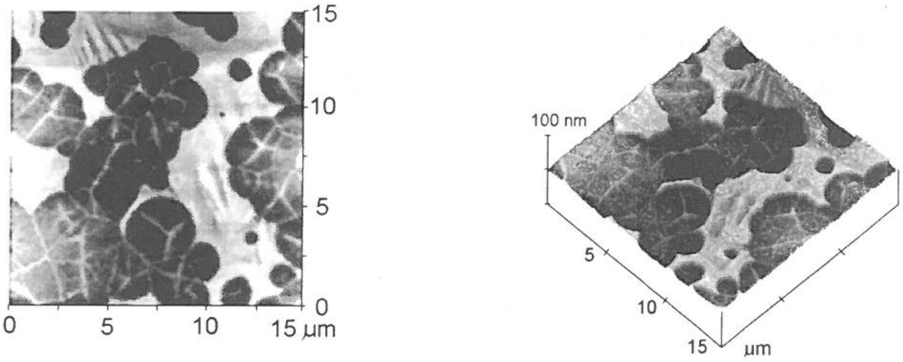

Fig.1. Morphology of titanium oxide film deposited at P_{o2}=2×10^{-5} Torrand baked at 450℃, RMS=1.7 nm

ble and near infrared. It is mechanical hard, environmentally stable. It can be produced by many kinds of deposition methods. However, the best method to produce the TiO_2 film with ultralow loss is ion beam sputtering deposition (IBSD). The optical properties of the TiO_2 film are influenced by oxygen partial pressure (P_{O2}) during deposition and the post-baking temperature in air[1]. The film deposited by IBSD at low temperature (<150℃) are completely amorphous. In general, the surface morphology of the as-deposited film has small grain structures in the surface. When the film is post-baked at an optimum temperature, 275℃, the surface roughness and the extinction coefficient (k) values decreased to the minimums[2]. If the films is post-baked at higher temperature, such as 450℃, there is amorphous-crystalline transformation which causes the k values increase[3] and the film re-crystallizes to the anatase and rutile grain[4]. The TiO_2 film also changes easily to oxygen deficient[5]. Fig. 1 shows the morphology as measured by atomic force microscope. The pure TiO_2 film which is produced by IBSD and post-baked at 450℃ for 6 hours. It is a mildew-like polycrystalline structure and so irregular that some areas draw the surface down obviously[1]. This might be due to the thermal instability of titanium oxide, since titanium has positive ions Ti^{+2}, Ti^{+3} and Ti^{+4}. The effective ionic radii of the ions are 100, 81, and 65 pm respectively[6]. The reduction of the ionic radii with increasing the positive charge value for titanium is more obvious than other metallic ion. The thermal energy from the higher baking temperature stimulates the titanium ion to the high positive charge, Ti^{+4}, which becomes smaller radius in the film. Then, the surface of the film is drawn down. Its microstructure becomes so irregular that the loss increases largely. This phenomenon can be improved by cosputtering deposition with some other materials[2]. We will extend out the studies in this article to explore how the cosputtered materials affect the titanium oxide films.

It is difficulty to determine the structure of the post-baked IBSD film with an x-ray diffractometer, since the measurement of the diffraction signal of the crystalline grain works well only for a thick film[7]. Thus, Raman spectroscopy is necessarily applied to characterize the films molecular structures. It is a simple and effective tool for dynamical study of such a phase transformation[3]. Moreover, atomic force microscope (AFM) is an auxiliary instrument to profile the morphologies of the samples. The deposited films are also examined though the patterns of binding energy revealed by x-ray photoelectron spectroscopy (XPS) for stoichiometry analysis.

EXPERIMENTS

Fig. 2 is the schematic diagram of sputtering system. I_1 and I_2 are main ion source and pre-clear ion source respectively. Both are made by Ion Tech Inc. with 3-cm grids. The target, mounted on a water-cooled polygon turret, is a pure titanium metal (99.995%) disk 100 mm in diameter. Before each deposition the vacuum chamber is cryogenically pumped down to a base pressure of less than 7×10^{-7} Torr. Oxygen is fed near the substrate and regulated at 2×10^{-5} Torr by a needle valve. The background pressure is about 1×10^{-4} Torr during the deposition. The substrate is Corning glass 7059, 2.5 cm×2.5 cm in size.

The beam voltage (V_b) and beam current (I_b) of the main ion source are 1100 V and 30 mA respectively, during the deposition process. The ion current density is about 1 mA/cm^2. The films are deposited with an optical thickness about 0.5 λ (at λ = 650 nm) as monitored by an optical monitor. Meanwhile, a quartz crystal thickness monitor measured the deposition rate.

The materials, selected for cosputtering simultaneously with the titanium target by IBSD, are aluminum (Al), fused silica (SiO_2) and silicon (Si) slices. The slices in various sizes are placed on the surface of the Ti target. Portions of the coatings are baked in an oven in air at 275℃ and 450℃ for 6 hours with a heating rate about 5℃/min. All the samples are examined by a spectrophotometer (Hitachi U-3501) with an error less than 0.1% in transmission

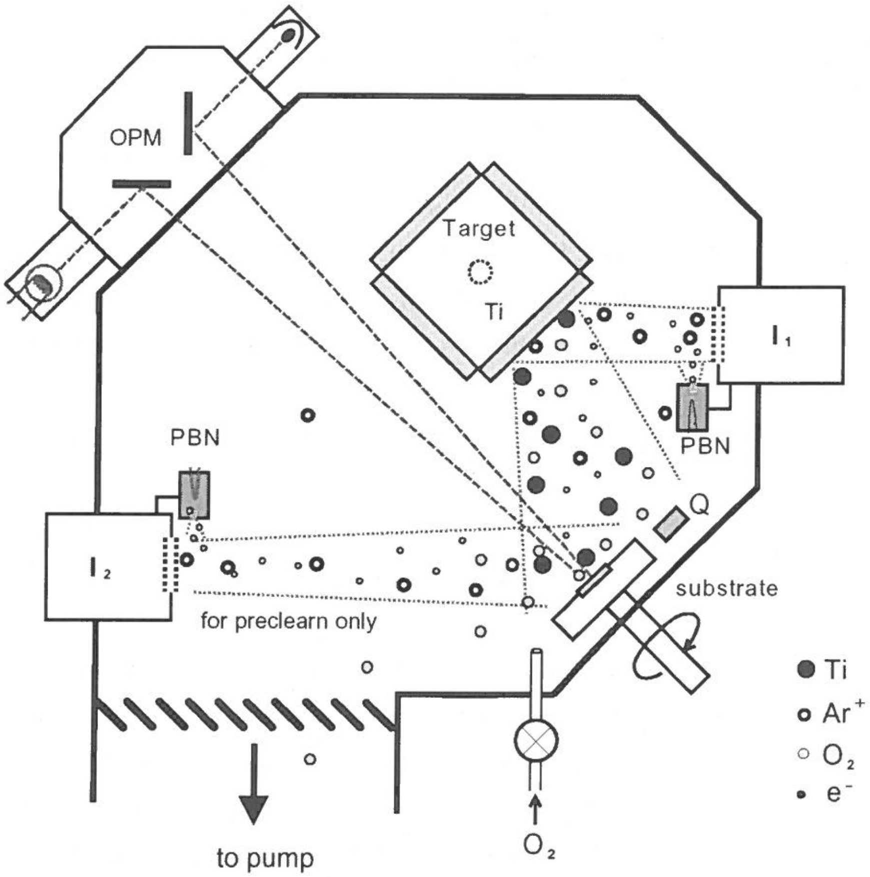

Fig. 2. Schematic drawing of the ion beam sputtering system.

spectral range from 240 nm to 1840 nm. The optical parameters, refractive index *n* and extinction coefficient *k*, are calculated from the transmittance spectra by the envelope method[8]. A Digital Instruments Nanoscope II atomic force microscope instrument is used to scan surface terrain of the samples in a typical area of 1 μm × 1 μm (256 × 256 pixels) on a vibrating-free platform. The RMS, surface roughness value, is obtained with the software that comes with the instrument. The film structures are invergated by a Raman spectroscope within the spectra ranges from 100 cm^{-1} to 1000 cm^{-1} wavenumbers. On the other hand, the XPS spectra are measured on a full binding energy scale and several expanded binding energy scales. Then, a superposition curve fitting process is utilized to analysis the XPS spectra.

RESULTS AND DISCUSSIONS

1. Optical constants

Let *M-R* be the co-sputtering films, where *M* is the selected material: Al, SiO_2, or Si; and *R* is the area ratio of *M* to titanium target in size. Fig. 3 shows the refractive index (n) and the extinction coefficient (k) of the films vs. post-baking temperature. The sample labeled by 'Ti' is deposited by ion-beam sputtering of pure Ti target. Comparing all the cosputtered samples with the 'Ti' film, the extinction coefficient and the refractive index of all the films are reduced. Specially, the index of the sample labeled by Si-1/10 is less than 2.1 due to the larger *R*-value for the Si cosputtered material.

2. Surface morphology

Fig. 4 shows the RMS values of the cosputtered films as comparing with that of the 'Ti' film. The surface roughness of some cosputtered films, such as Al-1/10, SiO_2-1/5 and all Si-*R*, are improved even though post-baking at 450℃. Regarding the sample labeled Al-1/10, the k value is higher than those of the other cosputtered samples due to the optical absorption, shown in Fig. 3.

Fig. 5 shows the morphology of the co-sputtered film baked at 450℃. The mildew-like area decreases when the size of Al, the co-sputtered material increases. For the SiO_2-1/20 and SiO_2-1/10 samples, the mildew-like area becomes small holes due to aggregation of the atoms of the film. When the size of SiO_2 increases as sample SiO_2-1/5, the holes disappear and become a flat surface. For all the samples of the Si-*R*, the surfaces are smooth and the RMS values are less than 0.15 nm.

3. Raman spectrum

The films baked at 450℃ and measured by Raman spectroscope is shown in Fig. 6. The Al-1/10, Si-1/20 and SiO_2-1/5 curves are recognized as the amorphous structures, because their Raman spectra respectively have an indicative low-frequency scattering shoulder near 480-cm^{-1} and 790-cm^{-1} that are similar to the features of the substrate spectra[3].

The two curves labeled by 'E-B' and 'Ti' are spectra of TiO_2 film respectively fabricated

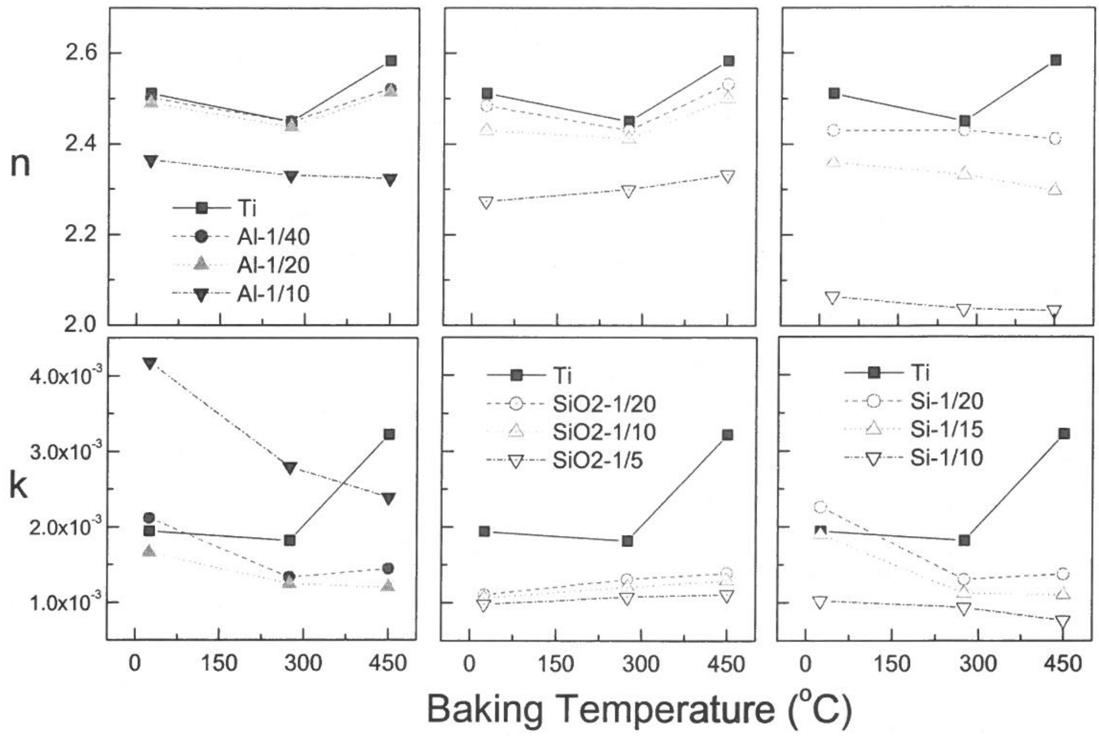

Fig. 3. The refractive index (n) and the extinction coefficient (k) of the cosputtered films vs. baking temperature.

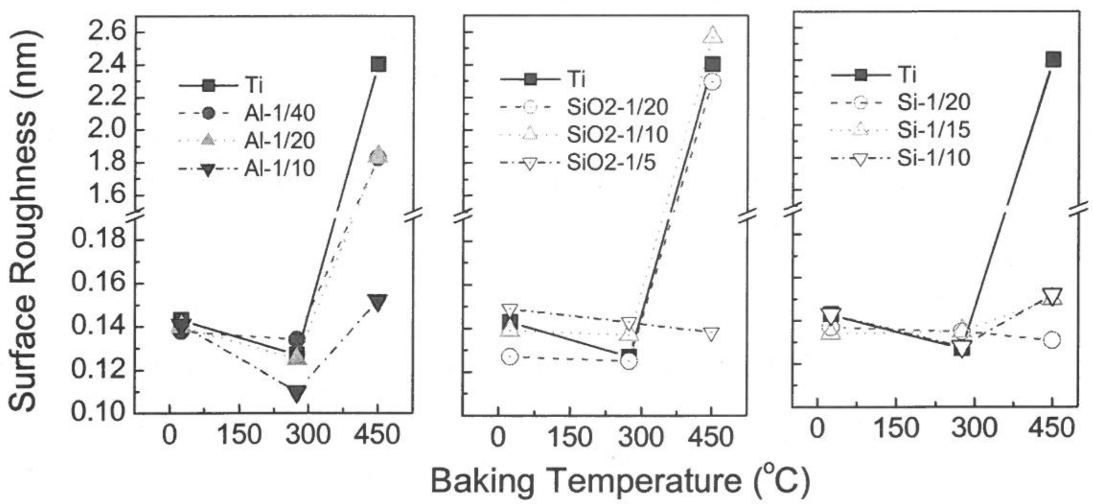

Fig. 4. The RMS surface roughness vs. baking temperature of cosputtered films deposited by IBSD.

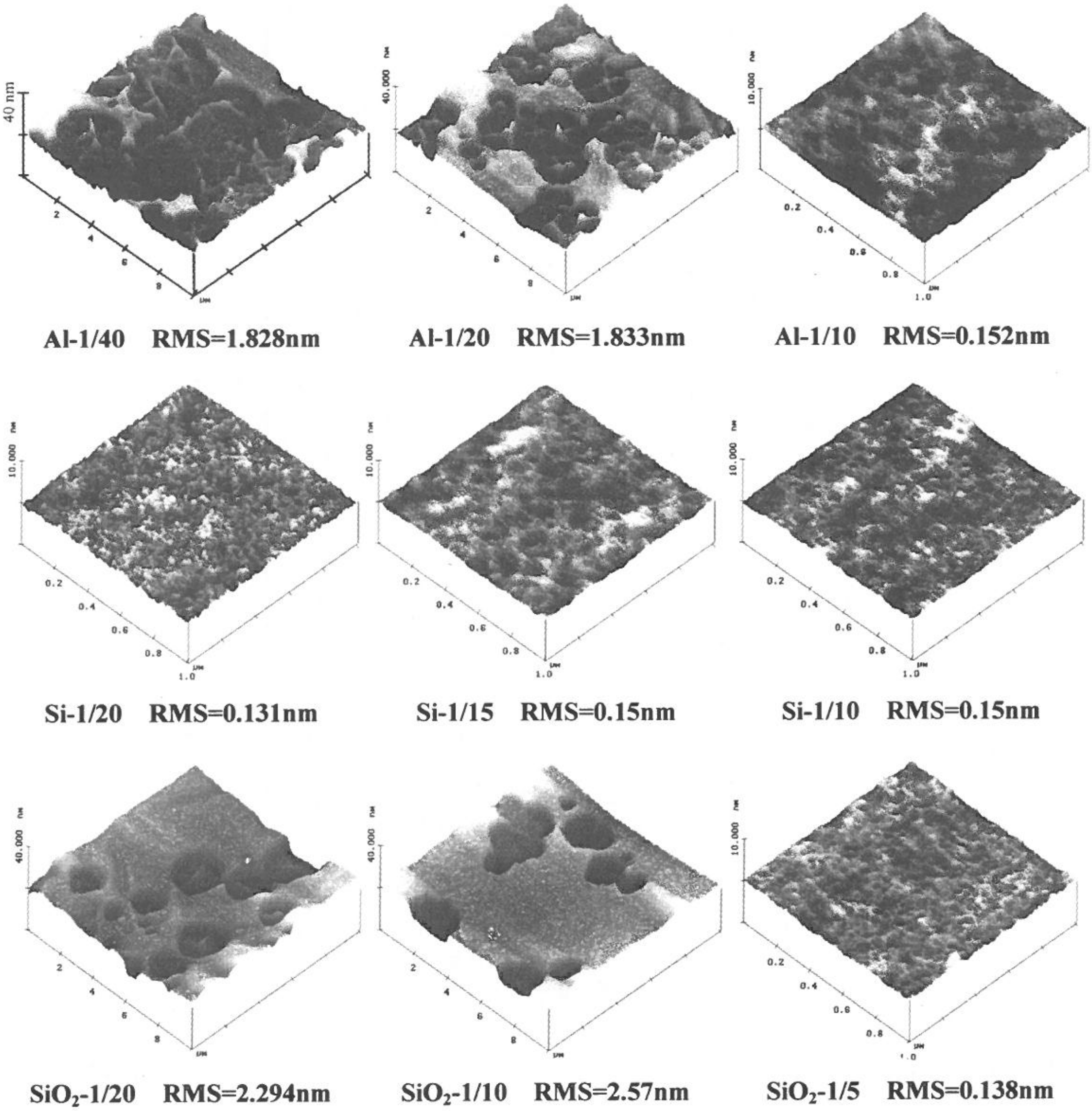

Fig. 5. The surface morphology and the roughness of IBSD films baked at 450℃

by electron-beam deposition at 250℃ temperature and by IBSD of pure Ti metallic target at an oxygen particular pressure of 2×10^{-5} Torr. Both films are made of the pure TiO_2 material and post-baked at 450℃. They have the Raman signals of anatase lines at ~550-cm^{-1} higher than that of the low–frequency scattering shoulder of the substrate spectrum near 480-cm^{-1}.

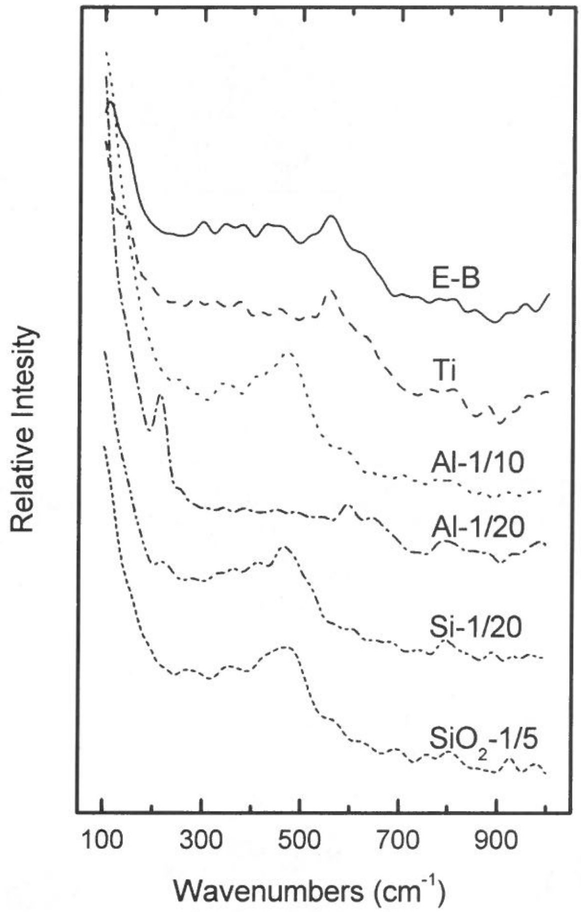

Fig. 6. Raman spectra of titanium dioxide films on Coning 7059 glass:
E-B: pure TiO_2 deposited by E-beam.
Ti: pure TiO_2 deposited by IBSD.

Both features of the anatase signals agree approximately with that of the peak signal reported by Pawlewicz *et al*[9].

Al-1/20 is not an amorphous type because that the Raman spectra rise at 200-cm^{-1} and 580-cm^{-1} and are relatively higher than the background signal of the substrate near 480-cm^{-1}. Oppositely, the Al-1/10 sample is an amorphous film since no anatase signal appears except the signal of the substrate in the Raman spectrum. So, the more cosputtered material, Al, makes the film the more amorphous-like. Then, Al-1/40 sample is neither an amorphous type since the amount of Al co-sputtered material in the film is less than that in Al-1/20 sample.

The cosputtered film, Si-1/20, is amorphous types from above discussion. Si-1/10 and Si-1/15 are also amorphous types due to the more amount of the Si material cosputtered into the films. For the SiO_2 cosputtered material, the film needs the more amount of SiO_2 material cosputtered into the film to become an amorphous type due to the larger *R*-value of SiO_2-1/5.

4. XPS spectrum

When the cosputtered films are measured with x-ray photoelectron spectroscopy (XPS), different binding energies of the atoms in the cosputtered films exhibit at the spectra as shown in Fig. 7 on an expanded energy scale. The Ti_{2p} lines of all films are doublets where the larger peaks theoretically are the $Ti2p_{3/2}$ lines and the smaller are $Ti2p_{1/2}$ lines. The larger $Ti2p_{3/2}$ peaks broaden strongly at ~460 eV because that the majority of Ti atom in the films is bonded by two oxygen atoms and a few cosputtered atoms. And, the broadened peaks can be separated into two sub-peaks with computer simulation software as the dotted lines are shown in Fig. 7. Furthermore, the right sub-peak areas relatively increase and the lefts decrease with the *R*-values, for the same cosputtered material (such as: SiO_2-1/20, SiO_2-1/10 and SiO_2-1/5). The energy of the right sub-peak basically is lower than that of the left as the scale shown in spectrum, which means that the binding energy of titanium atoms deceases due to the cosputtering effect.

Moreover, the oxygen atoms in the films are bonded by Ti atoms and a few cosputtered atoms. The O_{1s} peaks of the oxygen atoms can also separate two sub-peaks just like the $Ti2P_{3/2}$ peaks of the titanium atoms. But, the left sub-peak areas relatively increase and the rights decrease with the *R*-values (such as: SiO_2-1/20, SiO_2-1/10 and SiO_2-1/5). The energy of the left sub-peak is higher than that of the right. So, the cosputtering effect increases the binding energy of the oxygen atoms.

The cosputtering effect shifts and broadens their binding energy in the $Ti2p_{3/2}$ and O_{1s} regions. The binding energy of the oxygen atom increases but that of the titanium atom decreases. The oxygen atoms would absorb the cosputtered atom that replaces the titanium atom and deliver some binding energy between the titanium and oxygen atoms. So, the bond length between the titanium and oxygen atoms in the cosputtered film becomes larger than that in the pure TiO_2 film. Thus, the decrease of the binding energy between the titanium and oxygen atoms in the film may release the drawing force on the film surface[2], which make the surface

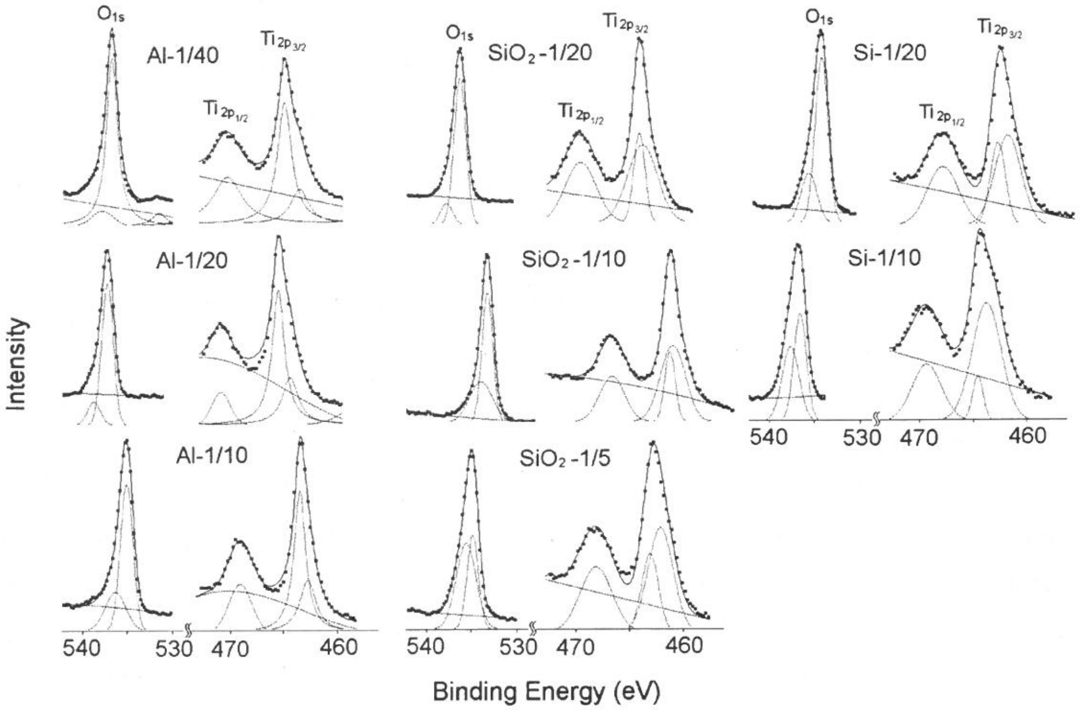

Fig. 7. XPS spectra of the cosputtered films at O_{1S} and Ti_{2p} energy regions. The square points are the measured data. The solid and dotted lines are the fitted curves of the measurement data and their sub-peaks respectively.

morphology smoother if the amount of the selected material in the film is sufficient.

At the same time, the XPS signals of Al_{2p} of the aluminum atom and Si_{2p} of the silicon atoms arise obviously at ~74.5 eV and ~103.4eV, respectively. However, the Al_{2p} signal only appears at the spectrum of Al-1/10 sample and the Si_{2p} signals appear at the spectra of SiO_2-1/5 and all Si-*R* samples. These samples are completely consistent with their smoother surface morphologies shown in Fig. 5. They are also confirmed to be the amorphous structure from the observation of the Raman spectrum illustrated in Fig. 6.

Comparing the three-selected material at the same *R*-value condition, the right $Ti2P_{3/2}$ and the left O_{1s} sub-peak areas of the films cosputtered by Si material are apparently larger than that of the other materials (such as: Al-1/10, SiO_2-1/10 and Si-1/10). Thus, we can that Si material has the best cosputtering effect.

CONCLUSIONS

On the whole, cosputtering with Al, SiO_2 or Si is beneficial to the titanium oxide film in IBSD process. The thermal stability and microstructure of the cosputtered films are obviously improved as baking at 450℃. Specially, Si is the best material for the cosputtering effect since that the cosputtered film is low surface roughness, low optical absorption and amorphous type. Otherwise, the size of the cosputtered Si slice is the smallest than that of the other cosputtered materials when the cosputtered film begin to an amorphous type; thus, the refractive index of the Si cosputtered film approaches to that of pure TiO_2 film as shown in Fig.3. The SiO_2 cosputtered material is also a good choice, but the size of the SiO_2 slice must be larger, then the refractive index of the cosputtered film becomes lower. Otherwise, Al is not recommendable cosputtered material due to the higher optical absorption film, although the surface roughness is improved.

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用離子束濺鍍方法參鍍其他材料以改善二氧化鈦薄膜

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摘 要

研究用離子束濺鍍方法製鍍二氧化鈦薄膜，同時參鍍了金屬鋁、二氧化矽或矽基板，參鍍後的薄膜光學特性、表面細微輪廓及結構的表現比純二氧化鈦的薄膜更好。

一般所參鍍的薄膜其消光係數及表面粗糙度會比純二氧化鈦的薄膜小，而且，其細微結構趨向於無序的非晶結構性狀態，即使經過 450℃的烘烤過程薄膜依然保持非晶結構。

關鍵詞：參鍍、離子束濺鍍、非晶結構。

A Study of Time-varying Population Based Location Management Schemes*

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Abstract

Location management including: paging and location update is an important issue for mobile communication systems. The moving behavior of mobile users is frequently used to guide the location management, however, there is a large class of mobile users without regular moving behaviors. This paper focuses on the case that individual mobility pattern is difficult to obtain. We propose location management schemes based on a time varying population of each cell. The time-varying population of each cell demonstrates the macro moving behavior of overall users in its cell. Such a property is also applied to pre-registration so as to reduce the pre-registration cost and realize seamless handoff. To further reduce the paging delay, group paging concept is proposed. Simulation results demonstrate the proposed time-varying population location management schemes significantly reduce the cost of location management.

Keywords: Mobility management, Location management, Location updating, Paging, Pre-registration

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INTRODUCTION

Location Management plays an important role of cellular and personal communication systems (PCS) and becomes even more significantly in third generation systems (3G) due to the requirements of multimedia mobile communications. In first generation systems, e.g. AMPS, whenever a call incoming, all the cells within the system were paged. Although this was the simplest possible approach, however, it was bandwidth inefficient. Therefore, in second generation systems, e.g. GSM, the hierarchical HLR/VLR database architecture was introduced. For management, a system's whole serving area is divided into several location areas (LA) and each LA maintains a location management database with two primary parts: Home Location Register (HLR) and Visiting Location Register. The HLR consists the profiles of those mobiles that permanently register to its LA and keep track of these mobiles. The VLR keeps the mobiles' profiles that permanently register to its serving area.

To provide convenient and efficient services to users, mobility management comprises three key processes: handoff, paging and location update. Sometimes pre-registration is also included to achieve fast and seamless handoff.

Handoff – In wireless communication systems, holding excellent communication quality while moving is an important issue. While a mobile user attempts to move out current location area during conversation, a handoff procedure is triggered and responsible for handling the redirection of call. Once the handling time is over than required, the call would be dropped. Thus, handoff delay is the most primary concern in this process. To reduce the dropping rate, some system support pre-registration (even pre-reservation).

Pre-registration – Before a handoff process proceeds, the mobile's profile is concurrently registered at nearby LAs. With the sufficient information, the handoff delay could be reduced significantly [4].

Location management – Paging and location update are usually known as location management. While a call is placed, a paging process is initiated to find the target mobile. Location update is used to keep track of the mobile user. Through a series of location update, the paging cost and delay could be decreased. However, for frequent moving user, the overhead of location update is high. Thus, how to make a compromise to reduce the overall cost is an important issue.

Recently, a rapid growth of user population and coverage areas for PCS systems has reinforced the lack of limited radio resources. Since the available channels of a system is restricted, to support the rapidly growing requirements of transmission bandwidths, diminishing the coverage area of cells to increase the bandwidth reuse seems to be the conclusive solution. This, however, increases the number of location updates and control overhead. Furthermore, the enormous location update traffic significantly consumes the limited radio resource as well as the power of handset battery and also introduces vast processing overheads for base stations. These motivate the development of effective location management.

Several efficient location management strategies have been proposed [3][9][11][12][14]. These strategies focus on optimizing registration zone design to reduce the cost of tracking and searching. Some other LA-based investigations focus on reducing paging costs and delays via sequential paging and mobile users' profile information [1][2][10][13][15][17][18]. Instead of paging the whole LA simultaneously, these approaches search the target mobiles by paging sequentially part of the LA. However, the LA scheme is not flexible enough to adapt to diverse mobility patterns and requirements of mobile users. Dynamic mobility management concept is thereby proposed that treat each mobile with individual mobility and call characteristics. Based on this concept, mobile users execute location update depending on either the elapsed time, number of crossed cells, traveled distance, or predicted mobility patterns [5]~[8]. Through accurate prediction of mobile location, these strategies significantly reduce mobility management cost. However, dynamic approaches suffer massive databases and numerous computation overheads since the system should collect individual mobility information for each mobile so as to predict its location. This makes them complicated and difficult to implement. Furthermore, there is large class of users without regular moving behavior. For this class of users, dynamic schemes generate poor performance due to low hit rate; furthermore, mining a regular moving pattern for them is indeed difficult and expansive. In [3], the concept of Moving Location Area (MLA) by combining registration zone and location prediction concept is introduced.

In this paper, in addition to individual mobile's moving behavior, we attempt to enlarge the point of view and focus on the macro moving behavior of the overall mobile users of each cell. Thus, a time-varying population of each cell is introduced to guide location management. The population transitions of nearby cells demonstrate the macro moving behavior. Such intelligence could also be applied to pre-registration so as to reduce the pre-registration cost and handoff delay. To reduce paging time effectively, the concept of simultaneously group paging is also introduced. Simulation results demonstrate that the proposed Time-varying population based location management scheme (TPBLM) significantly elevates paging performance. The TPBLM can cooperate with other dynamic location management approaches to obtain better location management performance.

The rest of this paper is organized as follows. Section 2 gives a brief overview of current location management schemes. The motivation and fundamental functions of the proposed approaches are presented in section 3. The performance evaluation and results of the proposed schemes are provided in Section 4. Section 5 concludes this paper.

AN OVERVIEW OF LOCATION MANAGEMENT

Location management attempts to grasp the mobility of mobile users so as to provide fast and efficient services to them and is usually comprised by two elementary operations: paging and location update. Paging is a searching process to locate a target mobile to deliver a call. Location update typically initiates by a mobile user to notify the system its current location. Frequent location update waste both radio bandwidth and server's processing time, but speedups the paging time. When to trigger a location update process is an important issue. According to the updating time, location update is classified into two categories: explicit and implicit. For explicit location update, when a mobile host moves cross LA boundary, a location update notification is immediately generated and sent to its HLR. On the other hand, the implicit location update delays the updating process till a new call is placed. Meanwhile, the update information is then piggybacked on the data or control message.

Since lots of the users have regular mobility habit, the system may collect the users' mobility behavior and record as part of the users' profile. Several existing intelligent paging schemes page target users according to their profile so as to reduce the paging cost and delay. However, for mobile users without any regular mobility habit, regular mobility patters are difficult to derive. Thus, for this class of users, explicit location update is applied to keep an accurate track of mobile users and reduce the paging cost. A location update requires both base station processing overhead, handset's power consuming, and radio resource, although, frequently location updates can reduce the paging delay and cost. However, for users with rapid moving but seldom being called, frequent location updates consume limited radio resource, system processing time, and mobiles' power. In the LA's point of view, when an LA is in a rush hour, the radio resource and system processing time are extremely limited and more costly, and massive location update messages exhaust resources seriously. In this case, implicit location updates are highly recommended. As well known, consuming low power for light-battery-equipped mobile terminals is highly desired, especially, for a high mobility user because power recharging is inconvenient. However, implicit location update results higher searching overheads and longer paging delay. To reduce paging delay and overhead, an intelligent paging scheme with shorter paging delay is designed. For low mobility users, they have mobility patterns, thus the system may search the targets according to their profile.

An intelligent paging process is usually preceded according to the user's mobility pattern. However, there are circumstances, such as users haven't patterns or the target mobile is absent in the locations recorded in patterns. For these cases, a fixed sequence paging starting from the latest location, denoted as Z_l, is employed. Suppose the target mobile is missing in the latest zone, the first surrounding cells around Z_l are paged. If the target mobile is still not found, the second circle cells, and the third circle cells, etc., are paged. Such a paging scheme accompanied with implicit location update is known as Fixed Sequence Location Management (FSLM) [5].

In this paper, we consider the case that users without individual mobility profile and introduce a time-vary population of each LA. The proposed location management scheme, denoted as Time-varying Population based Location Management (TPLM), employs an implicit location update to save handset's and server's power and radio link bandwidth, and time-varying population based paging schemes to speedup searching and reduce the paging cost. In the following section, the proposed TPLM is presented.

THE PROPOSED TPLM

The TPLM is designed to reduce location management cost and paging delay by taking advantage of the LA's property. Each LA maintains a time-vary population table to guide the location management. In the following subsections, we first introduce the time-varying population table (TPT), location update scheme, and finally the paging schemes of TPLM.

A. Time-varying Population Table

Both natural geographical characteristics such as mountains, lacks, and seas and artificial installations such as highways, stations, theaters, and shopping centers, affect the distributions and movements of mobile users. Not only the geographical characteristics influence mobile users' movements but also time. For example, lots of mobile users might locate in stations or highway in rush hour on weekday. They might move into theaters or shopping areas while getting off work or school, and rush into scenic areas on weekend. Thus, a LA's property similar to the mobile's moving behavior is introduced. Different from mobile's moving behavior, which is a micro view of each mobile, the LA's property is a macro view of overall mobiles' behaviors in its LA. In this paper, we simply use time-varying population as the LA's property. The quantitative information could be collected in the following approaches. Each base station through the registration messages, location update requests, and paging replies could collect the LA's population, since each registration message, location update request or paging reply represents a new incoming mobile user.

The observation time range T may be different length such as 24 hors or a week. Since it is difficult to find a function just fitting the population change, discrete population information is gathered. We divided time domain into a number of time units (i.e. basic observation unit). The time-unit may be fixed length (for example, one hour per unit) or dynamic varying. A dynamic time period may determine according to the population variation; a pre-defined population threshold is given. Whenever the variation crosses the threshold, a new observation period is triggered. Each base station logs the population variation.

B. Location Update Scheme

According to the users' mobility behavior, the mobile users are first divided into two classes: high and low mobility classes. High mobility users refer to users with highly random moving behavior, whereas low mobility users represent users with regular mobility patterns. Usually, a high mobility user produces frequent location updates and consumes high processing overhead and much power. However, consuming low amounts of power through the use of mobile terminals equipped with light batteries is highly preferred. Thus, for both high and low mobility users, an implicit location update is recommended so as to reduce the mobiles' overhead in the proposed TPLM. That is, the location update is delayed until a new call is attempted. The location update information is then piggybacked on the control message. The overhead of an implicit location update is thereby extremely limited.

C. Paging Schemes

The TPLM focuses on the case that mobiles' mobility patterns are difficult to obtain (i.e., high mobility users). For a low mobility user, the TPLM may cooperate with other intelligent paging strategies to page the target based on the user's mobility pattern. The system provides various mobility patterns including a paging sequence for working hours, evenings, or weekends. This information is located in the user's HLR. According to the paging sequence, the system sequentially searches for the target. If the target is unable to find within its mobility pattern or without a moving pattern, a paging process based on time-varying population information is then proceeded. Three different paging strategies are proposed and discussed as follows.

TPLM – Mobile users usually gather to popular area, thus it is reasonable to consider the amount of mobile users as the index to search mobile hosts. According to, TPLM sequentially pages the target according to each LA's population in a decreasing order. It starts from the target's last location Z_l, then the first layer LA surrounding Z_l, and so on. Consider an example illustrated in Fig.1. Assume the last location of mobile user is BS_0 and its current population is 743. If the target handset is not at BS_0, TPLM then searches following the sequence $\{BS_1, BS_3, BS_5, BS_6, BS_2, BS_4\}$. In this example, TPLM consumes three messages to locate the target handset.

M-TPLM – Here, we introduce the concept of multiplayer, a system predefined parameter. The multiplayer parameter (M) defines how many layers should be considered each time. Consider the example shown in Fig.2, the paging sequence of M-TPLM is $\{BS_1, BS_3, BS_5, BS_6, BS_2, BS_0, BS_4\}$. The M-TPLM spends only two paging message to locate the target.

G-TPLM – To decrease the paging delay, we apply the concept of group paging. The basic idea of G-TPLM is to simultaneously page a group of LAs. The predefined system parameter G specifies the number of simultaneous paged LAs. Consider the example shown in Fig. 3 with G=2, G-TPLM searches the target according to the following sequence: $\{BS_0\}$,

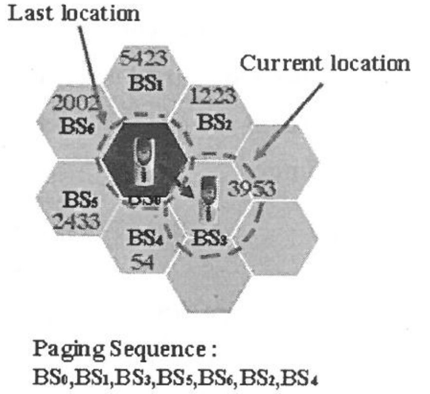

Fig. 1. An illustrated example of TPLM

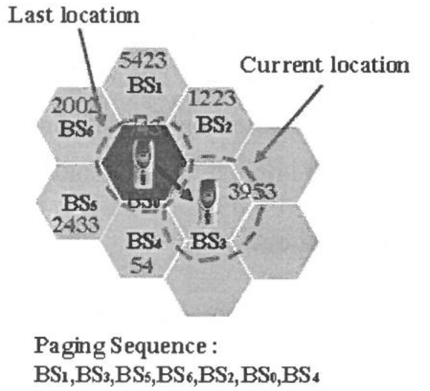

Fig. 2. An illustrated example of M-TPLM

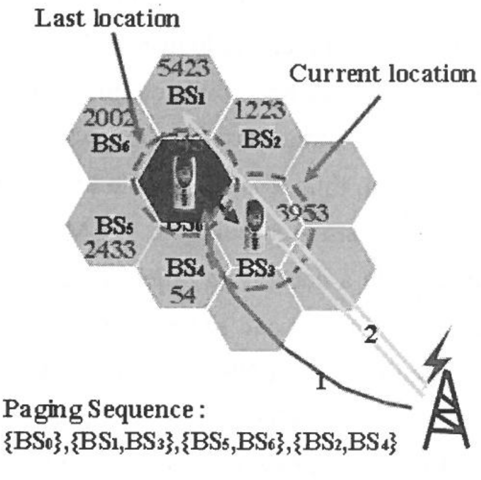

Fig. 3. An illustrated example of G-TPLM

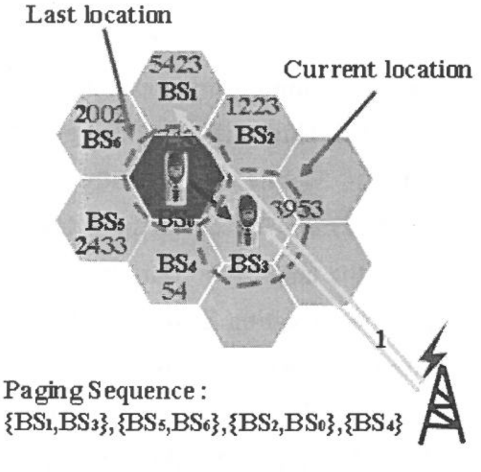

Fig. 4. An illustrated example of MG-TPLM

{BS_1, BS_3}, {BS_5, BS_6}, {BS_2, BS_4} and pages each group concurrently. As the result, the target mobile host locates at BS_3. Hence, it needs two units communicating time, and there are totally three paging messages delivered, since at second paging period, the G-TPLM concurrently pages two location areas at the same time.

MG-TPLM – MG-TPLM is a combination of G-TPLM and M-TPLM. In MG-TPLM, the paging procedure follows the rule of M-TPLM to decide the number of layers considered each time. The group of page sequence is then found. Finally, the paging procedure concurrently pages LAs group by group. Figure 4 demonstrates the paging behavior of MG-TPLM.

Since the target handset is inside the coverage of BS_3, MG-TPLM only spends one unit time and two paging messages.

IV. PERFORMANCE EVALUATION

In the subsequent section, the models, metrics, and assumptions used for the system's performance evaluation are presented. To evaluate the proposed TPLM, some computer simulations are made. We compared the performance of the proposed scheme with other implicit and explicit location management schemes, including FSLM, TPLM, M-TPLM, MG-TPLM and MLA.

Since the proposed TPT represents a macro moving behavior of overall users in the LA, it can also demonstrate the moving situation of highways. Thus, in the simulations, a system configuration with highway is also considered. Under such a system configuration, the simulation results of the proposed scheme are compared to that of MLA. Different from the proposed scheme, MLA employs explicit location update. It enables a location update whenever a mobile enters into a highway. After that, the corresponding mobile joins a dynamic register area. MLA would enable a location update procedure and change to anther dynamic register area whenever the mobile user decreases/increases its speed or changes to another highway. Some qualitative comparisons of the aforementioned methods are listed in Table 1.

Table 1. The qualitative comparisons of FSLM, TPLM, M-TPLM, MG-TPLM, and MLA.

	FSLM	TPLM	M-TPLM	MG-TPLM	MLA
Implicit L.U.	Yes	Yes	Yes	Yes	No
Explicit L.U.	No	No	No	No	Yes
Population information	No	Yes	Yes	Yes	No
Time-varying	No	Yes	Yes	Yes	No
Multilayer	No	No	Yes	Yes	No
Group	No	No	No	Yes	No
L.U. delay	Low	Low	Low	Low	High
L.U. cost	Low	Low	Low	Low	High
Paging delay	High	High	High	Medium	Low
Paging cost	High	High	High	High	Low

The proposed TPT represents macro moving behavior and in the other point of view, it reveals some prediction information. Thus, this prediction information could be also applied to pre-registration schemes. The system could pre-register for a group of mobiles according to the information of TPT so as to improve the handoff quality.

A. Simulation Assumptions

The simulation system model and selected parameters are presented as follows.

1. The serving area considered in the simulation is 15×15 LAs.
2. In the considered system, a LA consists of one cell.
3. For TPT, the observation time range T is set to be one week and fixed basic observation unit is considered in the simulations. The time-unit is set to be 2 hours. Thus, a 12 two-dimension matrix is used; where the x-axis represents 7 days of a week and the y-axis describe 12 basic time units of a day.
4. The low mobility user ratio is 20% and high mobility user ratio is 80%.
5. Two different classes of moving models are simulated. The first class is the uniform model, i.e., the probabilities of six moving directions are equal. The second class is zone population based model. In this model, the moving direction is decided by the time-varying zone population probability. A zone-population based ratio, denoted as δ, is used. Where the ratio δ = 0% represents uniform moving model.
6. The number of layers of the M-TPLM considered in the simulations is 2 (i.e., M=2).
7. The number of LAs in a group considered in the group paging is 3 (i.e., G=3).
8. In the simulations, two type of user moving model for both non-LA population-based moving model and LA population-based moving model. The first moving model is a uniform moving model; that is, the moving probabilities of six directions are equivalent. The LA population information is considered in the second type, i.e., the moving probabilities of six directions are based on the TPT.

B. Performance Evaluated Metrics

In this subsection, the evaluated metrics considered in this paper are introduced [13]. Let N_P denote the average number of paged cells for locating the target for each incoming call and N_U denote the average number of exchanged messages for location update. If λ is the average call-arrival rate per cell, the averaged number messages of each cell for paging and location update is given by λN_P and λN_U, respectively. For simplicity, assume the control message size for both paging and location update is the same and denoted as ϖ_c. Therefore, the total paging traffic of each cell is

$$T_P = \lambda \varpi_c N_P, \tag{1}$$

and the traffic generated by location update of each cell is

$$T_U = \lambda \varpi_c N_U. \tag{2}$$

The normalized paging traffic with respect to $\lambda \varpi_c$ is

$$T_P = N_P, \tag{3}$$

and the normalized traffic of location update (with respect to $\lambda \varpi_c$) is

$$T_U = N_U \tag{4}$$

Let τ denote the paging setup time.[1] Assume A_P is the average number of paging attempts to locate a target, the average paging delay D_P is derived from the following equation:

$$D_P = \tau A_P. \tag{5}$$

If the transmission rate of the paging channel is r bytes/second, in D_P seconds, there are $r\, D_P = r \tau A_P$ bytes generated. Since τ is the setup time for paging message, $r\tau$ becomes the size of paging message ϖ_c. Thus, in D_P seconds, a size of $\varpi_c A_P$ paging traffic is generated. A paging cost consisting of paging overhead (traffic) and delay is considered in this paper. Let C_P denote the paging cost and be given by the following equation.

$$C_P = \alpha T_P + \beta D_P = \alpha \lambda \varpi_c N_P + \beta \lambda \tau A_P = \alpha \lambda \varpi_c N_P + \beta \lambda \varpi_c A_P \tag{6}$$

Where α and β is the weight assigned to the paging traffic and paging delay, respectively. Hence, the normalized paging cost (with respect to $\lambda \varpi_c$) is

$$C_P = \alpha N_P + \beta A_P \tag{7}$$

To better understand the performance of proposed schemes, we consider paging cost and location management cost as indexes for performance evaluation. Since the location management is accomplished by two basic operations: location update and paging, we define the location management cost as a combination of the cost of paging and location update and paging delay. The location update time is not considered, because it is not a significant issue in location management. Let C_{LM} denote the location management cost and is derived from the following equation.

$$C_{LM} = \alpha T_P + \beta D_P + \gamma T_U = \alpha \lambda \varpi_c N_P + \beta \lambda \tau A_P + \gamma \lambda \varpi_c N_U = \alpha \lambda \varpi_c N_P + \beta \lambda \varpi_c A_P + \gamma \lambda \varpi_c N_U \quad (8)$$

Hence, the normalized total cost (with respect to $\lambda \varpi_c$) is

$$C_{LM} = \alpha N_P + \beta A_P + \gamma N_U \quad (9)$$

Where γ is the weight assigned to the traffic generated via location update.

C. Numerical Results

In this subsection, two categories of numerical results are demonstrated. To better understand of the proposed TPLMs' performance, the first simulation results demonstrate the normalized paging traffic, delay, and cost of four location management schemes with implicit location update. The performance comparisons of implicit and explicit schemes are demonstrated in the second category.

Class I: Simulation results of location management schemes with implicit location update

Figures 5 demonstrates the nomalized paging traffic (T_P) and paging delay (D_P) of three different zone property based paging schemes and Ring Paging Scheme (RPS). RPS searchs the target ring by ring. It starts from the lastest location. Suppose the target is missing in the latest LA, the first surronding LAs are then paged. If the target mobile is still not found, the second circle, and the third circle, etc., are paged. All these four schemes employ implicit location update. Althought the paging traffic of MG-TPLM is slightly higher then that of the other three approaches, its paging delay is signifacanly reduced. The average paging delay of M-TPLM is about 40% less than that of the other schemes. Figure 6 demonstrates the paging cost C_P obtained by four paging schemes with implicit location update under different weight values. For implicit paging schemes, since location update is piggybacked on calls, with the same call arrival ratio, each implicit paging scheme generates the same amount of location update attempts and the required overhead is low. Thus, we simply ignore the cost of location update here. Consider an example with α=30%, and β=70%, the paging cost of MG-TPLM is

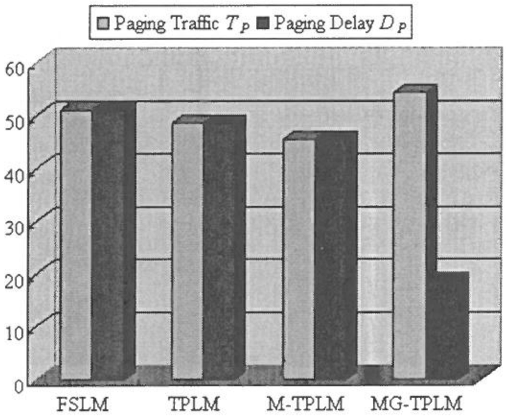

Fig. 5. Paging Traffic T_P and Paging Delay D_P obtained by FSLM, TPLM, M-TPLM, and MG-TPLM.

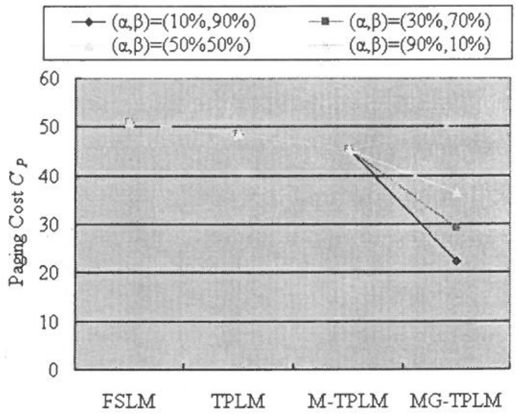

Fig. 6.Paging Cost C_P obtained by FSLM, TPLM, M-TPLM, and MG- TPLM under different weight values

about 40% less than that of the other schemes. As the weight value β increases, a lower paging cost is needed for MG-TPLM. This indicates that if paging cost is focused on paging delay, then MG-TPLM outperforms than other schemes and vice versa. Figure 6 also demonstrates an interested phenomenon that the paging cost C_P of RPS, TPLM, and M-TPLM are independent to the permutation of paging traffic T_P and paging delay D_P. Since RPS, TPLM, and M-TPLM page mobile host cell by cell, the number of paged cell (N_P) is equivalent to the number of attempts to locate the target (A_P). However, MG-TPLM obtains different paging cost for different weight assigned, because N_P is different from A_P for MG-TPLM.

Class II: The comparisons of location management schemes with explicit and implicit location update

The comparison of explicit and implicit location update schemes are demonstrated in Figures 7 through 11. The considered system environment of MLA is highway and it completely demonstrates macro-moving behavior. To demonstrate how time-vary zone information represents macro moving behavior of mobiles, the selected explicit location update scheme is MLA. Thus, all the simulation results of class II are obtained under a system configuration with highways. In Fig. 7, the average paging traffic (T_P), paging delay (D_P), and location update traffic(T_U) obtained by MLA, RPS, TPLM, M-TPLM, and MG-TPLM are demonstrated. Since MLA applies explicit location update, it obtains a lowest paging traffic

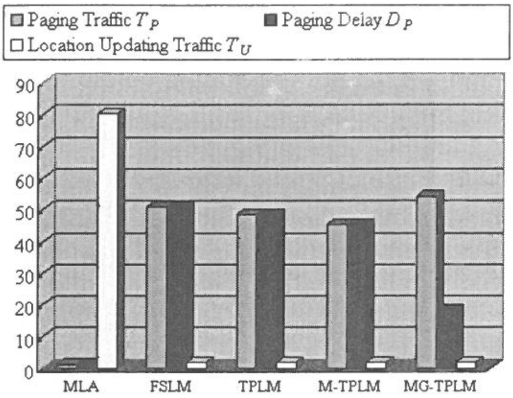

Fig. 7. Paging Traffic T_P, Paging Delay D_P, and Location Updating Traffic T_U obtained by explicit paging scheme (MLA) and implicit paging schemes (FSLM, TPLM, M-TPLM, and MG-TPLM)

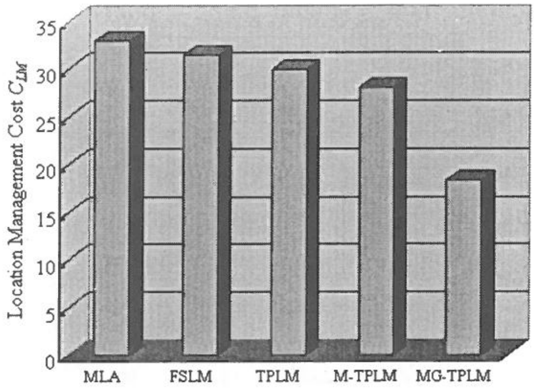

Fig. 8. Location Management Cost C_{LM} with (α, β, Υ)=(18%,42%,40%) obtained by MLA, FSLM, TPLM, M-TPLM, and MG-TPLM

and paging delay. For the other four paging schemes with implicit location update, the generated paging traffic is very close; however, the MG-TPLM gains the lowest paging delay. On the other hand, the location update cost of MLA is significantly higher than that of the other four schemes, since explicit scheme generate a location update whenever a mobile user crosses a different LA. Figure 8 demonstrates the total location management cost (C_{LM}) of MLA, RPS, TPLM, M-TPLM, and MG-TPLM. The considered total cost C_{LM} is obtained via equation (9) with (α, β, γ) = (18%, 42%, 40%). Figure 9 demonstrates the C_{LM} of MLA, RPS, TPLM, M-TPLM, and MG-TPLM with different weight values. For (α, β, γ) = (24%, 56%, 20%), the C_{LM} is computed mostly based on paging cost, MLA gains the best results. However, as γ increases, the required cost of MLA raises. Consider an example with (α,β, Υ)=(6%, 14%, 80%), MLA obtains the worst results. If based on the consideration that the paging delay is more important than the other costs, the proposed MG-TPLM obtains the best performance with (α, β, γ) = (18%, 42%, 40%). On the other hand, if the paging traffic is considered more important, the proposed M-TPLM gains a better performance than that of MG-TPLM. Briefly, from the service provider's point of view, the required maintaining cost (paging and location update traffic) is primary concern, whereas from the users' point of view, the delay time is most important.

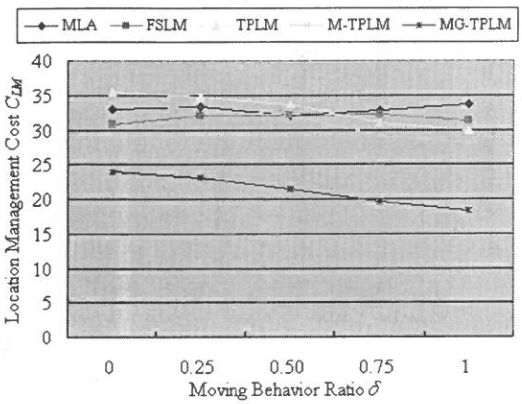

Fig. 9. Location Management Cost C_{LM} obtained by MLA, FSLM, TPLM, M-TPLM, and MG-TPLM under different weight values

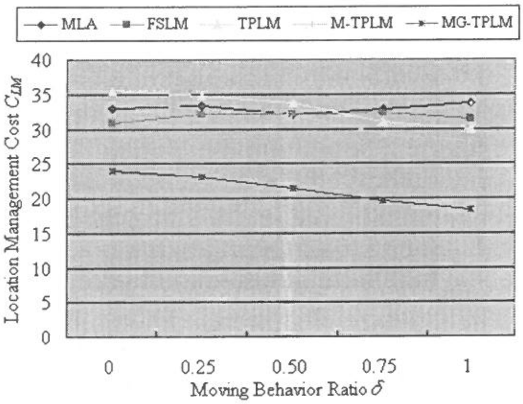

Fig. 10. Location Management Cost C_{LM} with (α,β,Υ)=(18%, 42%, 40%) obtained by FSLM, TPLM, M-TPLM, and MG-TPLM versus Moving behavior Ratio δ

An interesting observation of paging cost obtained by RPS, TPLM, M-TPLM, and MG-TPLM under different mobile moving behaviors is demonstrated in Fig. 10. The x-axis represents the ratio δ of mobile moving behavior based on LA's population. Where ratio 0% stands for uniform moving behavior, i.e., the probability of six directions are equal. Obviously, if mobile users' moving behavior trends toward popular area, such as downtown, or commercial center, the proposed zone-property based schemes gain better performance. Another interesting observation of paging cost vs. call arrival rate λ is shown in Fig. 11. The more calls arrive per unit time; the less paging cost is required for implicit paging schemes. Since for implicit paging schemes, location update is piggybacked on call attempts, the more calls arrive, the more accurate last location is obtained. Notably, MLA dose not suffer by the effect of call arrival rate.

We also introduce the basic idea of this paper (multiplayer, group and TPT) into pre-registration process to reduce the handoff time and present the simulation results in figures 12 and 13. Figure 12 demonstrates the handoff cost obtained by schemes without pre-registration, FSLM, TPLM, G-TPLM. The considered handoff cost C_{HO} is obtained following the same idea discussed in Sec. 4.2 and defined by the following equation.

$$C_{HO} = \alpha T_{HO} + \beta D_{HO}. \tag{10}$$

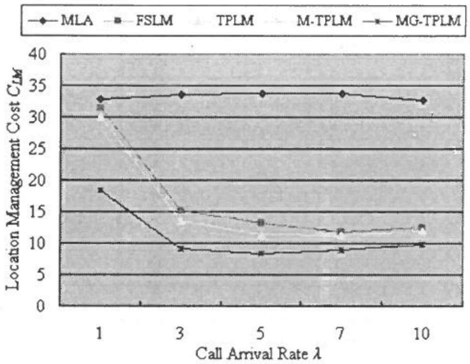

Fig. 11. Location Management Cost C_{LM} with (α,β,ϒ)=(18%, 42%, 40%) obtained by FSLM, TPLM, M-TPLM, and MG-TPLM versus Call Arrival Rate λ

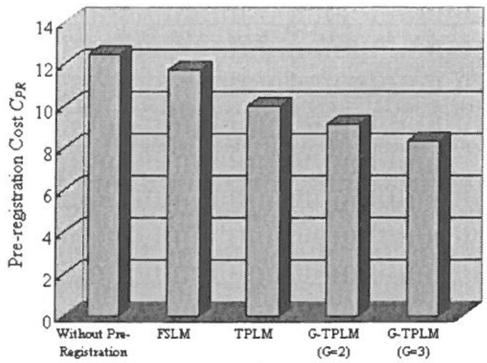

Fig. 12. Handoff cost C_{HO} obtained by without pre-registration, FSLM, TPLM, G-TPLM (G=2), and G-TPLM (G=3)

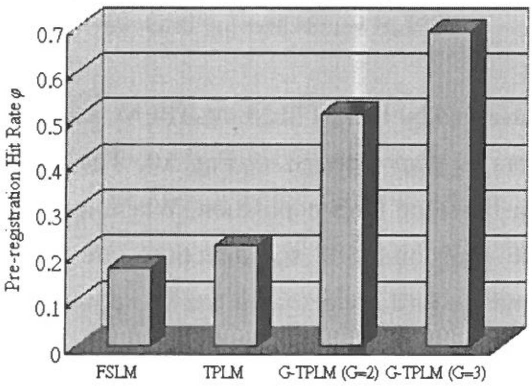

Fig. 13. Pre-registration hit rate φ versus FSLM-based, TPLM-based, G-TPLM-based (G=2), G-TPLM-based (G=3) pre-registration scheme

Where T_{HO} and D_{HO} denotes the traffic and delay generated by handoff, respectively. The considered handoff traffic includes the traffic generated by pre-registration (if any) and handoff. For simplicity, the amount of traffic generated by pre-registration each time is assumed to be the same as that of handoff. The handoff delay is simply ignored if the pre-registered LA is hit. Where α and β is the weight assigned to pre-registration traffic component and delay, respectively. The weight values considered in Fig. 12 is (α,β)=(10%, 90%). Figure 20 presents the pre-registration hit rate φ.

CONCLUSION

In this paper, we proposed a location management scheme utilizing LA information. A simplified time-varying LA population is estimated according to the collected LA information. The time-varying population is capable of representing the macro moving behavior of mobiles in its LA. Based on the time-varying population probability, some intelligent paging schemes have been proposed. Group paging concept has been introduced to reduce the paging delay. Simulation results have demonstrated that the proposed schemes significantly improve the location management performance.

The LA information applied in this paper is simplified but the obtained results are efficient. In the future, further LA's property will be investigated to improve the location management schemes.

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以時變用戶資訊為基礎之位置管理研究

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摘　要

位置管理包含：傳呼與位置更新是行動通訊系統上重要的議題之一，於位置管理中，行動使用者的移動行爲經常作爲管理的重要依據，因此建立使用者的移動資料庫以作爲傳呼或是位置更新的依據是一大要務，然而有許多使用者的移動行爲不具任何的規律性，因此移動樣板的建立極爲困難。 本文針對此類使用者提出一個以蜂巢爲觀察單位，透過觀察蜂巢隨時間的用戶數變化作爲位置管理的依據，由於隨時間之用戶數變化提供了蜂巢的巨觀移動行爲，此一特性亦可應用於預先註冊，如此可有效降低預先註冊的成本同時提升換手的品質，爲了更進一步降低傳呼延遲，本文同時提出群體傳呼的觀念。模擬成果顯示本文所提的以時變用戶數爲基礎的位置管理機制可有效降低位置管理的成本。

關鍵詞：行動管理、位置管理、位置更新、傳呼、預先註冊

領導行為與工作動機：情感關係的探討

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摘 要

西方的領導行爲研究大致將領導行爲分爲結構與體恤二大向度，但近年來在華人社會進行的本土研究，則發現領導者的品格及領導者與部屬之間的情感性關係是影響彼此互動的重要因素。本研究先以關鍵事件技術收集了大量的領導行爲描述，據以編製領導行爲量表，對來自不同公司的員工個別施測，並進行主成份因素分析，在前後間隔數年，分別進行的二個大樣本研究（受測人數各爲 750 人及 1111 人）中，均穩定地發現領導行爲量表可抽取出關心照顧、器重賞識、及教導協助等三個因素，徑路分析的結果，進一步指出這三種領導行爲會顯著地影響部屬在工作上的情緒感受與對主管的情感認同，繼而影響其努力工作的意願及工作表現。研究者於討論中指出華人的領導行爲可能並不是以結構與體恤來畫分，而是將情感融入於工作之中，部屬經由對領導者的情感認同提昇其工作動機與工作表現。

關鍵詞：領導行爲、工作動機、情感關係、情感報

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領導行爲與工作動機二者都是組織心理學的重要研究主題。領導者最主要的功能之一，就是帶領部屬達成組織賦予的任務，而工作動機研究想要回答的基本問題，則是「人爲什麼會努力工作？」(劉兆明，1992a)。領導者既然是帶領部屬工作的人，其表現出來的行爲或爲部屬所知覺到的行爲，自應是影響部屬工作動機的主要來源。近年來，西方的領導研究愈來愈重視部屬的因素，甚至有意提出與 leadership 相對應的 followership（Lippitt，1982；Hollander & Offermann，1990）概念，以加強領導者與部屬之間互動關係的研究（Heller & Van Til，1986；Meindl，1990），但這些研究卻很少深入探討領導行爲如何影響部屬工作動機的問題。

回顧西方組織心理學的文獻，不難發現在探討領導者與部屬之間的互動關係時，與其文化脈絡有密切的關係。首先，在 followership 的概念方面，西方研究者所關心的問題，大多是在權力結構下的社會交換關係（Hollander & Offermann，1990；Kochan，Schmidt & DeCotiis，1986），即使是強調要走出交換關係（transactional leadership）的轉型領導（transformation leadership）理論，也只是在強調領導者應具備的宏觀視野（vision）及運籌帷幄的能力，以喚起部屬對工作與組織的認同，而願憬然跟隨（Bass，1985）。在工作動機的文獻中，探討與領導行爲關係最具代表性的理論則是途徑目標論（path-goal theory）。此一理論植根於工作動機理論中的期望論（expectancy theory，Vroom，1964），再融合領導理論中的俄亥俄學派及權變論（contingency theories）觀點。House 及 Dessler（1974）在其理論命題中，曾指出領導者的動機性功能（motivational functions）包括以下六種領導行爲：(1）使部屬認知領導者所能掌握的工作成果（如獎金或某些實質鼓勵），並引發部屬對這些成果的需求；(2）增加部屬在達成工作目標後的個人所得；(3）經由教導及指示建立使部屬較易獲得個人所得的途徑；(4）協助部屬澄清期望（expectancies，即期望論中所指的行動成功可能性）；(5）減少部屬達成目標的挫折與障礙；以及（6）增加個人提昇績效與滿足的機會。領導者藉由這些工具性的行爲提升部屬努力工作的動機，經由部屬個人需求的滿足，以達成組織的目標，這正是典型的交換論觀點。

筆者過去在分析「報」的概念（劉兆明，1992b）時，曾經和西方的社會交換論進行概念比較。筆者指出社會交換論主要是以個體之間的工具性交換爲主，交換的目的在維持彼此利益的均衡。而華人「報」的概念，除了工具性的交換外，還有相當大的情感成份，且報的行爲受到彼此間的情感關係、差序格局、及道德規範的影響，回報雙方亦未必會清楚計算成本及利益，而更重視其實質意涵。黃光國（1985）在論述華人組織的權力結構時，亦曾指出「關係判斷」是資源分配者（即領導者）在權力遊戲

中的第一步，其所要判斷的「關係」可分爲三大類，分別爲工具性關係、情感性關係及混合性關係。華人組織中領導者與部屬之間的關係，應是工具性與情感性交雜的混合性關係。筆者進一步將「報」和「情感性關係」綜合爲「情感報」的概念。所謂的情感報，是指個人和他人建立情感性關係後，由於感受到對方在情感方面的對待，而表現出來的回報行爲（劉兆明，1996a），這樣的回報行爲是以情感或私誼爲基礎，雖不能完全排除工具性的成份，但表現出來的眞情流露與感激之情，往往超越了工具性交換的考量。在筆者所收集的訪談資料中，部屬以更加努力工作或盡忠職守來報答主管的照顧提拔與知遇之恩的事例屢見不鮮，這些都是西方領導與工作動機理論所未能突顯的重要觀點。因此，在華人社會探討領導者與部屬之間的互動關係時，就不能只侷限於工具性的交換論觀點，而更應關照到領導者與部屬之間的情感性關係。

鄭伯壎等人近年來對華人組織的家長式領導所進行的系列研究，已經注意到華人社會領導者與部屬之間的特殊互動關係。鄭伯壎（1995）在稍早的研究中曾指出台灣家族企業的家長式領導具有施恩和立威兩種行爲類型，其中每一種領導行爲類型都有特殊的行爲模式，部屬亦有相對應的反應。在最近的一篇回顧論文中，鄭伯壎、周麗芳與樊景立（2000）更綜合了本土心理學的研究成果，提出家長式領導行爲與部屬反應的對應模式。在此模式中，家長式領導包括了威權領導、仁慈領導及德性領導等三個重要面向。在威權領導下，主要的領導行爲包括專權作風、貶抑部屬能力、形象整飭、及教誨行爲。部屬的相對反應則爲順從、服從、敬畏、及羞愧等行爲。就仁慈領導而言，領導者表現出個別照顧與維護面子的行爲，部屬則相對表現出感恩與圖報的行爲，其中感恩行爲是指對領導者恩情的感念及緬懷，圖報行爲則包括勤奮工作、表現敬業、犧牲小我、及符合期望等行爲。在德性領導方面，領導者表現出公私分明與以身作則的行爲，部屬則會認同內化其價值與目標，並效法模仿領導者的行爲。

鄭伯壎等人的研究很清楚地指出社會文化脈絡對於領導行爲及其部屬反應的影響。而仁慈領導會引發部屬感恩圖報的行爲，也相當程度地呼應了「情感報」的概念。但這樣的對應模式，仍有待進一步實徵資料的支持，且在概念上亦有值得繼續探討與澄清之處。例如：（1）鄭氏等人的研究，是植基於家族企業的基礎之上，對於非家族企業，或是大型家族企業中，因組織層級而造成位居高位的「家長」與其基層部屬之間「斷層」（劉兆明、黃子玲、陳千玉，1995）時，部屬是否仍會知覺到與家族企業相同的家長式領導行爲？若部屬知覺到的領導行爲不同時，又如何影響其和領導者之間的互動關係？（2）在家長式領導行爲與部屬反應的對應模式中，其對應關係是否有如鄭氏所言之兩兩對應，還是有更複雜的交錯影響？而領導者與部屬之間的互動，

在領導行爲與部屬反應的對應關係之間，是否還有更複雜的歷程模式？

本研究的目的，是想繼續探討不同社會文化脈絡下的領導行爲意涵，再嘗試以工作動機的觀點，進一步探討領導者的行爲是否會經由部屬的情感反應（即情感性動機），而影響其努力意願與工作表現？研究對象擴及公民營及外商企業，並以基層員工爲主，以探討「家長式領導」概念所未及之領導型態與行爲。

方 法

本研究收集資料的過程可分爲三個主要階段。第一階段是以關鍵事件技術（critical incident technique，Flanagan，1954；Bownas & Bernardin，1988）對企業在職員工進行個別訪談，以普遍性地收集影響員工努力工作的具體事例。在 83 家企業中，成功地個別訪談了 524 位員工，收集到 955 個有效事件。這些事件被編寫爲細目後進行分類，其中超過半數以上的細目都與領導行爲有關。第二階段則將這些細目改寫爲問卷題目，分別編製了領導行爲問卷及工作動機問卷，對 750 位企業在職員工個別施測，經由典型相關分析，初步建立了領導行爲與工作動機之間的預測模式（劉兆明，1996b）。第三階段則將這二份問卷進行修訂，受測樣本人數亦擴增爲 1111 人。爲了擴大樣本的代表性，這三階段的取樣均以儘量增加樣本異質性爲原則，本研究以第二及第三階段的問卷資料進行分析，這二個階段受試的男女性別比例相若，且其中大約 70％爲基層員工，30％爲基層幹部（中高層主管不在取樣範圍之內）。受試所屬之組織背景則在前後二階段略有出入，公營事業在第二及第三階段分別爲 15％及 13％，大型民營企業 39％及 30％，中小企業 33％及 41％，外商公司 12％及 16％。

第二階段初步編寫的領導行爲問卷計有 75 題，都是根據第一階段訪談資料中受訪者對其主管行爲的描述改寫而成，其中正面的行爲描述（如對部屬的關懷、賞識、表揚、教導等）計 37 題，負面的行爲描述（如對部屬的指責、挑剔、遷怒、排擠、固執己見或假公濟私等）計 38 題。在以主成分分析、最大概似法及主軸法等各種因素分析模式進行分析時，均穩定地出現「正面行爲」及「負面行爲」這二個因素。筆者根據因素分析的結果刪除及改寫部分題目，編成 40 題的簡式量表在第三階段施測，亦獲得相似的因素結構，筆者乃以內隱論（implicit theory）的觀點詳細分析在華人社會出現此種正負對立的領導行爲內隱結構之意涵（劉兆明，2002），由於以正負向題目同時進入因素分析亦有可能受到「好惡度」（楊中芳，1996）或反應心向（response sets）的影響。筆者乃參考 Lorr 與 Shea（1979）以及 Yang 與 Bond（1990）等人的做法，將個

別受試在問卷上作答的原始分數轉換爲 Z 分數，再進行因素分析；在第二及第三階段的問卷均轉換爲 Z 分數進行因素分析後，取出在二次因素分析均穩定歸屬於相同因素的正向題目計 15 題，重新以原始分數進行因素分析，最後得到關心照顧、器重賞識、及教導協助等三個因素，其累積解釋變異量達 67.09%（如表 1），而三因素的內部一致性（Cronbach's α）分別爲.91、.86、.80，顯示由三因素所形成之分量表均具有良好的信度。

工作動機問卷亦是在第二階段根據訪談資料所編製，並進行探索性因素分析，初步浮現出可由個人性與社會性以及認知面與情感面等二個向度解讀的四因素結構（劉兆明，1996b）。第三階段則將這四個動機因素予以明確定義，並重新寫題，每一動機狀態均編寫 15 題，本研究將其中「情緒感受」及「情感認同」等二個情感性動機的分量表納入分析，「情緒感受」是指個人因目前工作而引發的各種情緒，包括順利、愉快、挫折、氣憤等等，「情感認同」則是指個人對目前工作上的主管產生的感激、信任、尊敬等情感，願意效法主管或爲主管效命。

在前述的第三階段資料收集過程中，問卷內容除了上述領導行爲與工作動機的測量外，另有「努力意願」及「工作表現」二份自編量表。「努力意願」量表有 12 題，內容爲個人主觀上願意在目前工作上努力的程度，「工作表現」量表 10 題，內容爲個人對其所從事的工作在品質、進度、數量、或成效上所作的自我評量。

本研究第二與第三階段之問卷均以個人爲施測對象，由受過訓練的訪員在受試工作以外的時間及場所個別施測。問卷及答案紙分別印製，答案紙直接由電腦光學閱讀，並以 SPSS 統計軟體分析資料。本文以下僅呈現第三階段之資料分析結果。

結　果

領導行為的因素結構

如前所述，本研究所編製之領導行爲量表在以正向題目進行因素分析時，得到關心照顧、器重賞識、及教導協助等三個因素，其結果如表 1 所示。

筆者將本研究所得的三因素結構分別與西方領導行爲研究最具代表性的領導行爲描述問卷（LBDQ，Fleishman，1953a）及鄭伯壎、周麗芳、樊景立（2000）等人的三元模式問卷內容比較，發現這三種問卷的結構各自反映了不同社會文化與組織脈絡下的領導行爲意涵。在本研究所發展的領導行爲問卷中，有 3 題與西方領導行爲描述問

表 1 領導行為問卷刪題後以原始分數進行主成份分析及直交轉軸後之結果

問卷題目	因素負荷量			共同性
	關心照顧	器重賞識	教導協助	
5. 他（她）關心我的升遷機會	**.80**	.28	.23	.77
6. 他（她）關心我的所得與福利	**.77**	.25	.30	.75
4. 他（她）利用機會照顧或提拔我	**.75**	.26	.36	.76
7. 他（她）關心我的生活狀況	**.67**	.25	.30	.61
2. 我努力工作時，他（她）給我獎勵	**.64**	.45	.11	.63
8. 他（她）鼓勵我努力表現以獲得升遷機會	**.64**	.36	.25	.60
11. 他（她）賞識我在工作上的努力或表現	.28	**.75**	.31	.74
9. 他（她）重視我的能力與工作上的貢獻	.22	**.70**	.36	.67
1. 他（她）稱讚或肯定我的工作表現	.40	**.69**	-.00	.63
10. 他（她）支持我對工作的提案或想法	.24	**.68**	.40	.68
14. 他（她）當眾表揚我的工作表現	.44	**.68**	.06	.66
13. 他（她）會教我在工作上不懂的地方	.24	.12	**.82**	.74
3. 他（她）從旁協助我解決工作上的問題	.43	.13	**.70**	.69
12. 他（她）體諒我的困難	.12	.48	**.62**	.63
15. 當我對工作有抱怨時，他（她）會開導我的想法	.39	.33	**.52**	.52
特徵值	7.96	1.09	1.02	累積百分比
解釋變異量百分比	26.80	22.75	17.54	67.09

卷的體恤（consideration）因素相近，分別爲領導者對部屬福利的關心（第 6 題）、稱讚部屬的工作表現（第 1 題）、以及支持部屬的工作（第 10 題），但沒有任何一題可歸屬於強調工作目標、績效及管理方式的結構（structure）因素。在與鄭伯壎等人的三元模式比較時，本研究的問卷有 4 題與鄭氏所稱的「仁慈領導」意涵相近，分別爲關心及照顧部屬的生活（第 4 及第 7 題）、以及協助解決工作上的問題（第 3 題），並對工作上所缺乏的能力給予適當的教育與輔導（第 13 題），但本研究的問卷內容並未出現「威權領導」與「德性領導」方面的題目。這些結果相當程度地反映了華人社會的領導行爲是以領導者與部屬之間的情感性關係爲基礎，而「威權領導」可能是家族企業中家長式領導的重要特質，但未必普遍存在於非家族企業的組織。至於「德性領導」未在本研究中彰顯，則可能與筆者另文（劉兆明，2002）討論的內隱論觀點有關，值得日後進一步深入探究。

領導行為與部屬的情感性動機

在關心照顧、器重賞識、及教導協助等三個領導行爲因素浮現後，本研究進一步

想要探討的問題是這三種領導行爲是否有促進部屬努力工作的動機意涵？如果華人社會的領導行爲確實是以領導者與部屬之間的情感性關係爲基礎，領導行爲所能影響的工作動機應是以情感層面爲主。換言之，領導者表現出來的行爲應會先引發部屬的情感反應（即情感性動機），繼而影響其努力意願及工作表現。筆者乃將問卷施測的結果依據工作動機的概念模式（劉兆明，2001）進行充足模式（full model）的徑路分析（path analysis），並將各變項之間的相關係數依徑路分析的結果進行直接效果與間接效果之分析，其結果如圖 1 及表 2 所示。

徑路分析的結果顯示：關心照顧、器重賞識、及教導協助等三種領導行爲都會顯著地影響部屬對主管的情感認同，其中以教導協助的影響最大（β=.43，p<.01），關心照顧及器重賞識次之（β 分別爲.23 及.10，皆爲 p<.01）；三種領導行爲合計可解釋部屬情感認同 47%的變異量，領導行爲對部屬工作時個人情緒感受的影響相對較小，只有器重賞識（β=.17，p<.01）及教導協助（β=.16，p<.01）二種領導行爲達顯著，解釋變異量亦相對偏低，僅有 11%。在部屬的情感反應對其努力意願的影響方面，部屬在工作上的情緒感受及對主管的情感認同都會直接影響其努力意願（β 分別爲.24 及.27，皆爲 p<.01），而領導者的器重賞識，對部屬的努力意願亦有明顯的直接效果（β=.23，p<.01），而領導者對部屬的關心照顧及教導協助，則是通過部屬對主

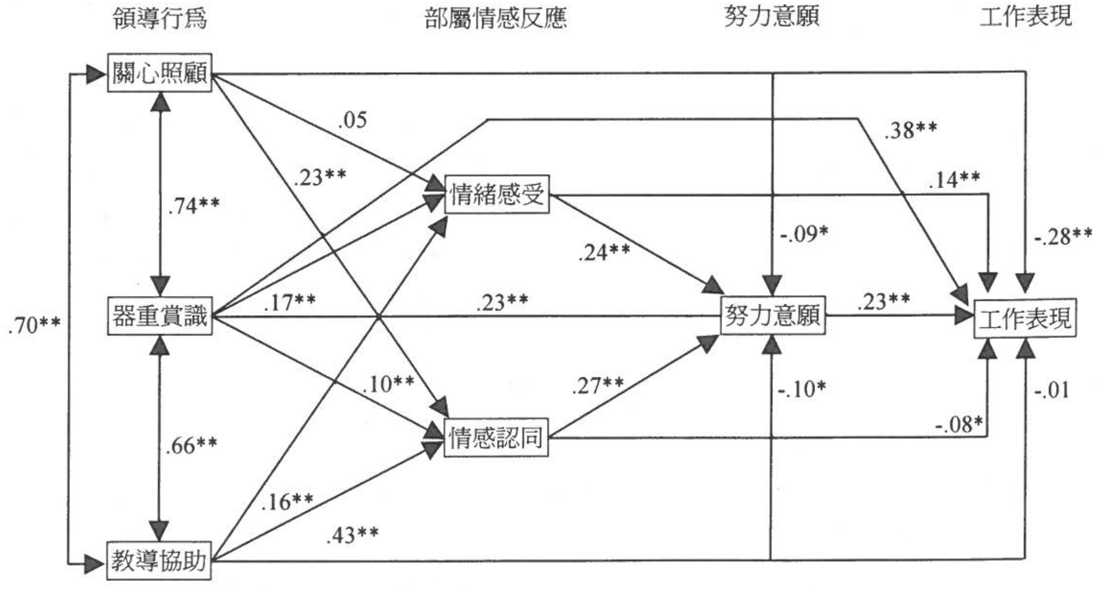

圖 1 領導行為對部屬情感反應、努力意願與工作表現之影響徑路圖

表 2　領導行為與部屬情感性動機之充足模式徑路分析與相關係數分析

自變項	依變項	已分析之相關			調整後的 R^2	未分析之相關及虛假效果	相關係數
		直接效果（β）	間接效果	總效果			
關心照顧	情緒感受	.05	-	.05	.11	.24	.29**
器重賞識		.17**	-	.17		.14	.31**
教導協助		.16**	-	.16		.15	.31**
關心照顧	情感認同	.23**	-	.23	.47	.37	.60**
器重賞識		.10**	-	.10		.45	.55**
教導協助		.43**	-	.43		.23	.66**
關心照顧	努力意願	-.09*	.07	-.02	.21	.25	.23**
器重賞識		.23**	.07	.30		.01	.31**
教導協助		-.10*	.16	.06		.17	.23**
情緒感受		.24**	-	.24		.13	.37**
情感認同		.27**	-	.27		.10	.37**
關心照顧	工作表現	-.28**	-.02	-.30	.16	.34	.04
器重賞識		.38**	.08	.46		-.23	.23**
教導協助		-.01	.00	-.01		.10	.09**
情緒感受		.14**	.06	.20		.02	.22**
情感認同		-.08*	.06	-.02		.12	.10**
努力意願		.23**	-	.23		.07	.30**

$p<.05$　** $p<.01$

管的情感認同而影響其努力意願。在部屬自評的工作表現方面，三種領導行爲皆可透過其情感反應影響其努力意願，進而影響到工作表現（努力意願對工作表現的β值爲.23，$p<.01$）。圖 1 所示的徑路分析結果，應可支持主管的領導行爲對其部屬工作動機的歷程性影響，亦即主管對部屬的關心照顧、器重賞識、及教導協助，的確會經由部屬對主管的情感認同，帶動其努力工作的意願，進而提升其工作表現。

討　論

本研究根據在台灣對各種類型企業的基層在職員工長期收集的大量訪談及問卷資料，發展出領導行爲的三因素結構，並進一步探討領導行爲對部屬工作動機的影響。在領導行爲的意涵方面，研究結果很清楚地顯示出社會文化及組織脈絡對領導行爲的影響，也因而使得領導者在不同的社會文化及組織脈絡下，顯現出的「動機性功能」

可能亦有不同。

首先，就社會文化脈絡而言，西方最具代表性的領導行爲理論將領導行爲分爲體恤與結構兩大向度。體恤向度主要是領導者表現在增進與部屬關係方面的行爲，例如尊重部屬的意見、關心部屬的感受、建立雙方溝通與友善、互信的氣氛等等。結構向度則是領導者表現在工作方面的行爲，例如指示工作方法、澄清工作角色、進行規劃、協調，以達成組織整體目標等等（Fleishman，1953b）。本研究所發展出來的領導行爲問卷，有部份題目的意涵與體恤向度相近，但卻沒有可直接歸屬於結構向度的題目，若由題目的內容進一步分析，可發現本研究領導行爲問卷所描述的領導者並非不重視部屬的工作表現，但他們並不傾向於直接介入部屬的工作，要求其訂定目標與達成績效，而是藉著對部屬的器重、賞識、與提拔，對部屬產生「知遇之恩」，建立情感上的認同，而更加地努力工作。質言之，領導者與部屬之間的互動，並不是如西方理論般地將人（體恤因素）與事（結構因素）那麼清楚地分開，領導者未必會依工作績效或目標來「就事論事」，而是將對事的要求建立在對人的情感之上。因此，在華人社會探討領導者與部屬之間的互動行爲時，就必須要將對事的要求放在人的關係脈絡上來理解。領導者與部屬之間並不只存在著工具性的交換關係，而是以更複雜的情感性關係爲其互動的基礎，這種工具性關係與情感性關係交錯的「混合性關係」（黃光國，1985），造成西方領導行爲的概念與測量工具運用於華人社會的侷限。

其次，就組織脈絡而言，即使在相同社會文化脈絡下的華人社會，也可能會因組織脈絡的不同，而表現出不同的領導行爲。例如鄭伯壎等人長期以家族企業爲對象，觀察到在「家長式領導」中甚爲普遍的「威權領導」行爲，當本研究以公民營及外商企業等各種類型組織爲收集資料的對象時，「威權領導」的概念就未能突顯出來。此外，本研究雖然有部份領導行爲問卷的題目與鄭氏「仁慈領導」的題目內容接近，但這些題目分散於「關心照顧」與「教導協助」二因素之內，已經沒有重視尊卑倫理的「仁慈」意涵了。由此可見，相類似的領導行爲描述在不同的社會文化或組織脈絡下，可能會被賦予不同的概念意涵。問卷及因素結構往往只是反映了題目彼此之間的相互關係，因素結構背後的概念及用以測量的問卷題目由何而來，才是理解概念意涵的重要關鍵。

第三，就領導者的「動機性功能」而言，本研究的結果顯示在不同的社會文化脈絡下，領導者亦各有其「動機性功能」。由途徑目標論所列舉的六大功能來看，領導者似乎只具有工具性的功能。領導者存在的主要目的，就是透過各種協助途徑或幫助部屬掃除達成目標的障礙，增加部屬的所得，以達成提昇部屬績效的工具性目的。本研

究所顯示出來的領導者功能，則有相當大的情感性成分。領導者帶人要先帶心，使部屬心存感念而在工作上全力以赴；即使是工具性的目的，也須先獲得部屬的情感認同，才易於發揮領導的功能。這種經由部屬對領導者行爲的情感認同，帶動其努力工作的意願，進而提升其工作表現的歷程模式，進一步印證了部屬會以努力工作回報主管的「情感報」概念（劉兆明，1996b），也說明領導行爲與部屬反應之間不只是兩兩對應的關係，而可進一步由部屬反應（本研究所探討的是部屬的情感反應）探討對其努力意願與工作表現之影響歷程。

本研究以長期累積的關鍵事件訪談及二個異質性大樣本的問卷測量資料，初步勾勒出華人社會在「家長式領導」之外的領導行爲意涵，並藉由領導行爲與部屬情感反應及其努力意願與工作表現之間的連結，建構了領導行爲與工作動機的歷程模式，這樣的資料收集與理論建構的途徑，較接近於以部屬爲中心的研究取向（follower-centered approach），不同於傳統的領導行爲研究是以領導者爲中心（leader-centered approach）。Meindl（1990）在比較這二種研究取向時，曾指出以領導者爲中心的研究較重視的是領導者表現於外的行爲、特質、及其效能，以部屬爲中心的研究取向則較重視部屬的內在思維系統（thought systems）及社會影響歷程（social psychological process），也因而較容易發展出內隱的組織理論（implicit theories of organizations）。筆者認爲這兩種研究取向彼此有互補的功能，若能相互爲用，將有助於概念的澄清及理論品質的提升。因此，後續研究可朝與傳統理論的對話及部屬觀點的深入分析兩大方向並進：在與傳統理論的對話方面，可進一步探討本研究所發展出來的領導行爲與傳統領導行爲理論之間的相互關連及其在概念上的異同。具體的作法，可將不同的領導行爲與效能問卷同時施測，重新分析其因素結構，並比較不同類型組織（如家族色彩濃厚的傳統產業與不具家族色彩的新興產業）之間的差異；在部屬觀點的深入分析方面，則可以過去研究所得的豐富資料爲基礎，探討可能存在於部屬心目中的內隱結構及其對於領導行爲知覺的影響，亦可經由質化資料的故事性分析（narrative analysis），以更鮮活地呈現主管與部屬之間的情感性互動。

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0301-H-030-005)，第三階段之研究計畫為二年期「工作動機理論的建構與驗證」(計畫編號 NSC87/88-2413-H-030-001)。本文圖表之數據，係以第三階段問卷之部份資料進行分析而得。筆者感謝該會對本研究長期之支持，並感謝所有曾參與本研究的訪員、受訪者、及提供協助的相關人士。

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Leader Behavior and Work Motivation: Analysis on Affective Perspective

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Abstract

Leader behavior is mainly divided into structure and consideration in Western research. However, recent indigenous studies in Chinese societies find out that the character of a leader as well as the affiliation with his/her subordinates are also major factors in their interaction. In the present study, critical incident technique is used to collect leader behavior descriptions, then to compile a leader behavior inventory. Employees from various companies are undertaken the inventory individually in two samples （N=750 and 1,111 respectively）. Principal component analyses in both samples consistently indicate three leader behavior factors: caring, recognition, and mentor. Path analysis in the second sample further indicates that the three leader behaviors can significantly influence subordinates' work feeling and affiliation with their superiors. Moreover, the feeling and affiliation will then influence their willingness to work hard and self-rated performance. The author points out in discussion that Chinese leader behavior may not merely be divided by structure and consideration, rather feeling is infused into work. A subordinate's work motivation and performance is transcended through his/her affiliation with the leader.

Key Words: Leader behavior, work motivation, affective relations, affective *bao*

Synthesis of Liquid Crystalline Compounds of Alkyl or Aryl 6-(4-Alkylphenyl) Nicotinates

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Abstract

This study describes an efficient approach to synthesize pyridine-containing liquid crystalline compounds by using of 4-alkylphenyl magnesium bromide to react with alkyl or aryl *N*-phenyloxycarbonylnicotinium chloride and subsequent oxidation by *o*-chloranil to give regioselective alkyl or aryl 6-(4-alkylphenyl)nicotinates in a fair yield.

Key Words: Synthesis; pyridine-containing compounds; liquid crystalline compounds.

INTRODUCTION

Interest in liquid crystal (LC) technology is increasing rapidly because it is a leading candidate for full color, monochrome and black and white displays in computers, aircraft and other vehicle cockpits and for the large next-generation television market. Although some pyridine-containing liquid crystalline compounds have been synthesized before,[1-4] there is a large demand for new liquid crystalline materials for more advanced displays. Recently, certain pyridine-containing liquid crystalline compounds have shown enhanced properties in display application.[5]

Previously, we have prepared various 2- or 4-substituted pyridines and alkaloids by re-

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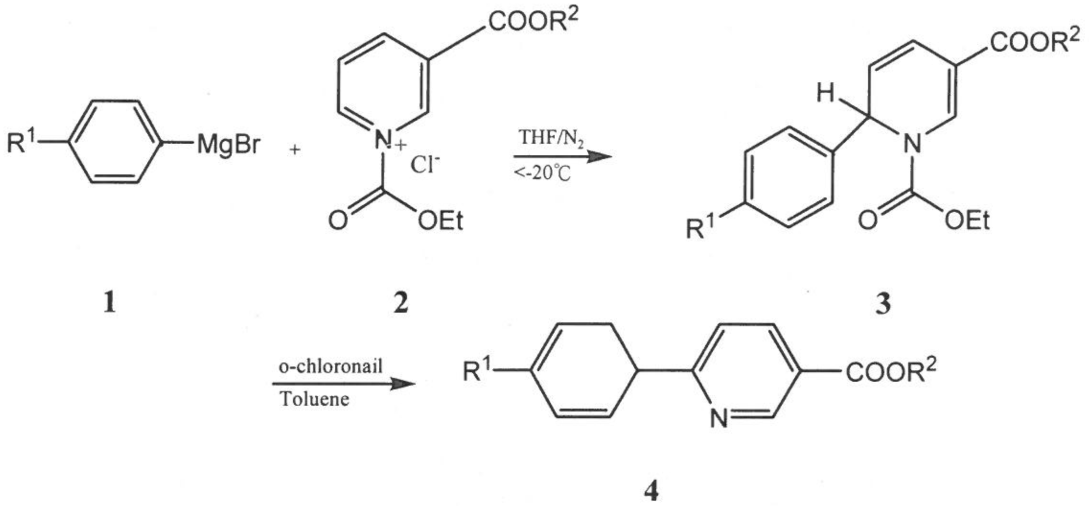

Scheme 1

gioselective addition of organometallic reagents to 1-acylpyridinium salts.[6] Recently, we have successfully applied this methodology to prepare liquid crystalline 5-substituted 2-(4-alkylphenyl)pyridines.[7] In this paper, we wish to report an efficient synthesis of liquid crystalline compounds of alkyl or aryl 6-(4-alkylphenyl)nicotinates **4** (**Scheme 1**).

RESULTS AND DISCUSSION

Synthesis of alkyl or aryl 6-(4-alkylphenyl)nicotinates :[8]

Efficient syntheses of alkyl or aryl 6-(4-alkylphenyl)nicotinates **4** were carried out by using 4-alkylphenylmagnesium bromide **1** to react with alkyl or aryl nicotinates **2** and subsequently oxidized by *o*-chloranil (**Scheme 1**). Yields were fair for these alkyl or aryl 6-(4-alkylphenyl)nicotinates (**Table 1**).[9] Low yield of these products is probably attributed to the withdrawing nature of the 3-substitutents on the pyridine ring; while, electron-donating 3-substituted pyridines provide high yields of the corresponding products.[7] α-Regioselectivity on the pyridine rings was completely dominant in the products from all these reactions. In regard to the purity of these compounds, the crude products were further purified by recrystallization from hexane. All compounds gave satisfactory data by ^{13}C NMR (75MHz,

Table 1. Synthesis of alkyl or aryl 6-(4-alkylphenyl)nicotinates 4a-4f

Entry	R^1	R^2	Mp(℃)[b]	Yield[a](%)
4a	H	Ph	144	44
4b	Me	Ph	141	33
4c	Bu	Me	87	33
4d	Bu	Ph	113	31
4e	Bu	Benzyl	50	31
4f	Pentyl[c]	Ph	104	34

[a]Isolated yield by column chromatography (methylene chloride/hexane) on silica gel.
[b]Recrystallized from hexane and according to the second heating cycle.
[c]*p*-Bromopentylbenzene was synthesized according to a known procedure.[13]

$CDCl_3$) and IR spectra. This methodology to synthesize pyridine-containing liquid crystals is quite effective and products can be obtained in a short two-step reactions.

Thermotropic behavior of alkyl or aryl 6-(4-alkylphenyl)nicotinates :

Thermotropic behavior of these alkyl or aryl 6-(4-alkylphenyl)nicotinates synthesized can be clearly observed using differential scanning calorimetry (dsc). Only two of these alkyl or aryl 6-(4-alkylphenyl)nicotinates were found to be liquid crystalline, they were phenyl 6-(4-*n*-butylphenyl)nicotinate **(4d)** and phenyl 6-(4-*n*-pentylphenyl)nicotinate **(4f)**.

Phenyl 6-(4-*n*-butylphenyl)nicotinate **(4d)** was found to be monotropic and its mesomorphic range was between 91.16℃ and 72.15℃, when a second cooling cycle was conducted, phenyl 6-(4-*n*-pentylphenyl)nicotinate **(4f)** was found to be enantiotropic and its mesomorphic ranges were between 104.19℃ and 108℃[10] when a second heating cycle was conducted and between 109.06℃ and 75.67℃ while cooling cycle was conducted. The magnitudes of the enthalpy changes between crystal-to-mesophase were found to be much higher than those between mesophase-to-isotropic for both **(4d)** and **(4f)**.[11] This indicates a less ordered (or highly mobile) mesophase might occur in the mesomorphic range. It is known that the lone pairs of electrons on the nitrogen atoms act to broaden the molecule and also introduce attractive forces which aid smectic formation. Focal conic fan textures were observed and smectic A phases[12] presumably appear in both phenyl 6-(4-*n*-butylphenyl)nicotinate **(4d)** and phenyl 6-(4-*n*-pentylphenyl)nicotinate **(4f)** when using a polarized optical microscope **(Figure 1)**. However, the exact identification of the mesophases of these two compounds needs to be further verified by the x-ray diffraction method.

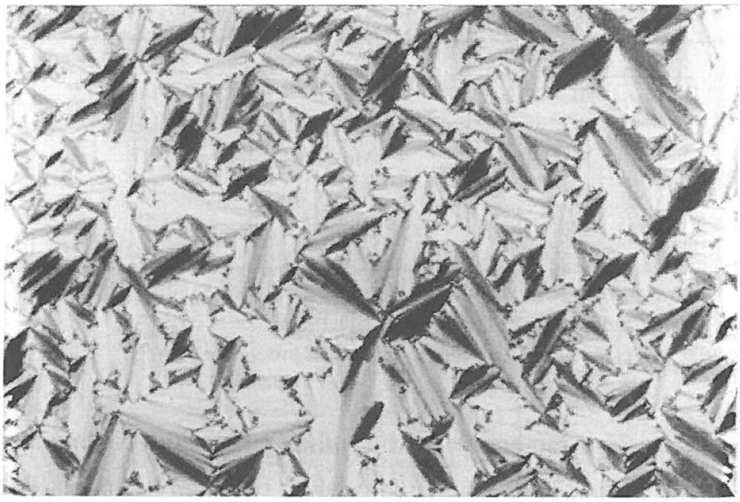

Fig. 1. Focal conic fan texture of the mesophase of phenyl 6-(4-*n*-pentylphenyl)nicotinate (4f) arises from isotropic phase on cooling to 80℃. Polarized optical micrographs with magnification of ×200.

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(8) Representative experimental procedure of **3d**: To a (Grignard) solution of 1-bromo-4-butylbenzene (10 mmol) in 20 ml THF was added freshly dried magnesium granules (11 mmol) under an inert atmosphere. The Grignard solution **1** was then slowly added by syringe into a preformed solution of nicotinium chloride **2** (10 mmol ethyl chloroformate, 10 mmol phenyl nicotinate, 20 ml dry THF at -20℃, 0.5 h) at -20℃. The resulting solution was warmed slowly to room temperature and stirred for another 8 h. After evaporating the THF, the residue was extracted with ether. The organic layer was further washed twice with 10% HCl solution and brine and dried with magnesium sulfate. Yields of the intermediates were found to be around 60%. For **4d**: To a solution of 20 ml dry toluene and crude **3d** was added about 1.5eq. *o*-chloranil. The reaction mixture was heated to reflux for a number of hours under inert atmosphere and then quenched by adding 25 ml 1N NaOH solution and 25 ml ethyl ether and filtered through celite. Normal aqueous work up and isolation with column chromatography affords the product **4d** (31%). The crude products were further purified by re-crystallization from hexane.

(9) ^{1}H NMR (400MHz, $CDCl_3$). **4a**: 9.46 (s, 1H), 8.48 (dd, 1H, J_1=8.34 Hz, J_2=2.25 Hz), 8.10 (d, 2H, J=7.86 Hz), 7.87 (d, 1H, J=8.34 Hz), 7.43-7.55 (m, 5H), 7.31-7.24 (m, 3H); **4b:** 9.42 (s, 1H), 8.46 (dd, 1H, J_1=8.36 Hz, J_2=2.26 Hz), 8.00 (d, 2H, J=8.22 Hz), 7.85 (d, 1H, J=8.38 Hz), 7.45 (t, 2H, J=7.67 Hz), 7.24-7.33 (m, 5H), 2.43 (s, 3H); **4c:** 9.19 (d, 1H, J=2.10 Hz), 8.25 (dd, 1H, J_1=8.33 Hz, J_2= 2.19 Hz), 7.90 (d, 2H, J=8.23 Hz), 7.71 (t, 1H, J=8.34 Hz), 7.23 (d, 2H, J=8.23 Hz), 3.89 (s, 3H), 2.61 (t, 2H, J=7.83 Hz), 1.61-1.53 (m, 2H), 1.34-1.28 (m, 2H), 0.87 (t, 3H, J =7.36 Hz); **4d:** 9.45 (s,1H), 8.47 (dd,1H, J_1=8.40 Hz, J_2=2.04 Hz), 8.05 (d, 2H, J=7.98 Hz), 7.86 (d, 1H, J=8.36 Hz), 7.47 (t, 2H, J=7.97 Hz), 7.26-7.36 (m, 5H), 2.71 (t, 2H, J=7.69 Hz), 1.71-1.64 (m, 2H), 1.46-1.39 (m, 2H), 0.98 (t, 3H, J=7.60 Hz); **4e:** 9.30 (dd, 1H, J_1=2.16 Hz, J_2=0.70 Hz), 8.33 (dd, 1H, J_1= 8.34 Hz, J_2=2.22 Hz), 7.97 (d, 2H, J=8.27 Hz), 7.77 (dd, 1H, J_1=8.38 Hz, J_2=0.68 Hz), 7.46 (d, 2H, J=8.25 Hz), 7.42-7.33 (m, 3H), 7.31 (d, 2H, J=8.23 Hz), 5.40 (s, 2H), 2.67 (t, 2H, J=7.70 Hz), 1.67-1.59 (m, 2H), 1.34-1.40 (m, 2H), 0.93 (t, 3H, J=7.34 Hz);

4f: 9.42 (d, 1H, J=2.12 Hz), 8.45 (dd,1H, J_1=8.36 Hz, J_2= 2.28 Hz), 8.15 (d, 2H, J=8.20 Hz), 7.84 (d, 1H, J=8.36 Hz), 7.44 (t, 2H, J=7.96 Hz), 7.22-7.33 (m, 5H), 2.67 (t, 2H, J=7.88 Hz), 1.70-1.62 (m, 2H), 1.38-1.31 (m, 4H), 0.90 (t, 3H, J=7.00 Hz); All compounds gave satisfactory data by ^{13}C NMR (75MHz, $CDCl_3$) and IR spectrum.

(10) These two peaks were too close to separate unambiguously, the onset temperature of the second peak is only an estimated value.

(11) The magnitudes of the enthalpy changes between crystal-to-mesophase and mesophase-to-isotropic phase for **(4d)** were 44.96 J/g and 5.76 J/g, respectively, when a second cooling cycle was conducted. Those for **(4f)** were 52.81 J/g and 6.763 J/g respectively.

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烷基或芳基 6-(4-烷苯基)尼古丁酯液晶化合物的合成

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摘　要

這個研究是在描述一有效的含比啶的液晶合成, 其方法是利用烷基苯溴鎂與烷基-或芳基-氮-乙烷氧醯基氯化尼古丁反應, 所得之中間物再用氯化鄰苯二酮氧化, 便可得一還算好的產率且具區域位置選擇性的烷基或芳基 6-(4-烷苯基)尼古丁酯。

關鍵詞：合成，含比啶的化合物，液晶化合物