# A MULTILAYER BANDPASS FILTER INTEGRATED INTO RF MODULE BOARD

Hsin-Chin Chang*, Chin-Chih Yeh*, Wei-Cheng Ku*, and Kuang-Chung Tao**

*Huafan Institute of Humanities and Technology, E.E. Department, Taipei, Taiwan
**Industrial Technology Research Institute, ERSO, Hsinchu, Taiwan

## ABSTRACT

A bandpass filter using multilayer structure is designed and manufactured. This filter is for the DECT handset RF module, hence must be compact, easy for mass-production, and low cost. This design uses standard (yet lowloss) FR4 board ($\varepsilon r$=4.8) and tapped I/O for the ease of manufacturing. A zero is introduced at the image frequency. Its multilayer structure occupies only three layers, and allows the filter to be integrated into the RF module board, while its tapped I/O increases manufacturing tolerance, and is easy for connection.

## I. INTRODUCTION

The emergence of the PCN and PCS (1.7~2.1 GHz) markets opens a new era for the RF module design technologies. These technologies, such as miniature RF filters, SAW filters, and MMIC's, meet the demand for handsets that must be compact, low-cost, and suitable for mass-production. The RF frontend filters remain key components in RF modules, for only a few company can manufacture large quantity and good quality miniature ceramic filters. It would be desirable if the RF frontend filter can be realized as a part of the RF module multilayer board, with fairly good quality.

Such kind of filter approach must meet the following criteria. Firstly, the size must be small and the geometry must be simple. Typical RF module board contains three material layers and four metal layers, in which this filter must be contained. Secondly, the filter must have good tolerance on dimensions. Sensitive geometry, such as gap coupling, must be avoided wherever possible. Thirdly, receiver sensitivity often require filters to have transmission zero at the image frequency. Filters with two poles at the center frequency and one zero at the image frequency can provide image rejection as good as two two-pole filters without transmission zero.

Modern microwave filter synthesis provides several useful elliptic function approximations [1-3]. For miniature filter design, one resorts to planar stepped coupled line configurations[3-6]. In this paper, a tapped I/O stepped coupled line configuration is proposed, as shown in Fig.1:

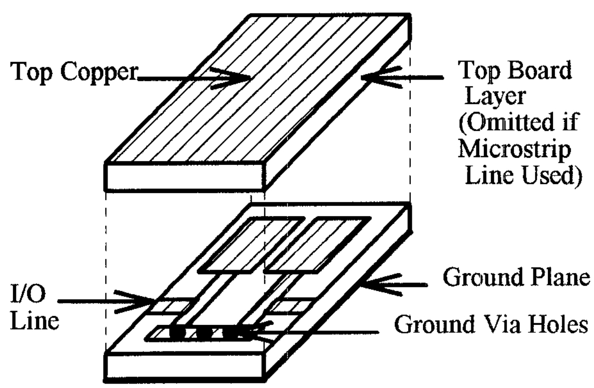


Fig. 1 A Tapped I/O Stepped Coupled Line Planar Filter

Notice that this configuration is intended to be integrated into multilayer board design, hence both strip line and microstrip line structures are considered. If one wishes to realize the RF module using strip lines (for easy shielding), the filter will be in the same layer as all the other lines. The tapped I/O line (matched to 50 ohm) is readily connected to any other components adjacent to the filter. This I/O configuration avoids another layer (yet capacitors do not) and dimension sensitive coupling gap.



0-7803-3246-6/96/$5.00 © IEEE
1996 IEEE MTT-S Digest

## II. ANALYSIS

The configuration is modeled by typical four-port coupled line Y or Z parameters, with proper shorting and opening at two ports[6-7]. It is shown in Fig. 2:

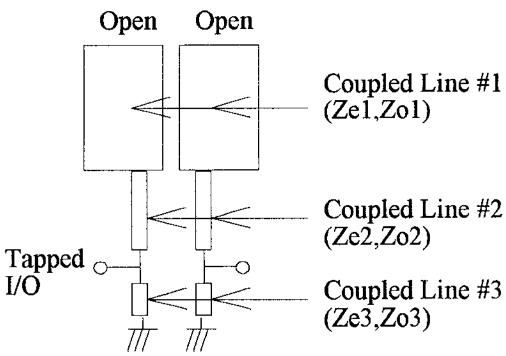


Fig.2 Equivalent Circuit of a Tapped I/O Stepped Coupled Line Filter

When looking down to the shorted ends, the coupled line #3 can be modeled by the Y matrix:

$$Y_3 = \begin{pmatrix} \frac{Ye3+Yo3}{2\cdot t} & \frac{Ye3-Yo3}{2\cdot t} \\ \frac{Ye3-Yo3}{2\cdot t} & \frac{Ye3+Yo3}{2\cdot t} \end{pmatrix} \quad (1)$$

,where Ye3,Yo3 are the even and odd mode admittance of the coupled line #3, t is the Richard's Variable, v is the phase velocity, and $C_{11,3}$ $C_{12,3}$ are the self and mutual capacitances of the coupled line #3.

When looking up to the opened ends, the two coupled lines are cascaded. It is shown that this cascaded coupled line can be modeled by:

$$Y_{1,2} = \frac{Y_{e1}+Y_{e2}}{2}\,\frac{t}{Ke\cdot t^2+1}\begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} + \frac{Y_{o1}+Y_{o2}}{2}\,\frac{t}{Ko\cdot t^2+1}\begin{pmatrix} 1 & -1 \\ -1 & 1 \end{pmatrix} \quad (2)$$

,where Ye1,Ye2,Yo1,Yo2 are the even and odd mode admittance of the coupled line #1 and #2, t is the Richard's Variable, Ke= Ye1/Ye2, Ko= Yo1/Yo2.

When the two two-port networks are put in parallel, the total admittance matrix is obtained by adding $Y_3$ and $Y_{1,2}$. It can be seen that this admittance matrix can be used to realize filters having two poles at the center frequency. The Y matrix of a second order Chebyshev bandpass filter can be looked up readily[8]. The transmission zero frequency is the one that makes the off-diagonal term zero. These two conditions are used to determine the dimensions which give the desired even and odd admittances. The $Y_3$ is used to match the I/O line to a standard 50 ohm by adjusting the length of coupled line #3. The adding of $Y_3$ matrix would give the desired $K_{01}$, while offset the off-diagonal term a little. A few iterations are made to correct for the position of transmission zero.

## III. RESULT

The filter is intended to be integrated into a RF module board for the DECT handset. The system design uses IF at 110 MHz, and requires image rejection at the lower side of the RF frequency. Therefore, the center frequency is designed at 1890 MHz. and the transmission zero 1670 MHz.

Two filters are designed, one for the strip line and one for the microstrip line structure. The initial design was:

Board: FR4, er=4.8
Thickness: H=31(microstrip),B=63(strip)
Line #1: Ze=28, Zo=21,30 deg.
Line #2: Ze=60, Zo=53, 23.5 deg.
Line #3: Ze=60, Zo=53, 6.5 deg

The final design, however, takes into these considerations. The effect of tap tee junction has to be optimized. The effect of tap on zero frequency has to be optimized. The gap is widened intentionally to increase the dimension tolerance. Also, it is impossible to specify dimensions under one mil. The final dimensions are:

| (unit: mil) | Microstrip | Strip |
|---|---|---|
| Line #1 | W=160,S=9, L=262 | W=74,S=13 L=253 |
| Line #2 | W=40,S=78 L=225* | W=19,.S=35 L=209* |
| Line #3 | L=26* | L=45* |
| 50 ohm | W=54 | W=25 |

* Does not include tapped line width

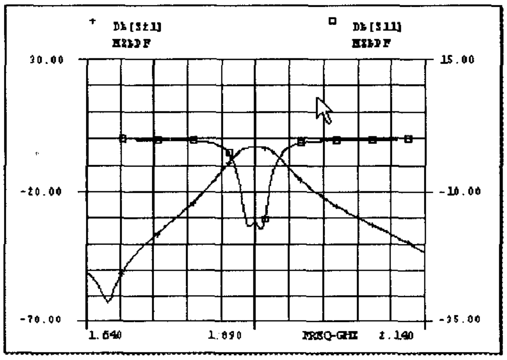


Fig.3 Simulated Response of the Designed Tapped I/O Stepped Coupled Line Filter

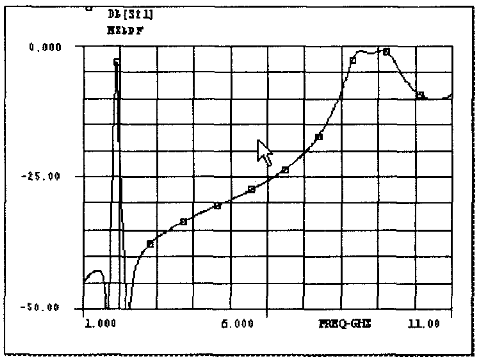


Fig.4 Simulated Spurious Response of the Designed Filter

Simulation was first made to verify the above design. Fig.3 shows the response of the pass band, and Fig.4 shows the spurious response. It is seen that this filter gives excellent spurious clearance.

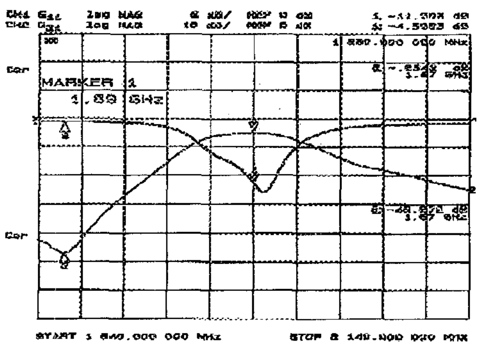

Fig.5 Measured Response of the Designed Tapped I/O Stepped Coupled Line Filter

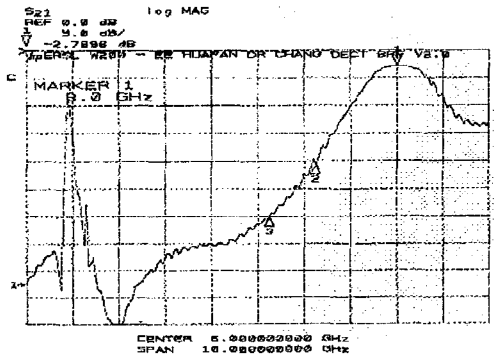

Fig.6 Measured Spurious Response of the Designed Filter

The measured frequency responses of the designed filter are in the Fig.5 and Fig.6. It is seen that excellent agreements are achieved.

The insertion loss of the filter is more than expected. It is estimated that the unloaded Q of each of the resonant line is around 80. This is due to the relative poor loss tangent of a typical FR4 board. This problem will be resolved once a low loss version of the FR4 board is used. The increased board material cost is justified by the saving of component cost. It is noticed that this filter gives excellent spurious repines, which is free up to at least 6~7 GHz. The I/O lines are at the opposite sides of the filters, hence gives good feedthrough isolation.

Another important feature for this filter is that the filter response is very insensitive to the I/O line tapped position. Fig. 7 shows the tolerance analysis of the frequency response with +/- 2.5 mil variance of the tapped position.

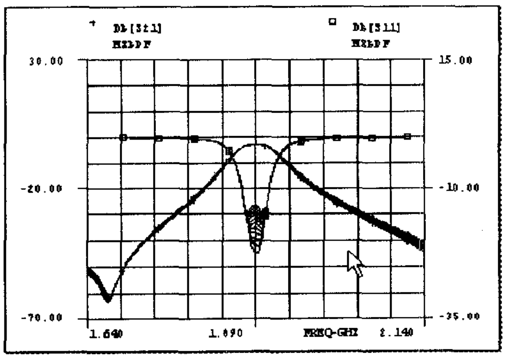


Fig.7 Tolerance Analysis of the Tapped Position of the I/O Line. (Variance = +/- 2.5 mil)

It is found that the 2.5 mil variance hardly affect the response. Therefore, this design can increase the yield rate, compared to those with typical coupled I/O lines. It is also mentioned that the gap between the two resonant lines is intentionally widened, and an optimization procedure is used to tune the response back to the desired. This procedure is also for making the gap dimension less sensitive to manufacture variations.

## IV. CONCLUSION

A multilayer bandpass filter with tapped I/O and stepped coupled line is designed and manufactured. This configuration is designed for integrated into a typical FR4 multilayer RF module board. Both strip line and microstrip line structure are designed. The tapped I/O has the advantage of minimizing the required number of layers, relieving the manufacture tolerance, and easy to connect to adjacent elements.

A design procedure for the tapped I/O stepped coupled line filter is described. The simulated results and measured results are presented. Some tolerance analysis are also made. It is found that the designed filter meets the expectations successfully.

## Reference

[1] R. Levy & I. Whiteley, "Synthesis of Distributed Elliptic-Function Filters from Lumped-Constant Prototypes " ,*IEEE Trans. Microwave Theory Tech.*,Vol. MTT-14, No.11, pp.506-517, Nov.1966.

[2] M.C.Horton, & R.J.Wenzel, "The Digital Elliptic Filter-A Compact Sharp Cutoff Design for Wide Bandstop or Bandpass Requirements " ,*IEEE Trans. Microwave Theory Tech.*,Vol. MTT-15, No.5, pp.307-314, May 1967.

[3] J. D. Rhodes, "The Stepped Digital Elliptic Filter " ,*IEEE Trans. Microwave Theory Tech.*,Vol. MTT-17, No.4, pp.178-184, Apr.1969.

[4] M.Makimoto & S.Yamashita, "Compact Bandpass Filters Using Stepped Impedance Resonators " ,*Proc. IEEE.*,Vol.67, No.1, pp.16-19, Jan.1979.

[5] T.Nishikawa, "RF Front End Circuit Components Miniaturized Using Dielectric Resonators for Cellular Portable Telephones " ,*IEICE Trans*,Vol. E 74, No.6, pp.1556-1562, June1991.

[6] T. Ishizaki & T.Uwano, "A Stepped Impedance Comb-Line Filter Fabricated by Using Ceramic Lamination Technique " ,*1994 IEEE MTT-S Digest*,WE1C-4, pp.617-620, Jan.1994.

[7] J. Helszajn, "Synthesis of Lumped Element, Distributed and Planar Filters", McGraw Hill, 1990

[8] G.L.Mattaei, L.Young and E.M.T.Jones, "Microwave Filters, Impedance-matching Networks, and Coupling Structures", McGraw Hill, 1964