Diplexers With Cross Coupled Structure Between the Resonators Using LTCC Technology

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Abstract: This paper presents the thin low temperature co-fired ceramic (LTCC) diplexer with cross coupled structures between resonators which have different feeding methods. One is connected by electric coupling feed between I/O ports and resonators and the other is connected by series inductor feed between I/O ports and resonators. Diplexers provide a good match between generator impedance and two complex channel loads as well as a good isolation between filters. The equivalent circuit models are derived to explain the characteristic of the high frequency bandpass filters and to search the location of transmission zero. Sizes of diplexers are 5 mm×9.5 mm×0.283 mm, 6 mm×6 mm×0.283 mm, respectively. Simulation data of the diplexer which has filters with magnetic coupling feed indicate 1.7 dB and 1.25 dB of insertion losses at 1.8GHz, 2.63GHz as well as 42 dB and 41 dB of attenuations at refraction frequencies of 2.8 GHz, 1.8 GHz, respectively.

Key-Words: LTCC, Diplexer, Bandpass filter, multilayer

1 Introduction

Recently, multi-band services and miniaturization of system are required for the modern wireless communication. These trends should need the miniaturized diplexer that split a single channel carrying two frequencies into two separate channels. The design of diplexer using low temperature co-fired ceramic (LTCC) technology which fit the miniaturization, the light weight and the mass product are suitable for the previous requirements [1-5].

Among the methods for the diplexer design, the bandpass filters configuration is most useful, for reduced noise, and relieve the specification of following RF front-end section, compared to the low pass filters and band stop filters configuration. However, the design of the diplexer using bandpass filters with narrow bandwidth has high loss since dielectric loss was increased by reducing coupled dimension. Therefore, we should appropriate design the filter with a wide bandwidth in a particular coupling space which has the bandwidth limitation. To solve the problem, this paper proposed cross electric coupling structure. Using this structure, we can realize the arbitrary value of capacitance and can reduce the parasitic capacitance.

Fig.1 shows the diplexer with the two bandpass filters and matching lines. The bandpass filters are designed by using the different feed methods. The lower band and the higher band were design to satisfy the KPCS/PCS and Bluetooth/DMB service bands.

2 Bandpass filter design

2.1 Circuit design

Fig. 2 and Fig. 3 show the equivalent circuit and the result of the circuit analysis which have designed by different feed methods between I/O port and the resonator. In Fig. 2, the lumped element values of the lower bandpass filter are $C_I = C_O = 1.2$ pF, $C_P = 3$ pF, $C_S = 0.75$ pF, $L_P = 1.7$ nH, M = 0.53 nH and the higher bandpass filter are $C_I = C_O = 0.7$ pF, $C_P = 1.25$ pF, $C_S = 0.85$ pF, $L_P = 1.56$ nH, M = 0.29 nH, respectively.

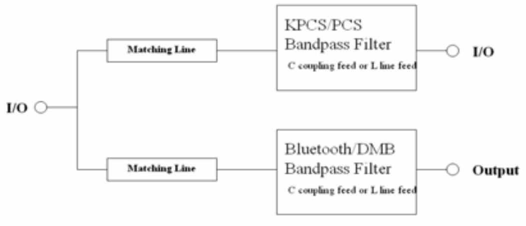
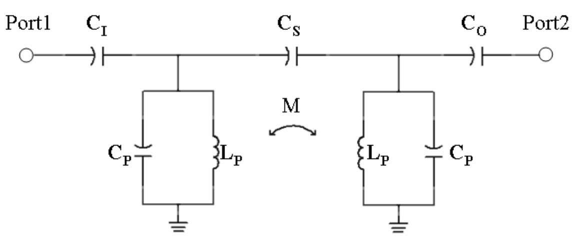
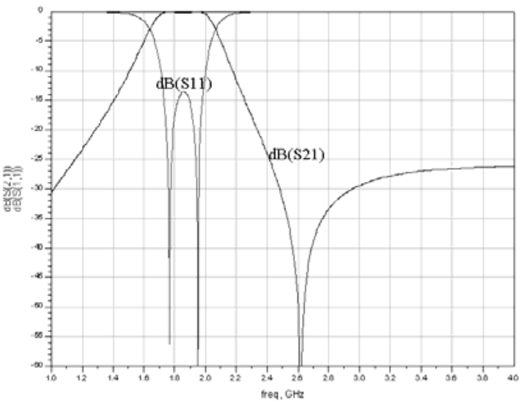


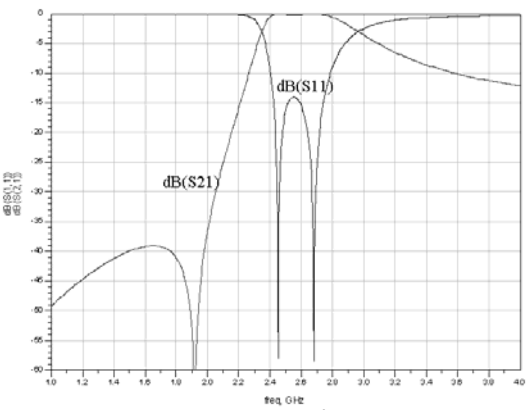
Fig.1 The block diagram of the diplexer.



(a) Equivalent Circuit



(b) Circuit analysis result of the lower band



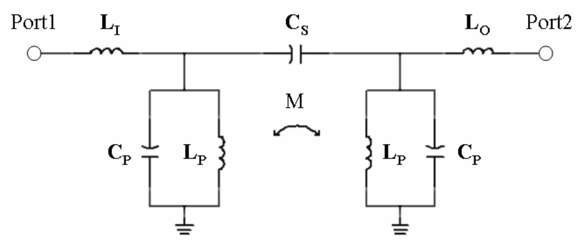
(c) Circuit analysis result of the higher band

Fig. 2 The equivalent circuit and result using the electric coupling feed method.

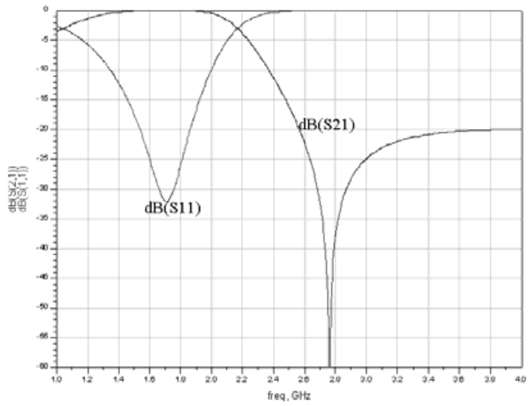
Otherwise, In Fig. 3, are $L_I = L_O = 0.2$ nH, $C_P = 3$ pF, $C_S = 1.3$ pF, $L_P = 2.8$ nH, M = 1.8 nH and the higher bandpass filter are $L_I = L_O = 0.2$ nH, $C_P = 1.6$ pF, $C_S = 1.8$ pF, $L_P = 1.15$ nH, M = 0.25 nH, respectively.

The location of transmission zero is fined by making S21 = 0. f_{cut_off} can be derived as [6-8]

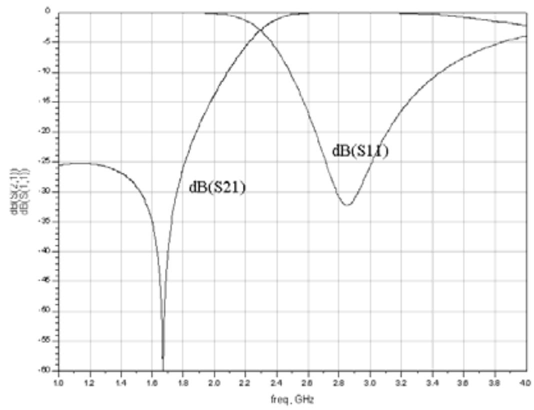
$$f_{cut\_off} = \frac{1}{2\pi\sqrt{\left(\frac{L_P^2}{M} - M\right)\cdot C_S}} \quad . \qquad (1)$$



(a) Equivalent Circuit



(b) Circuit analysis result of the lower band

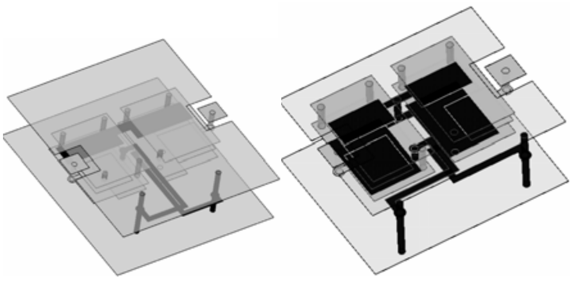


(c) Circuit analysis result of the higher band

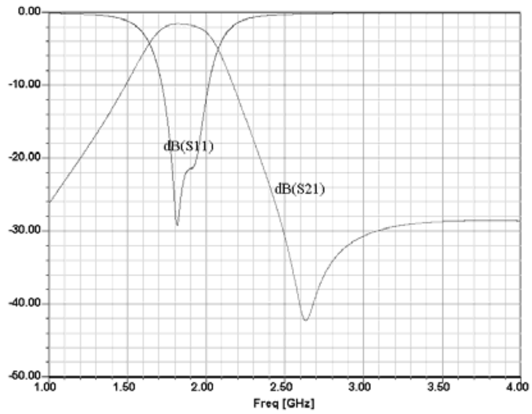
Fig. 3 The equivalent circuit and result using the inductor line feed method.

2.2 Structure design

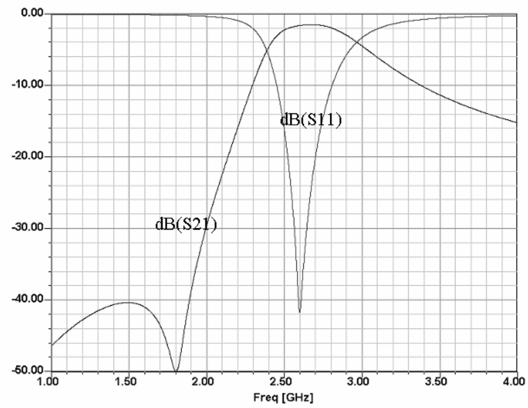
The equivalent circuits of the thin LTCC bandpass filters are designed with the substrate of Dupont951. Their dielectric constant, loss tangent, and the material of conductor are 7.8, 0.0045, and silver with 0.007 mm thickness, respectively. The thin bandpass filters are designed on one lower layer with the sheet of 0.095 mm, four layers with the sheet of 0.047 mm. Theirs overall sizes are 4.0 mm×3.4 mm×0.283 mm, 2.4 mm×3.4 mm×0.283 mm, 2.4 mm×3.4 mm×0.283 mm, and 4.8 mm×2.4 mm×0.283 mm, respectively.



(a) Bandpass filters with C Coupling Feed



(b) EM simulation result of the lower band

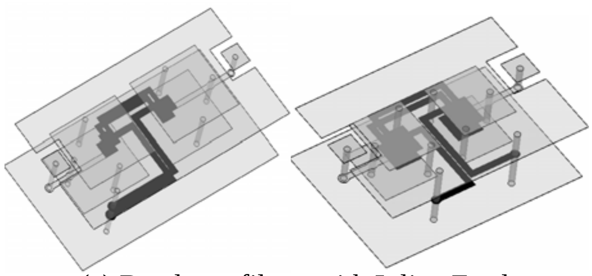


(c) EM simulation result of the higher band

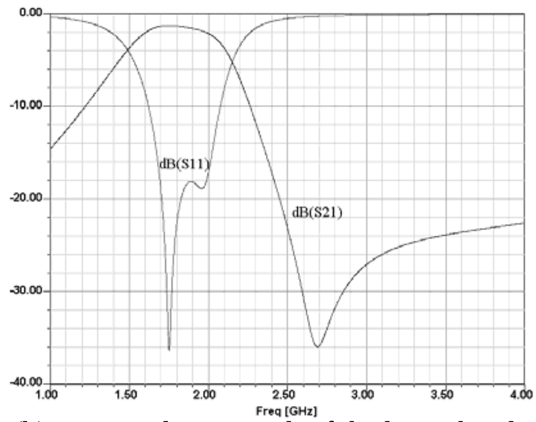
Fig. 4 The structure and EM simulation result using the electric coupling feed method.

The simulation is carried out with the assistant of the full wave electromagnetic (EM) simulator HFSS9.1 from Ansoft Inc.

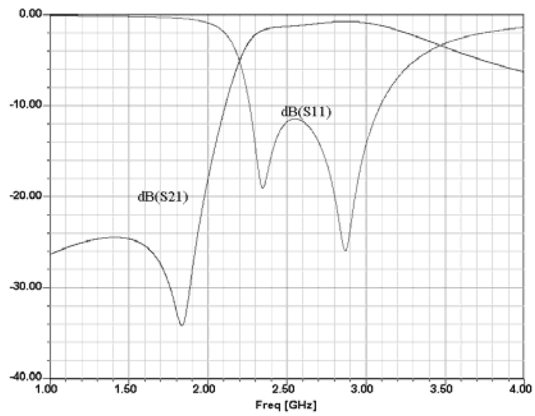
Fig. 4 shows the three-dimensional (3-D) structures of the bandpass filter with C coupling feed. The KPCS/PCS bandpass filter is reduced by embedding ground plate that can be designed capacitor with high capacitance in restriction space [1]. The DMB bandpass filter is constructed by using double coupling plate for realization of needed capacitance.



(a) Bandpass filters with L line Feed



(b) EM simulation result of the lower band

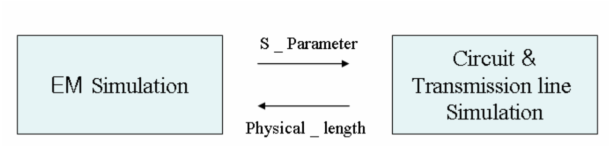


(c) EM simulation result of the higher band

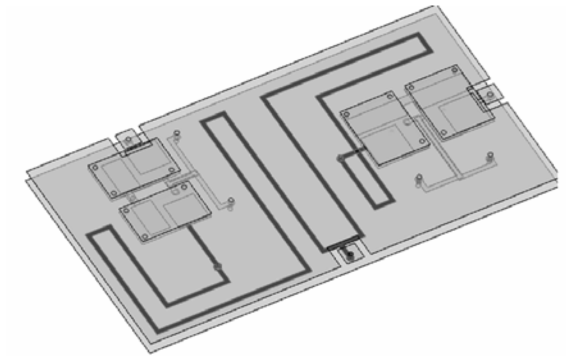
Fig. 5 The structure and EM simulation result using the electric coupling feed method.

Fig. 5 shows the three-dimensional (3-D) structures of the bandpass filter with L line feed and cross coupled structure. These can not realize high C_S, but can also reduce dielectric losses compare to structures of Fig. 4.

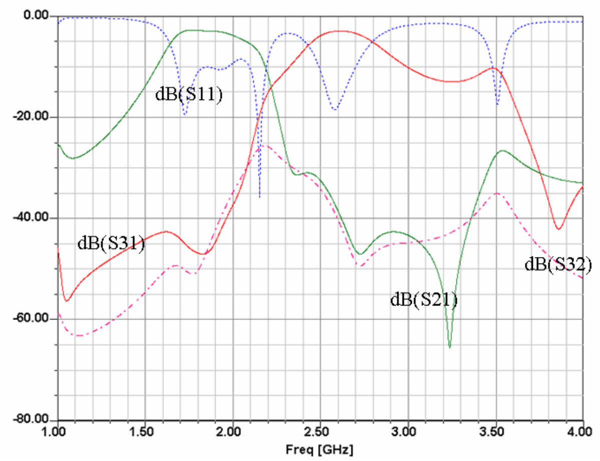
Insertion losses are 1.68 dB, 1.72 dB, 1.5 dB, 1.4 dB at the center frequency as shown in Fig. 4 and Fig.5. In Fig. 5, the DMB bandpass filter has low loss and wide bandwidth since the coupling dimension is wide. Attenuations at the reject bands are below -30 dB.



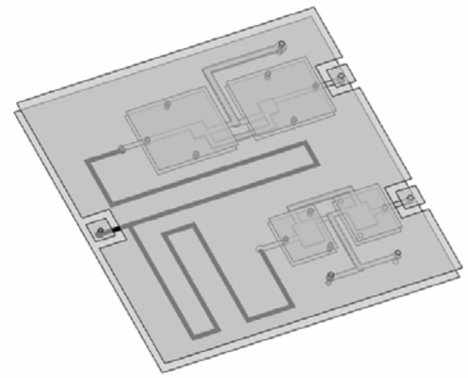
(a) Relations between EM simulation and circuit and transmission line simulation



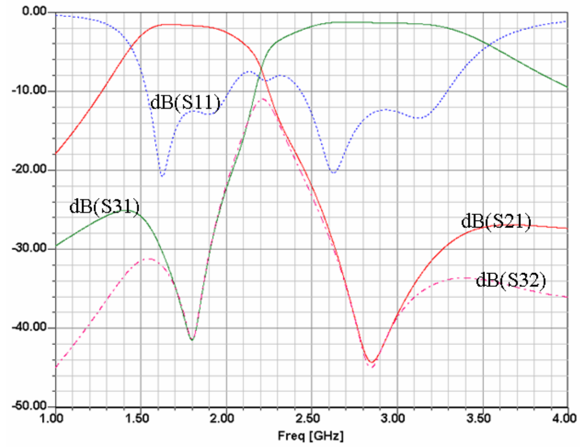
(b) The diplexer using C coupling feed



(c) The EM Simulation result of the diplexer using C coupling feed



(d) The diplexer using L line feed



(e) The EM simulation result of the diplexer using L line feed

Fig. 6 Diplexer designed with multilayered structure.

3 Diplexer design

In this paper, we designed the diplexer using bandpass filters which were presented previous section. The matching network should be required for operation without interference between the bandpass filters. The method of matching network configuration has existed two ways. One is that the added imaginary part goes zero and the other is that the input impedance (Zin) goes infinite value at the refraction frequency by changing the phase. Since the former do not exist the solution in all frequency, the latter is preferred.

The proposed diplexer design procedures are shown in Fig. 6. Sizes of the simulated diplexers are 5 mm×9.5 mm×0.283 mm, 6 mm×6 mm×0.283 mm, respectively. Moreover, the size can be more reduced by multilayered matching line. Since the transmission zeros of the filters with C coupling feed located below dimension in smith's chart, the length of the matching line goes long. It arises to increase the metal loss and generate the resonance by harmonics. In Fig. 6(c), insertion losses at the center frequencies are 2.5 dB and 2.4 dB. In Fig. 6(e), insertion losses at the center frequencies are 1.7 dB and 1.25 dB.

4 Conclusion

We present the design and characterization of the thin LTCC diplexers which have bandpass filters with the variable structures. Though these work, we can find out the best solution to design diplexer. The best result present when the filter has L line feed and the cross coupled structure. Moreover, any other RF elements can be mounted on the proposed thin diplexers that have top ground and bottom ground.

References:

[1] Yuseon Kim, Hun Nam, Jaechun Lee, Yeongseog Lim, A design of the thin LTCC bandpass filter using parasitic capacitance and embedded small ground plate, *The 21st International Technical Conference on Circuits/System, Computers and Communications*, Vol. I, 2006, pp. 165-168.

[2] A. Sutono, J. Laskar, and W. R. Smith, "Design of miniature multilayer on-package integrated image-reject filters", *IEEE Trans. Microwave Theory Tech.*, vol. 51, no. 1, pp. 156-162, Jan. 2003.

[3] Ching-Wen Tang, Sheng-Fu You, "Design methodologies of LTCC bandpass filters, diplexer, and triplexer with transmission zeros", *IEEE Trans. IEEE Trans. Microwave Theory Tech.*, vol. 54, no. 2, pp. 717-723, Feb. 2006.

[4] L. K. Yeung, K. -L. Wu, "A compact second-order LTCC bandpass filter with two finite transmission zeros", *IEEE Trans. Microwave Theory and Tech.*, vol. 51, no. 2, pp. 337-341, Feb. 2003.

[5] C. F. Chang, S. J. Chung, "Bandpass filter of serial configuration with two finite transmission zeros using LTCC technology", *IEEE Trans. Microwave Theory and Tech.*, vol. 53, no. 7, pp. 2383-2388, Jul. 2005.

[6] George L. Matthaei, Leo Young, and E. M. T. Jones, *Microwave Filters, Impedance matching Networks and Coupling Structures*, Artech House, Dedham, Mass., 1980.

[7] Jia-Sheng, M. J. Lancaster, *Micro-strip Filters for RF/microwave Applications*, Willey Inter science, 2001.

[8] David M. Pozar, *Microwave Engineering, second Edition*, Wiley, Chapter 2, 4, 8, 1998.

[9] A. R. Djordjevic, T. K. Sarkar, "Closed form formulas for frequency dependent resistance and inductance per unit length of microstrip and strip transmission lines", *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 241-248, Feb. 1994.

[10] C. Patrick Yue, S. Simon Wong, "Physical modeling of spiral inductors on silicon", *IEEE Trans. Electron Devices*, vol. 47, no. 3, pp. 560-568, Mar. 2000.

[11] T. Ishizaki, M. Fujita, H. Kagata, T. Uwano, and H. Miyake, "A very small dielectric planar filter for portable telephones", *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 2017-2034, Nov. 1994.

[12] A. Simine, V. Piatnitsa, A. Lapshin, E. Jakku, D. Kholodnyak, S. Leppaevuori, and I. Vendik, "Design of quai-lumped element LTCC filters and duplexers for wireless communications", *33rd European Microwave Conference*, pp. 911-914, 2003.

[13] K. L. Wu, R. Zhang, M. Ehlert, and D. G. Fang, "An explicit knowledge embedded space mapping technique and its application to optimization of LTCC RF passive circuits", *IEEE Trans. Components and Packaging Tech.*, vol. 26, no. 2, pp. 339-406, Jun. 2003.