POS-A-49

Proceedings of ISAP'04, Sendai, JAPAN

THICK-FILM APPROACH OF DESIGNING A WIDEBAND DIPLEXER FOR WLAN APPLICATION

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Abstract

This work is to design a diplexer applied for two operating bands, namely, IEEE 802.11a and 802.11b/g of wireless local area network. By employing a hairpin-line and a L-shape parallel-coupled band-pass filter, this work uses a thick-film process to realize a compact, planar, low weight, and low cost design. It is also suitable to the application of handling high-power. The unique feature of this design is able to provide a full and wide band operation for continuous 5.15 ~ 5.825GHz spectrum.

I. Introduction

Wireless LANs have quickly become a significant role in the LAN market, mainly because it's mobility for users. The physical layer standards IEEE 802.11a/b/g bands [1] are the most popular ones currently in such a kind of applications. IEEE 802.11a operates in the 5 GHz band (5.170~5.805GHz) at data rates up to 54Mbps, IEEE 802.11b operates in the 2.45 GHz band (2.412~2.484GHz) at 5.5 and 11 Mbps. On the other hand, the IEEE 802.11g standard defines the way wireless LAN gear communicates at up to 54 Mbps while remaining backward compatible with 11Mbps 802.11b. Different portions of the spectrum are approved for wireless LAN use in different countries. For example, the U.S. and Canada currently allow Wi-Fi [2] to operate in both the 5.15 to 5.35 GHz band and the 5.725 to 5.825 GHz band. Europe allows wireless LANs to operate in these bands and also in the 5.47 to 5.725 GHz band.

Referring to the illustration in the Fig. 1, without a switching mechanism, a diplexer [3] functions to separate two bands' RF signal from a common antenna at the port 1, or to combine mon antenna at the port 1, or to combine them to the common antenna in a reverse way. Hence, usually there are two bandpass filters of different bands following the common port.

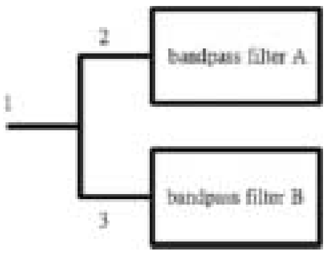

Fig. 1 The structure of a diplexer

Instead of designing different individual narrow bands within the 802.11a spectrum, this work is to design a diplexer covering 802.11b/g band and the whole bands used in different countries where the 802.11a standard could be applied.

Based on the ceramic substrate, the realization of this design is employing the thick-film process [4][5]. Even it does occupy larger area comparing with the commercialized diplexer ICs, it is more capable of handling high power which is expected to be met in the future MAN (Metropolitan Area Network) based on these spectra.

II. Design of a Diplexer

Each diplexer has one common port [6] that serves to split up the RF power into two following individual paths of different bands. Moreover, it is a critical role of determining the diplexer performance. The common port structure applied in the present diplexer design is shown in the Fig. 2, which uses three sections of microstrip line. The lengths of λ_1 and λ_2 are approximately corresponding 1/4 resonant

ISBN: 4-88552-207-2 C3055©IEICE

wavelengths of the two different following bandpass filters. If the length of λ_1 is longer than the length λ_2, the length of λ_0 is $\lambda_1 + \Delta L$. This ΔL is a certain length related to impedance matching of the structure, but it can not be longer than $\lambda_1/8$. On the other hand, if the length of λ_2 is longer than λ_1, the length of λ_0 is $\lambda_2 + \Delta L$. Similarly, the ΔL is a certain length related to impedance matching of the structure, but it can not be longer than $\lambda_2/8$. S_1 and S_2 are the gaps between these microstrip lines. The widths of these two microstrip lines – W_1 and W_2 are individually related to its external quality factor (Q_e) as a quarter-wavelength resonator, and also related to the impedance matching of the following bandpass filter. The width W_0 is determined by the input impedance of the diplexer seen from the antenna port. The external quality factor (Q_e) is a parameter of filter design.

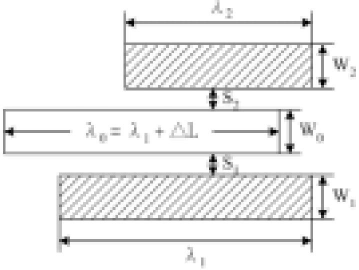

Fig. 2 The common port used in this diplexer

As for the bandpass filter design, the Chebyshev type [7] is chosen, for it owns characteristics of equal ripple and its amplitude-squared transfer function (S_{21} of S-parameters) representing the frequency response is,

$$\left|S_{21}(j\Omega)\right|^2 = \frac{1}{1+\varepsilon^2 T_n^2(\Omega)}$$

in which ε is the ripple constant set in the Chebyshev filter that is defined by the Chebyshev functions listed below,

$$T_n(\Omega) = \begin{cases} \cos\left(n\cos^{-1}\Omega\right) & |\Omega| \le 1 \\ \cos\left(n\cosh^{-1}\Omega\right) & |\Omega| \ge 1 \end{cases}$$

Considering the lower band used for IEEE 802.11 b/g transmission standard, the hairpin-line [7] resonators, referring to the Fig. 3, are designed to form the bandpass filter. The hairpin-line resonators are quite to meet the purpose of compactness for the diplexer.

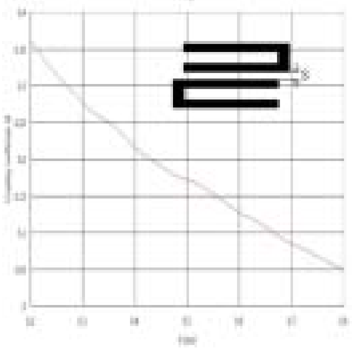

Fig. 3 The hairpin-line resonator and its calculated coupling coefficients

Fig. 3 also shows the calculated relative coupling coefficients in terms of hairpin-line spacing, which is a parameter in designing the whole filter too. Computations for it and the external quality factor (Q_e) mentioned above are executed by making use of the EM simulation package IE3D [8]. This design has a fractional bandwidth of 4.9% of a central frequency f_0 = 2.45GHz. Using insertion loss method [9], a two-pole (n = 2) Chebyshev lowpass prototype with a passband ripple of 0.5 dB is chosen.

For the higher band used for the IEEE 802.11a application, the needed bandwidth is about 800 MHz. The popular wideband bandpass filters could be parallel-coupled, half-wavelength resonator filter, interdigital bandpass filter, or combline filter, etc. Because the resonators of interdigital bandpass filter and combline filter need to be connected to a ground by via holes, they are difficult to fabricate by using the thick-film process. Parallel-coupled, half-wavelength resonator filter is a good choice, but its dimension becomes too large when it is applied for 5GHz band.

To meet the compactness requirement, the original line-shaped half-wavelength resonator is transformed to be a L-shaped one, see Fig. 4. Fig. 4 also shows the calculated relative coupling coefficients in terms of hairpin-line spacing, which is a parameter in designing the whole filter. On the other hand, to achieve the goal of wide band characteristics, the number of resonators must be increased.

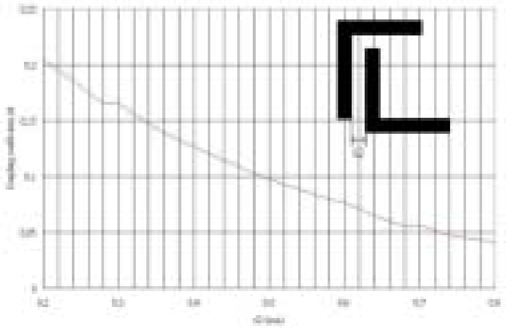

Fig. 4 L-shaped half-wavelength resonator and its calculated coupling coefficients

The microstrip wideband bandpass filter is designed to have a fractional bandwidth of 16.22% of the central frequency $f_0 = 5.5$ GHz. Using the insertion loss method again, a five-pole (n = 5) Chebyshev lowpass prototype with a passband ripple of 0.5 dB is chosen. The resultant layout of the bandpass filter design for 5 GHz band is shown in the Fig. 5

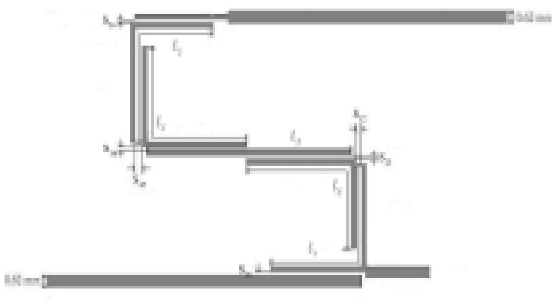

Fig. 5 The layout of the bandpass filter design for 5 GHz band

For RF filters, the band-isolation is always an important issue, because of its affection on the whole performance. In the present work, it is that two bandpass filters operate for two different bands yet are integrated onto one single diplexer. These two different operating bands are supposed to be separated far away in spectrum, but there are still harmonics caused by the bandpass filter of 2.45GHz band and happening at 4.9 GHz to affect the response of the bandpass filter of 5GHz band. In order to reduce the effect of harmonic, the overlay of the harmonic by 2.45GHz band and main resonant responses of 5GHz band should be decreased. Skills are applied to reduce the overlay and enhance their isolation in the present design.

III. Realization and analysis

Based on the ceramic substrate with a dielectric constant 9.4, the present diplexer design is realized with the screen-printing technique on an area of 20 x 22 mm^2, see the Fig. 6. The EM simulation package IE3D [8] is adopted to help the whole design process. The port A is to go to the antenna, and the port B and port C are connected to the 5GHz and 2.45GHz receiving/ transmitting circuit, respectively.

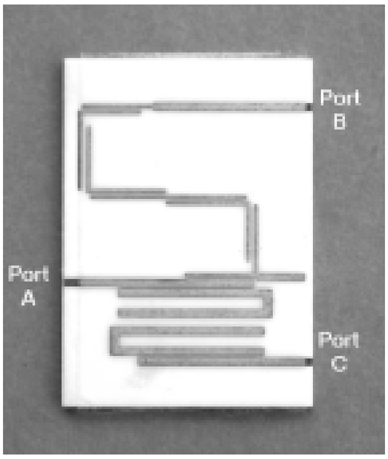

Fig. 6 A diplexer realized by the thick-film process

Considering the isolation problem in this design, one possible method is to depress the harmonic of 2.45GHz bandpass filter [10]. The other way is to make the shapes of response very sharp to reduce the overlay range. Because of the former will make the structure of bandpass filters more complex, the latter is chosen to treat it. Before measuring the whole response characteristics of this diplexer, the necessary calibration technique should be taken into account. The TRL calibration [11] is the better choice to calibrate network analyzer when measuring the diplexer in this work. Since using a two-port measurement system, the third port of diplexer is always terminated by using a SMA connector with a 50 ohms broadband load.

Fig. 7 shows the whole measured response of this diplexer. The curve —□—□ is the measured $|S_{21}|$ between Port A & C for the 2.45 GHz band, and the curve —◇—◇ is the measured $|S_{21}|$ between Port A & B for the 5 GHz band. On the other hand, the filter-to-filter isolation $|S_{21}|$ response is measured between Port B & C by loading the common Port A with a broadband load. The curve —△—△ shows the result. All the responses show that a diplexer with a 2.45GHz band and a full 5 GHz wide band has been achieved, and it is a good candidate for being operated in the IEEE 802.11a/b/g bands. The filter-to-filter isolation is related to the RF rejection of the individual filters, and it has been shown that the coupling from 5GHz filter to the 2.45GHz filter is down below –60dB, and is around –40dB *vice versa*.

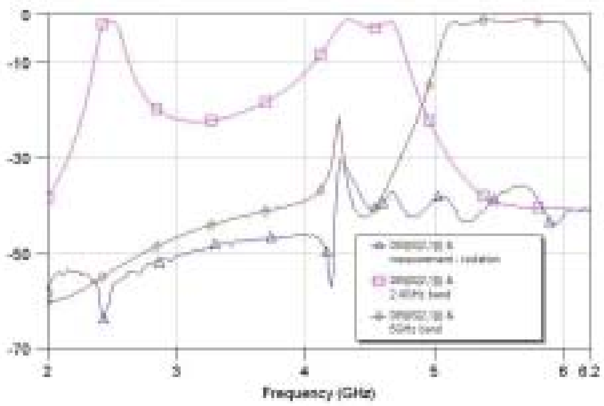

Fig. 7 Transmission and isolation $|S_{21}|$ response of the diplexer

III. Conclusion

In this paper, a design procedure for a diplexer which works for both of 2.45 GHz and 5 GHz bands for the IEEE 802.11 a/b/g wireless transmission standards has been realized. The unique feature of this design is that it provides a full continuous spectrum operation for all individual narrow ISM (Industrial, Scientific and Medical) bands [12] within the 5GHz band, in addition to the operation in a lower 2.45GHz band. By realizing this design by the thick-film process on a ceramic substrate, it does offer such a specification of diplexer plus a satisfied isolation as a band splitting device. It is able to handle higher power comparing with IC-based diplexers because of its realization technology.

IV. Acknowledgements

The authors are deeply to show their appreciation to Mr. Ming-Hsun Yang of Instrument Center, Tatung University, for his help in the thick-film fabrication process of the present diplexer design.

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