Design of Integrated Bandpass Filter-Vivaldi Antenna for Microwave Applications

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Abstract – *This paper presents the proposed design of Integrated Bandpass Filter-Vivaldi Antenna for microwave system applications. Both of these passives components play important roles as the front-end device in transceiver technology. Conventionally, antenna and filter are connected separately leading to impedance mismatch that would affect the whole performance of the overall system. To overcome this problem, an integrated filter-antenna design is proposed, where both devices are combined together into a single sub-module. The proposed design would benefit so much in terms of miniaturization and cost. The proposed antenna and filter used in this research is the antipodal Vivaldi antenna and an Open-Loop Resonator Bandpass Filter (OLRBPF) operating at 2.4GHz frequency band. The structure is constructed on an FR4 substrate with a thickness of 1.6 mm and permittivity of 4.7 using cascaded and co-design method. The proposed designs are simulated in Agilent Advance Design System (ADS2016). It is shown that the size of both devices is reduced, the performance of the filter antenna is also enhanced in terms of directivity up to 9.538dBi (co-design) and 5.860 dBi (cascaded).*

Keywords: *integrated, Vivaldi, Filter, cascaded, co-design*

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I. Introduction

In most communication and radar systems, filters and antennas are critical components and usually needed to function simultaneously [1]. In general, filter is used to receive and reject any signals that fall outside the required desired frequency range, while antennas are electrical devices used to convert electrical power to radio waves. The optimal size of an antenna depends on the frequency of a signal and the wavelength, the higher the frequency, the shortest wavelength required in the design process. They are always treated as an individual device and mostly connected via transmission lines which might increase loss and circuit area. Thus, one of the solutions is by integrating both devices into a single module. This would solve the current problem involving impedance mismatch, reducing both loss and the size thus enhancing the overall performance of the system.

The idea of integrating filter and antenna has caught a lot of attention among the researchers [2][3][6]. Besides, dealing with the impedance mismatches is one of the crucial concerns that all the designers should take seriously in designing integrated filter-antenna due to separate interconnection between them that will contribute to extra impedance transformation needed [3]. Recent research shows that different researchers introduced different design and method on integrating filter and antenna. For example, the co-design approach for integrating filter and antenna for UWB application, resulted in compact size, range of gain between 2.8dBi to 4.6dBi in the bandwidth of S_{11}<-10dB [3]. Not only that, the cascaded approach or known as traditional method also still being used in integrating filter-antenna that serve in [4].

In this paper, integrated filter-antenna is discussed with two design methods proposed; cascaded and co-design approach to combine both devices into a single sub-module. These devices are fabricated on dielectric substrate of FR4 with the thickness of 1.6mm and dielectric permittivity of 4.7.

II. Theoretical Design of Vivaldi Antenna and Bandpass Filter

A. Vivaldi Antenna

In recent years, Vivaldi antennas have received quite an amount of attention due to their wide bandwidth characteristics. Vivaldi antenna belongs to the group of aperiodic continuously scaled antenna structures with exponentially tapered curve [5]. Vivaldi antennas have been greatly utilized in modern communication such as military and civil applications and also in high-speed wireless communication due to some of its interesting features [5]. The antipodal Vivaldi antenna provides many advantages such as good return loss and minimal signal distortion. These advantages play important roles in having good impedance mismatch. Fig. 1 shows the proposed Vivaldi Antenna and its parameter with width (W) = 53.03mm and Length (L) = 52.45mm. R_1 and R_2 represents the curve measurement needed when designing the antenna using ADS2016 tools.

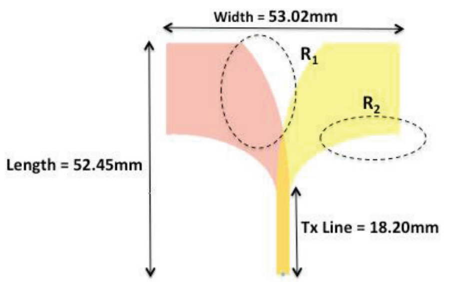


Fig.1 Proposed Design of Vivaldi Antenna.

Fig. 2 shows the simulated result obtained from Vivaldi antenna. Based on the result, it is noted that the frequency fell at two points, 2.026GHz and 3.914GHz. The return loss value, S_{11}, both points showed good return loss value, which is below -10dB. This also shows that the antenna has good matching impedance characteristic.

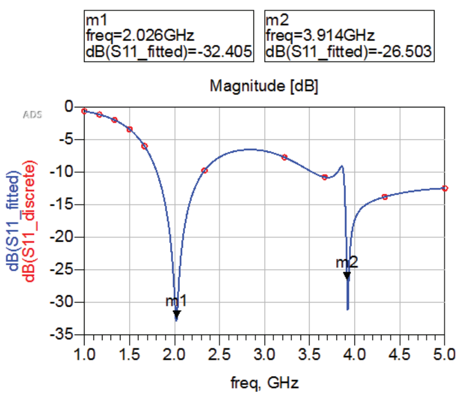


Fig. 2 Simulated Result of Vivaldi Antenna

Fig. 3 shows the antenna parameter (both vertical and horizontal) for Vivaldi antenna in terms of its gain, directivity and radiation efficiency. The antenna gives 3.185dBi directivity, gain of 1.285 and radiation efficiency of 64.5%.

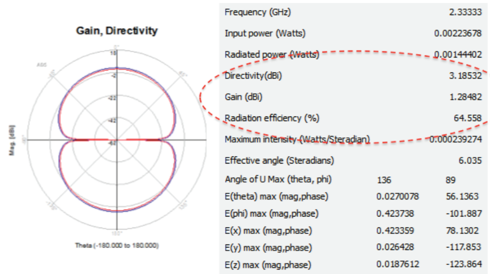


Fig. 3 Gain and Antenna Parameter of Vivaldi Antenna

B. Open Loop Resonator Bandpass Filter (OLRBPF)

Open loop resonator bandpass filter (OLRBPF) is used as the filter for the proposed design with the method of filter synthesis [6-7]. In this project, the OLRBPF with Chebyshev's characteristic is proposed because this type of filter form a smaller transition region than the same order of the Butterworth filter which is at the expenses of the ripples in its pass band and very efficient to minimize the height of the maximum ripple thus allows some ripple in the pass band and stop band, thus, stepper cut-off frequency will be realized. OLR is one examples of the compact and miniature filter. It is composed of a microstrip line that having both ends loaded with folded open stubs. Folded arm of open stub is generally not only for increasing the loading capacitance to the ground, but it is also used for producing cross coupling. In facts, this kind of resonator filter is definitely differs from the miniaturized hairpin resonator especially in terms of their concepts and purposes. The researchers stated that the cross-coupled structure will helps to achieve high selectivity characteristics with transmission zeros. Thus, it can improve the skirt rejection of the microstrip filter. Besides, filter with high selectivity would give the best performance with minimum insertion loss.

The proposed design of OLRBPF in this research is implemented with a chamfered bend structure in its band-pass filter design. Fig. 4 shows the proposed filter with chamfered bend. The chamfering technique is the best solution that will help to overcome discontinuities at microstrip bend that can contribute to error in phase and amplitude, thus decreasing the loss and increasing the performance of the design [7].

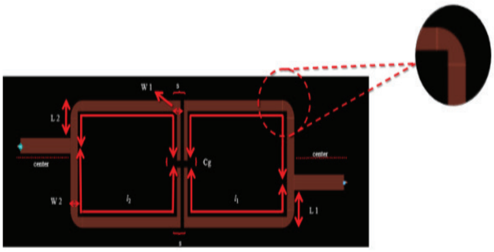


Fig. 4 OLRBPF with Chamfered Bend.

Chamfered bend has been used in many researches to reduce the losses at the right bend corner. Fig. 5 shows some techniques to design the chamfered bends. It shows a swept bend method to chamfer the curve of the microstrip line and to reduce the effect of parasitic continuity capacitance from the right-angle bend. By using swept bend method, the radius of the circular curve must be r > 3W. As for Figure 5 (b), the right-angle curve can be compensated by mitering the corner with the optimum value of miter length, a, which depends on the characteristic impedance and the bend angle. However, the value of a = 0.18W is often used in practice.

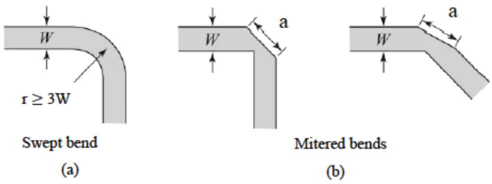


Fig. 5 Techniques Available in Chamfered Bends [8]

Fig. 6 shows the result of the OLRBPF with chamfered bend. Based on this result, the value of the return loss, S_{11} of -13.366dB and insertion loss, S_{21} is -7.206dB respectively.

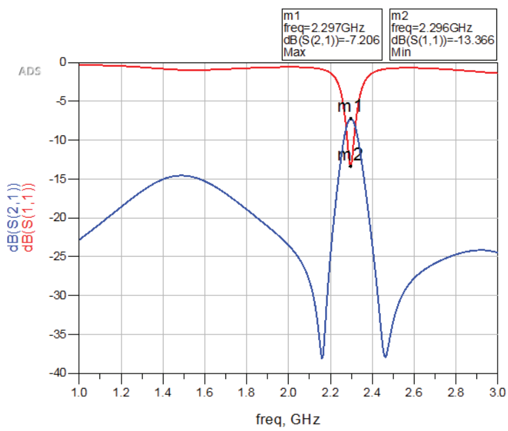
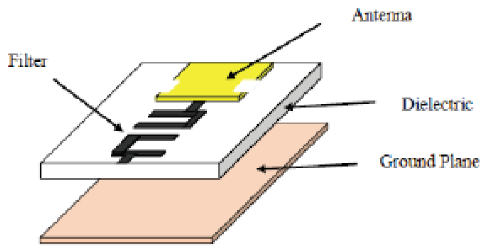


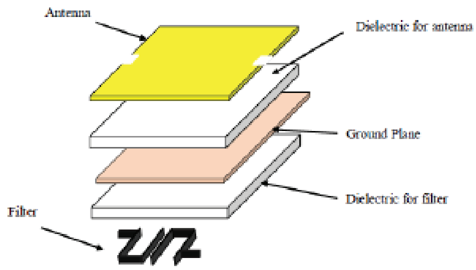
Fig. 6 Simulated result of OLRBPF with chamfered bend

C. Integration Method

Microwave communication system is developing very prosperously, which corresponds to the need of low-cost, compact and highly efficient systems. This is when the idea of integrating both the filter and antenna together as a single component is introduced. The reason behind this idea is because the impedance mismatch between the individually designed antenna and filter causes interference, increases the insertion loss and thus affecting the whole performance of the circuit. Therefore, two types of integrating methods are proposed in this research; the cascading method and the co-design method. Both approaches are different in terms of the connection between the filter and antenna. However, both favor the same purpose that is to reduce the size of the system. Fig. 7 shows the construction of cascaded and co-design method (ignoring the shape of antenna and filter).



(a) Cascaded method



(b)

Fig. 7 (a) Cascaded and (b) Co-design method [9]

Fig. 8 shows the proposed integrated filter antenna design using cascaded method.

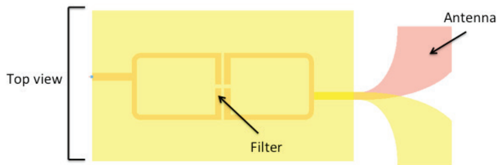


Fig. 8 Integrated Filter Antenna in Cascaded Approach

Another approach is so-called the co-design method. This method differs from the previous method; the components are connected using stacked of dielectric layers. The components still share the same ground plane however they are connected with metal via holes. Via holes play important role as the connector to both antenna and filter. The proposed integrated filter antenna is shown in Fig. 9.

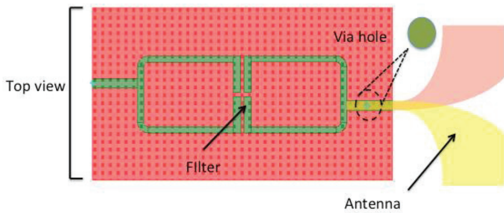


Fig. 9 Integrated Filter Antenna in Co-design Approach

III. Results

Simulations have been carried out using Agilent Advanced Design System (ADS) version 2016 to analyze the result of the proposed designs. Two methods were implemented during the integration of Vivaldi antenna with OLRBPF; cascaded method and co-design method.

Fig. 10 shows the current distribution on the proposed cascaded design approach. The high intensity current is observed at the port of the filter and reduce as it goes throughout the antenna.

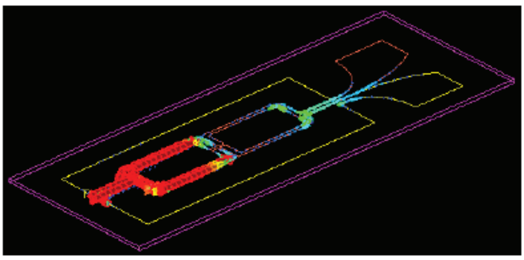


Fig. 10 Current distribution on the proposed cascaded method approach

The return loss of the integrated filter antenna is shown in Fig. 11. Even after the integration, the resonance frequency still falls at two points. However, the first resonance frequency shows better value of return loss, S_{11}, which is <-10dB. The parameter results for the cascaded approach with directivity of 5.862dBi, gain of -0.764 and radiation efficiency of 21.575 respectively.

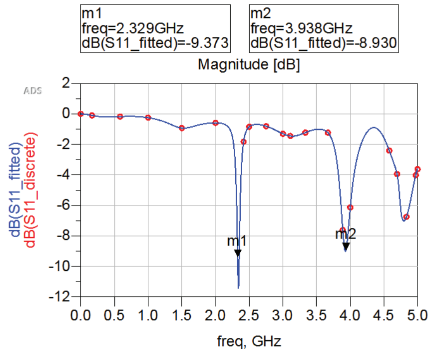


Fig. 11 Simulated Result of Integrated Filter Antenna in Cascaded Approach

Fig. 12 shows the current distribution of integrated filter antenna with co-design approach. All currents are well distributed throughout the filter before it goes out to the antenna.

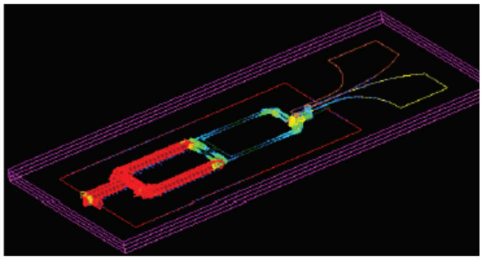


Fig. 12 Current distribution using Co-design approach

Fig. 13 shows the return loss, S_{11} of the proposed integrated filter. It is noted that the resonance frequency fell slightly further than the one in cascaded approach. However, the integration in co-design approach shows better impedance matching, S_{11}, than that in cascaded approach. The S_{11} goes from -9.373 in cascaded approach to -24.026 in co-design approach. The co-design filter antenna gives directivity of 7.68dBi, gain of 0.392 and radiation efficiency of 18.654% respectively. The results are summarized in Table 1 for both methods proposed in this research.

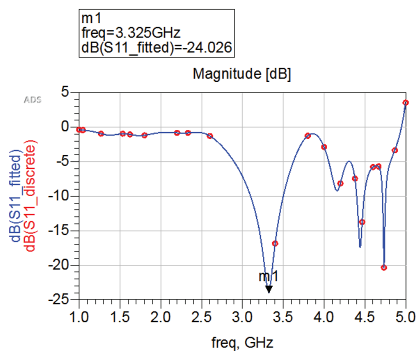


Fig. 13 Simulated Result of Integrated Filter Antenna in Co-design Approach

TABLE 1
COMPARISON BETWEEN INTEGRATED FILTER ANTENNA IN CASCADED AND CO-DESIGN APPROACH

	S11 (dB)	Resonance Frequency (GHz)	Directivity (dBi)
Cascaded	-9.373	2.329	5.860
Co-design	-24.026	3.325	9.538
Other [10]	-23.441	2.36	8.01

IV. Conclusion

In conclusion, the proposed integrated bandpass filter-antennas show good results comparing both cascaded and co-design method. Good impedance matching shows when both filter and antenna is design in co-design method, with stacked of substrates and vias. It shows that the S_{11} is -24.06dB with resonance frequency at 3.325Ghz and 9.538dBi directivity comparing to cascaded method of S11 is -9.373dB, resonance frequency of 2.329GHz and 5.860dBi directivity. Comparing with other research in [10], it shows that the co-design method produces good results in terms of directivity. In the future, it is suggested to improve and enhance the performance of the proposed design to achieve desired frequency band.

References

[1] J. B. Jadhav and P. J. Deore, Filtering antenna with radiation and filtering functions for wireless applications, *Journal of Electrical Systems and Information Technology, 2016.*

[2] H. Tang, J. X. Chen, H. Chu, G. Q. Zhang, Y. J. Yang and Z. H. Bao, Integration Design of Filtering Antenna with Load—Insensitive Multilayer Balun Filter, *IEEE Trans. on Components, Packading and Manufacturing Tecnology, vol.6(*Issue 9*), September 2016.*

[3] Wei-Jun Wu, Qi-Feng Liu, Qi Zhang, and J.-Y. D., Co-Design of A Compact Dual Band Filter-Antenna For WLAN Application, *Progress in Elec. Res. Lett., vol. 40, pp. 129–138, 2013.*

[4] N. I. A. Zainuddin, *Integrated Filter Antenna for 2.4 GHz Application*, Bac. Eng. (Hons.) dissertation, Dept. of Elect. and Electronic Eng., University Malaysia Sarawak, Malaysia, 2014.

[5] R. Natarajan, J. V. George, M. Kanagasabai, L. Lawrance, B. Moorthy, D. B. Rajendran and M. G. N Alsath, Modified antipodal Vivaldi antenna for ultra-wideband communications. *IET Microwaves, Antennas & Propagation, 10(*4*), 401-405, 2016.*

[6] G. Mansour, M. J. Lancaster, P. S. Hall, P. Gardner, and E. Nugoolcharoenlap, Design of Filtering Microstrip Antenna Using Filter Synthesis Approach, *Prog. Electromagn. Res. Lett, vol. 145, no. February, pp. 59–67, 2014.*

[7] N. N. M. Noor, D. A. A. Mat, A. Amran., D. K. A. Zaidel, and A. Joseph, The Effect of Chamfering Structure towards the Design of Open Loop Resonator Bandpass Filter for Microwave Applications, *Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 8(*12*), 123-127, 2016.*

[8] N.N.M. Noor, *Development of open-loop resonator bandpass filter with chamfering folded structure for 2.4GHz application*, Bac. Eng. (Hons.) dissertation, Dept. of Elect. and Electronic Eng., University Malaysia Sarawak, Malaysia, 2016.

[9] S. S. Pawar, An Integrated Antenna-Filter Co-Design Cascade Approach for UWB Range, *International Journal of Engineering Research & Technology (IJERT), vol. 4 (Issue 5), pp. 1225–1227, May 2015.*

[10] D. A. A. Mat, A. Amran, N. S. Hasim, D.N.A. Zaidel, A.S.W.Marzuki & R. Sapawi, Integrated open loop resonator filter with notch patch antenna for microwave applications, Telecommunication, Computing, Electronics and Control (TELKOMNIKA), vol. 5 (5), 2017.