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Coplanar Waveguide Filter using Stub Resonators for Ultra Wide Band Applications

Bindu C J\textsuperscript{a},*, S Mridula\textsuperscript{a}, P Mohanan\textsuperscript{b}

\textsuperscript{a}Division of Electronics, Cochin University of Science and Technology, Kochi 682022, India
\textsuperscript{b}Department of Electronics, Cochin University of Science and Technology, Kochi 682022, India

Abstract

The paper presents a compact coplanar waveguide filter employing stub resonators for ultra wide band applications. A cascade connection of series and shunt stubs quarter wavelength long is used for achieving bandpass characteristics. The performance requirement of the filter decides the number of cascaded sections. The filter has reduced insertion loss in its passband and good attenuation in lower and upper stopbands. The flat group delay in the passband ensures its use in communication applications. Measured frequency response of the fabricated prototype shows good agreement with simulated response.

Keywords: Airbridge; CPW; Stub resonators; UWB

1. Introduction

The wide commercial acceptance of UWB communication is not merely because of its merits like high data rate, low power and good multi path rejection, but due to the FCC report in 2002 announcing the deregulation of the 7.5 GHz band extending from 3.1GHz to 10.6GHz\textsuperscript{1}. This paved the way to the design of large number of filters and antennas in this frequency band. Since the technology is promising and attractive for local area networks, most of these designs are intended for consumer electronics products for which compactness along with performance

* Corresponding author. Tel.: +91-944-750-9658; fax: +91-484-257-5800.
E-mail address: bindudevan@gmail.com
happens to be a main design metric. Several works have been reported to meet the design challenges of UWB filters. The use of stub resonators for filtering applications originates from transmission line theory, which equates an open circuited and short circuited half wavelength line as a parallel LC and series LC circuit respectively. Hence, a bandpass filter which is a ladder structure of series and parallel LC circuits can very well be realized using such stub resonators. Microstrip filters using open/short circuited stubs are reported. Coplanar Waveguide (CPW) is a uniplanar structure, where the conductor strip and ground are in the same plane. Hence no backside wafer processing is required. This eases the use of short circuited stubs as it does not require any via holes to be introduced. CPW structures have low dispersion characteristics and are almost insensitive to substrate thickness. The medium supports two modes of propagation with three conductors. These modal field distributions can be characterized by their even and odd spatial symmetries. The existence of these two differing modes can be utilized from a design perspective to create a rich variety of coupling structures and hybrids. In the recent past different CPW filter configurations have been reported for ultra-wideband applications. But the issues such as size reduction and simultaneous performance enhancement have not necessarily been addressed in most of the filter designs. Also many of them use either conductor backed coplanar or a hybrid circuit using both microstrip and coplanar waveguide. This work concentrates on simple short circuited and open circuited stub resonators to realize the desired bandwidth. The structure exhibits good stopband characteristics while maintaining a reasonable roll off at both lower and upper cut off frequencies and low insertion loss in the pass band.

2. Design Evolution and Geometry

As per transmission line theory, short circuited and open circuited half wavelength lines act as series and parallel resonant circuits respectively. Similarly short circuited and open circuited quarter wavelength lines act as parallel and series resonant circuits respectively. When length of a series open stub is less than $\lambda_g/4$ it behaves like a series capacitor. Similarly when length of a series short stub is less than $\lambda_g/4$ it acts as a series inductor. Transmission characteristics of the stubs are studied. A CPW series open stub quarter wavelength long at centre frequency, with its equivalent circuit model and variation of $S_{21}$ with varying length ($L_{seo}$) and width ($W_{seo}$) is shown in Fig. 1 (a-c). The resonant frequency varies with lengths of the stubs. As the width of the stub affects the guide wavelength, stubs having same length may have slightly different resonant frequencies for different widths. However the variation is not significant for varying widths, but can be used for fine tuning of the band. Similar study conducted on a quarter wavelength series short stub is shown in Fig. 2 (a-c). CPW layout with a pair of shunt short stub and its transmission characteristics for varying lengths ($L_{shs}$) and widths ($W_{shs}$) of stub are shown in Fig. 3 (a-c).

Basic circuit model of a bandpass filter has a parallel resonant circuit controlling its lower cutoff frequency and a series resonant circuit controlling the upper cutoff frequency. A half wavelength open stub or a quarter wavelength short stub will act as parallel LC resonator. Since it is easy to realize shorted stubs in CPW, the choice is for shunt short stubs, which make the structure compact. In the proposed filter, required series resonant circuit is realized with quarter wavelength series open stub and shunt resonant circuit is realized with quarter wavelength shunt short stubs. Fig. 4 (a-b) shows the cascade connection of resonators giving bandpass response.

The ideal CPW structure is conveniently considered as a pair of coupled slotlines with odd and even modes referred to as the CPW mode and the slot line mode, respectively. The signals on finite ground coplanar waveguide is a superposition of these two modes. If there is asymmetry in the ground plane or if there exist discontinuities in the circuit, the unwanted slotline mode may get coupled to the desired CPW mode. Shunt short stubs and coupled open ends are considered as discontinuities in CPW which cause parasitic modes. In order to suppress these spurious modes, crossover connections need to be made between the ground planes. Note the airbridges in Fig. 4 (a) placed across the shunt short stubs at the beginning of the discontinuity. In this type of air bridge, the unwanted slotline mode is prevented by introducing slots across the stubs. Difference in transmission characteristics with and without air bridges is shown in Fig. 4 (b).
(a). CPW series open (SEO) stub ($\lambda_g/4$ at 6.85GHz) and equivalent LC circuit

(b). Simulated S$_{21}$ for varying Lengths ($W_{seo}=1\,\text{mm}$)  
(c). Simulated S$_{21}$ for varying Widths ($L_{seo}=6.75\,\text{mm}$)

Fig. 1. CPW Series Open Stub and Simulated Responses

(a). CPW series short (SES) stub ($\lambda_g/4$ at 6.85GHz) and equivalent LC circuit

(b). Variation of S$_{21}$ for Varying Lengths ($W_{ses}=1\,\text{mm}$)  
(c). Variation of S$_{21}$ for Varying Widths ($L_{ses}=6.75\,\text{mm}$)

Fig. 2. CPW Series Short Stub and Simulated Responses
Introduction of air bridges between the stubs suppress unwanted slotline mode giving reduced insertion loss in the pass band. Performance improvement can be achieved by introducing series inductors in the form of series short stubs shorter than quarter wavelength.

The three transmission line sections discussed above can be combined suitably to obtain desired bandpass characteristics. The addition of more number of resonators can improve the characteristics as evident in Fig. 5 (a-b). The role of air bridges is clear from the surface current vectors at the centre frequency 6.85GHz shown in Fig. 5 (c-
d). The required UWB bandwidth is achieved by fine tuning of resonators. The final layout of the filter with simulated S parameters is shown in Fig. 6 (a-b). The average insertion loss for the filter is 1dB. The roll off rate is 15dB/GHz at both band edges.

Fig. 5. Layout with a Cascade of 2 Sets of Resonators and Improved Transmission Characteristics

3. Simulation Studies

Surface current vectors at various frequencies are plotted to analyze the transmission characteristics. Capacitive nature of series open stub at lower frequencies is revealed in the plot of electric field at 1.5GHz shown in Fig. 7 (a). The shunt short stubs are responsible for the lower side transmission zero as indicated by the plot of surface current vector at 3.1GHz in Fig. 7 (b). At centre frequency, all the signals are coupled to the output port as shown in Fig. 7 (c). Upper band edge at 10.6GHz is determined mainly by the series open stub as evident from the current distribution in Fig. 7 (d).
4. Fabrication and Results

The filter structure is fabricated on a single sided substrate with relative permittivity of 4.4, dielectric loss tangent of 0.02 and thickness 1.6mm. Fig. 8 shows the photograph of the fabricated filter structure along with the SMA connectors. The structure is compact as can be seen in figure. Standard photolithography is used for the fabrication process. Transmission and reflection parameters are measured using Agilent 8753ES Vector Network Analyzer. The measured results shown in Fig. 9 (a-c) agree well with the simulated results. Small discrepancies in the result can be attributed to the inaccuracies in the fabrication process and/or numerical errors in simulation. Average insertion loss is -2.4dB including those introduced by the SMA connectors. The roll-off rate is 15dB/GHz at both band edges and the fractional bandwidth attained is approximately 109%. The flat group delay characteristics reveal the linear phase nature of the filter, making it suitable for communication applications. Group delay variation is less than 0.2ns over the entire passband.
Table 1 gives a comparison of filter parameters with similar reported works. It can be seen that the proposed filter achieves the required bandwidth with comparable performance.

Table 1. Comparison with Similar Works

| Parameters/Ref                  | Neil Thomson, et.al.⁷ | Shau-Gang Mao, et.al.⁸ | SN. Wang, et.al.⁹ | Proposed Filter |
|--------------------------------|-----------------------|------------------------|-------------------|-----------------|
| Passband (GHz)                 | 3.5-9.3               | 3.4-10.5               | 2.8-10.1          | 3.06-10.6       |
| Insertion Loss (dB)            | 0.6                   | 0.37                   | Not Specified     | 2.4             |
| Attenuation                    | 40,15                 | 26,19                  | 30,10             | 40,17           |
| Lower, Upper (dB)              |                       |                        |                   |                 |
| Roll off Rate Lower, Upper (dB/GHz) | Not specified | Not specified | 28,30             | 15,15           |
| Group Delay (ns)               | 0.2                   | 0.28                   | 0.3-0.6           | 0.2             |
| Overall Size (mm x mm)         | 8.8 x 2.8             | 23.3 x 5               | 36 x 36           | 22 x 11.5       |
| Substrate (εr/h mm)            | 3.05/0.508            | 2.2/1.57               | 3.48/1.524        | 4.4/1.6         |
| Remarks                        | Microstrip/            | Coplanar               |                   | Coplanar       |
|                                | Coplanar, multilayered|                        |                   |                 |
5. Conclusion

The design is based on conventional coplanar waveguide. Hence it is easy to integrate to any PCB. The design is simple and dimensions are easy to fabricate. Roll off achieved is 15dB/GHz on both sides and the attenuation in the stop bands is reasonable. It can be further brought down by cascading more sections as desired. However, there is a limitation that the structure may become complicated as more sections are to be incorporated.

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