Design, Simulation and Fabrication of Microstrip Hairpin and Interdigital BPF for 2.25 GHz Unlicensed Band

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ABSTRACT:
A frequency hopping spread spectrum data link that works in the unlicensed frequency band of 2.2 GHz to 2.3 GHz, needs to be compliant with EMI/EMC Issues to reject or attenuate the unwanted input signals (interferences) and also preventing of spreading out spurs and harmonic signals. Because of unlicensed band and no affordable commercial filters, two types of microstrip band pass filters called hairpin and interdigital were designed, simulated and fabricated on FR4 substrate as application specific filters. The results showed achievement of needed performance.

KEYWORDS: Microstrip Band Pass Filter, Hairpin, Interdigital, EMI/EMC, Interference Rejection, Spur Attenuation.

1. INTRODUCTION

Filtering is one of the important parts of any communication system especially in wireless cases. The need of rejecting or attenuating interferences from others sources to make the system more robust and providing electromagnetic compatibility (EMC) as well as not spreading out spur signals and harmonics to provide the electromagnetic interference (EMI) criteria and not bothering other communication systems, indicates the important role of filtering in RF systems [1], [2]. Also different types of filters and structures have been introduced, but microstrip filters have become more interesting than m-derived filters for design engineers because of following advantages: simplicity, lightness, cheapness. Of course the main disadvantages of this kind of filters are poor power handling level and attenuation. It is remarkable that for unlicensed frequency bands because of no commercial filters, using microstrip filters has become interesting [3], [4]. In this paper, because of no available ready filters, two band-pass microstrip (hairpin and interdigital) filters have been simulated and fabricated for using by an RF data link in unlicensed frequency band of 2.2 GHz to 2.3 GHz with 2.25 GHz central frequency for special purposes. The simulation and fabrication results showed good performance of microstrip filters.

2. DESIGN, SIMULATION AND FABRICATION

As mentioned in the previous section, there is an wireless data link with frequency hopping spread spectrum (FHSS) modulation technique that has to work in the 2.2 GHz to 2.3 GHz unlicensed frequency band and because of observing the EMI/EMC issues, and not any affordable ready Filters, we had to design an application specific band pass filter. So according to advantages explained in previous section, microstrip filters were selected instead of m-derived filters.

Consider the interdigital filter, The common strips length are L, the width of the i^{th} strip is w_i, the gap spacings between adjacent strips are s_i, the source admittance is Y_S and the load admittance is Y_1, so the transmission line equations for the N coupled lines would be:

$$\frac{d}{dz}[V] = -(jw[L]+[R])[I] \quad (1)$$

$$\frac{d}{dz}[I] = -(jw[C]+[G])[V] \quad (2)$$

In which, [C], [L], [R] and [G] are the capacitance, inductance, resistance and conductance matrices, respectively. The dispersion effects might be incorporated into the models, with considering C, L, R and G to be functions of frequency. Thus equations could be combined to introduce:

$$(jw_k[L]+[R])(jw_k[C]+[G]) - \gamma^2[U] = 0 \quad (3)$$

$$(jw_k[L]+[R])(jw_k[C]+[G])[M_v]_{i,k} = \gamma^2_{i,k}[M_v]_{i,k} \quad (4)$$

In which, $[M_v]$ and $[\gamma]$ are the eigenvectors matrix and the eigenvalues vector for $(jw[L]+[R])(jw[C]+[G])$. You might then calculate the N propagation constants because of the N conducting strips in the non-homogeneous medium like micro-strips. As a result, we can introduce the voltages and currents on the N strips as functions of z

$$[V_i]_k = [M_{v_{ij}}]_k \left[a_j e^{-\gamma_{j,k} z} + a'_j e^{\gamma_{j,k} z}\right] \quad (5)$$

$$[I_i]_k = ([Y_a]_k \cdot [M_{v_{ij}}]_k) \left[a_j e^{-\gamma_{j,k} z} - a'_j e^{\gamma_{j,k} z}\right] \quad (6)$$

In which, a_j and a'_j are the amplitudes of forward and backward traveling waves on the lines, k is the subscript showing the frequency in the band, and $[Y_a]$ is the characteristic admittance of the lines regarding to the propagation constants. Y_{ij}, the $[Y_a]$ entry, is the characteristic admittance of the ith line for the jth propagation constant. Thus, the admittance matrix of the input/output two port network regarding the load and source terminals [1, 5]:

$$\begin{bmatrix} I_l \\ I_s \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_l \\ V_s \end{bmatrix} \quad (7)$$

In which, I_l and I_s are the currents of the load and source, and V_l and V_s are the voltages of the load and source, respectively. We might thus get the scattering matrix from the admittance matrix. The scattering parameter s_{21} as the transfer function would be:

$$s_{21} = -\frac{2Y_s Y_{21}}{(Y_s + Y_{11})(Y_l + Y_{22}) - Y_{12} Y_{21}} \quad (8)$$

And the insertion loss would be:

$$IL_k = -20 Log\, |s_{21}|_k \quad (9)$$

The Filter design goals and needed specifications are introduced in Table 1.

2.1. Design and Simulation of Hairpin and Interdigital Microstrip BPF

Two types of microstrip band pass filters called hairpin and interdigital band pass filters were selected and by using the keysight software, they were designed and simulated [6]. The results of this part of project are depicted in figures 1 to 6.

Table 1. Filter Specifications.

Parameter	Value
Central Frequency	2.25 GHz
Lower Cutoff Frequency	2.2 GHz
Upper Cutoff Frequency	2.3 GHz
Order of Filter	6
Impedance	50 Ω
Substrate Material	FR4
Out of Band Rejection	≥ 20 dB
Die electric Constant ($\in_r$)	4.4
Substrate Height	0.5 mm
Cooper Foil Thickness	0.035 mm

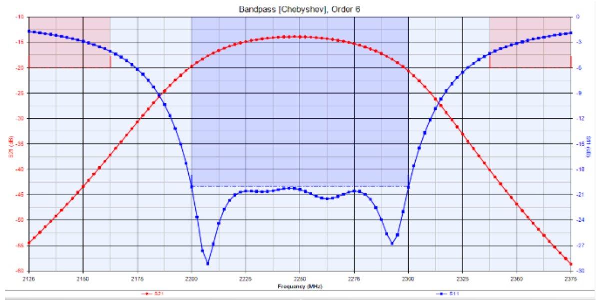

Fig. 1. Hairpin Filter Frequency Response Simulation

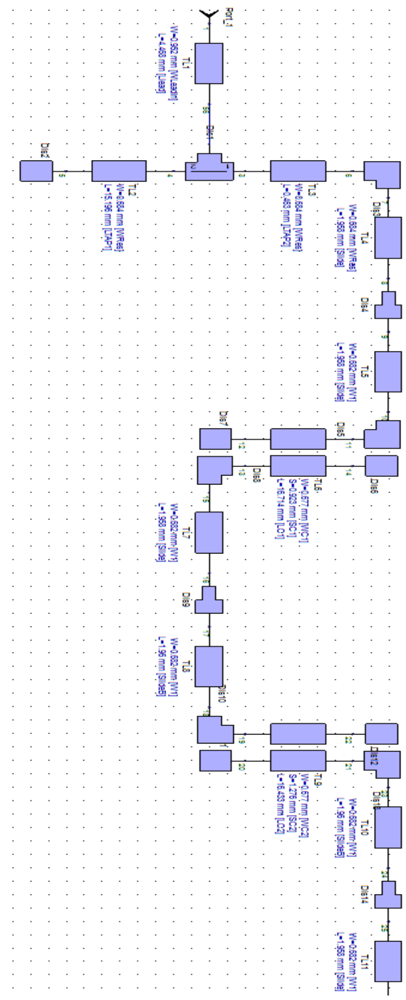

Fig. 2. Part of Designed Hairpin Filter Structure

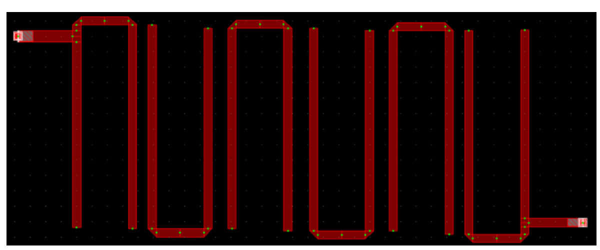

Fig. 3. Model of Designed Hairpin Filter

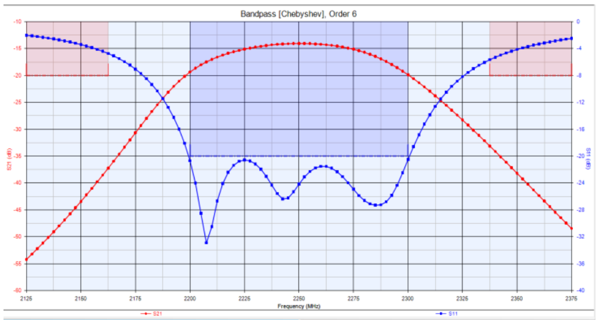

Fig. 4. Interdigital Filter Frequency Response Simulation

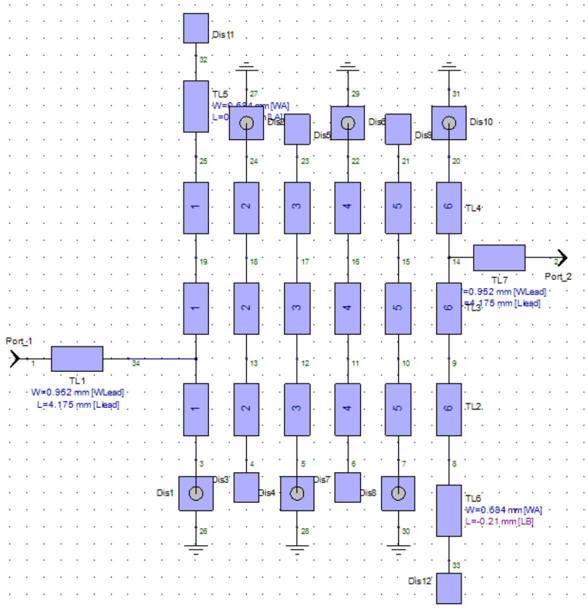

Fig. 5. Structure of Designed Interdigital Filter

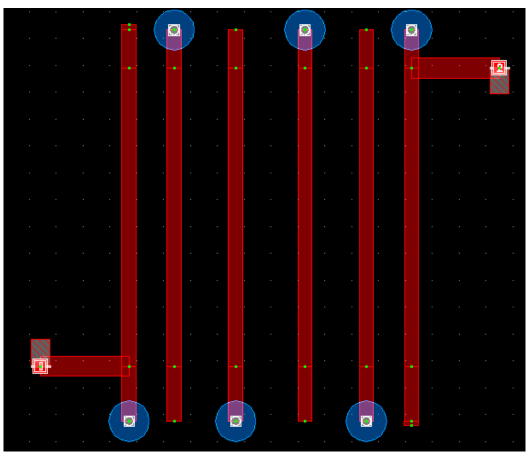

Fig. 6. Model of Designed Interdigital Filter

2.2. Implementation and Fabrication

After design and momentum simulation of filters, the Gerber files were generated for fabrication of filters based on an FR4 substrate with the specifications introduced in Table 2.

Table 2. FR4 Specifications.

Parameter	Value
Specific gravity/density	1.850 g/cm^3
Water absorption	0.125 in < 0.10%
Temperature index	140 °C (284 °F)
Thermal conductivity, through-plane	0.29 W/(m·K)
Thermal conductivity, in-plane	0.81 W/(m·K)
Rockwell hardness	110 M scale
Bond strength	> 1,000 kg
Flexural strength - LW	> 415 MPa
Flexural strength - CW	> 345 MPa
Dielectric breakdown	> 50 kV
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Dielectric strength	20 MV/m
Relative permittivity	4.4
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Dissipation factor	0.017
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Dielectric constant permittivity	4.70 max., 4.35 @ 500 MHz, 4.34 @ 1 GHz
Glass transition temperature	Can vary, but is over 120 °C
Young's modulus - LW	3.5×10^6 psi
Young's modulus - CW	3.0×10^6 psi
Coefficient of thermal expansion - x-axis	1.4×10^{-5} K^{-1}
Coefficient of thermal expansion - y-axis	1.2×10^{-5} K^{-1}
Coefficient of thermal expansion - z-axis	7.0×10^{-5} K^{-1}
Poisson's ratio - LW	0.136
Poisson's ratio - CW	0.118
LW sound speed	3602 m/s
SW sound speed	3369 m/s
Copper foil thickness	0.035 mm

So the implemented filters are shown in figures 7 and 8.

Fig. 7. Implemented (Fabricated) Hairpin Filter

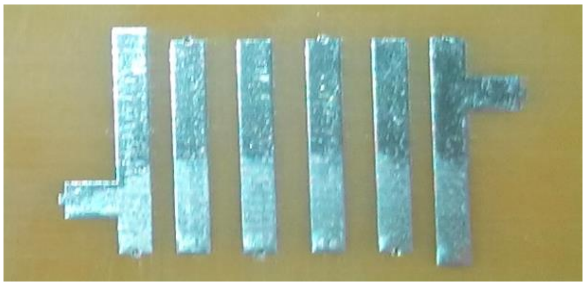

Fig. 8. Implemented (Fabricated) Interdigital Filter

The practical frequency responses of realized filters which are generated by spectrum analyzer instrument, are depicted in figures 9 and 10.

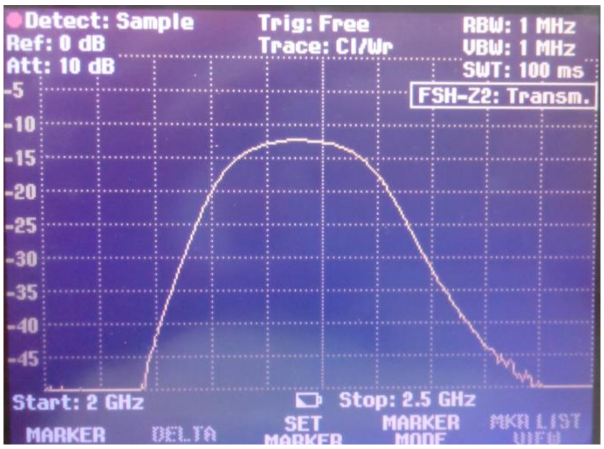

Fig. 9. Practical Frequency Response of Realized Hairpin Filter

Fig. 10. Practical Frequency Response of Realized Interdigital Filter

These structures can be used in land based, ship borne and airborne vehicles for different communication, navigation and electronic warfare systems [7], especially because of their advantages in reduced size, weight, cost and complexity [8].

3. CONCLUSION

Two different types of microstrip 6 order band pass filters (hairpin and interdigital) were designed, simulated and fabricated on FR4 substrate. The filters were designed for 2.25 GHz unlicensed band spread spectrum data link to meet the requirements of EMI/EMC issues. Because of non-standard unlicensed frequency band used here (2.2 GHz to 2.3 GHz), there were no affordable filters in the market so application-specific filters were implemented. The practical results were acceptable based on the design goals.

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