

Miniaturized Microstrip Low Insertion Loss Band-Pass Filter for L-Band Receiver

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Abstract:

Miniaturization of Microstrip Band-Pass Filter with 15% fractional Bandwidth for L-Band Receiver is a challenging task without compromising the Insertion Loss and the Rejection Parameters. Usually, InterDigital is the preferred configuration for compact structure. But in order to reduce the dielectric loss and thereby reducing the Pass Band Insertion Loss, using a Low Dielectric Constant Substrate with low Loss Tangent is inevitable. But $\lambda/4$ Resonator length on low Dielectric Material is naturally higher than what it would be in a high dielectric constant substrate. A new type of Interdigital structure is devised to miniaturize the size without compromising the Insertion loss which uses meandered $\lambda/4$ resonators. This reduces the overall size by 40% and the length by half compared to the conventional design

This complete design is carried out using Agilent ADS. Manual tuning is incorporated in this design, hence final 3D EM Optimization is carried out in CST Transient Solver. After this, Board is fabricated on Rogers 5880 with 31 mil substrate thickness and Insertion loss less than 1 dB over the bandwidth with Rejection better than 30 dBc at 1.5 Bandwidth away from center frequency is achieved in measurement.

Keywords:

Miniaturization, L-Band, Inter-Digital BPF, Microstrip

I. INTRODUCTION

Modern RF systems are placing higher demands on reducing the size of RF components. Microwave filters are no exception when more demand is being placed on selectivity due to increasing demand on RF & Microwave Systems.

Traditional filter designs are documented in a number of texts. One such filter design is the Interdigital filter design. The InterDigital Band Pass Filter is popular due to the advantages in providing a wideband, low loss and compact structure. The Interdigital Band-pass filter's main advantage is in its use of $\lambda/4$ wavelength resonators with alternate short-circuit and open-circuit ends. This offers the advantage of reduction of the overall footprint when compared to other parallel coupled filter designs. But, in order to reduce the dielectric loss and hence the Pass Band

Insertion Loss designing with low Loss Tangent, low Dielectric Constant substrate is inevitable. As we know $\lambda/4$ Resonator length on low Dielectric Material is naturally higher than what it would be in a high dielectric constant substrate. Change coupled structure and increase the effective coupling area of the microstrip line can make the structure of filter more compact, so as to reduce filter area. Based on these conclusions, a new type of Inter-digital structure is devised to miniaturize the size without compromising the Insertion loss which uses meandered $\lambda/4$ resonators. This reduces the overall size by 40% and the length by half compared to the conventional design

II. THE DESIGN AND OPTIMIZATION OF TRADITIONAL MICROSTRIP INTERDIGITAL FILTER

The conventional design method of an Interdigital microstrip bandpass filter is based on classical network synthesis method. It usually begins by finding out the lumped element low-pass prototype, and then obtaining the frequency transform of band-passfilter lumped parameters, through the existing formula. This design approximates the self-capacitance of each stroke, as well as the mutual capacitance between the adjacent poles, obtains the Cross-finger capacitors filter network parameters, and then achieves the microstrip parameters. However using this design method is relatively more complicated.

Here, filters outside the terminal Q value and the inter-resonator coupling coefficient K were used to seek the microstrip filter parameters, and calculated by :

$$K_{i,i+1} = \frac{BW}{f_0 \sqrt{g_i g_{i+1}}} \quad (1)$$

$$Q = \frac{f_0}{BW} g_1 = \frac{f_0}{BW} g_{n+1} \quad (2)$$

where, BW is the filter passband bandwidth.

After calculating the $K_{i,i+1}$ between adjacent resonators, the spacing $S_{i,i+1}$ of the adjacent resonator, filter can be identified quickly by use of S/h (h is substrate thickness) with the K curve relationship. The impact of end-effects should be considered, so the actual length of the

resonator.

$$L = \frac{\lambda_g}{4} - 0.412h \frac{\epsilon_e + 0.3}{\epsilon_e - 0.258} \cdot \frac{w/h + 0.264}{w/h + 0.8} \quad (3)$$

The location of tap can be obtained by the following formula:

$$l = \frac{2L}{\pi} \sin^{-1} \sqrt{\frac{\pi Z_0}{4Z_{0f} Q}} \quad (4)$$

where, Z_0 is the feeder characteristic impedance of the microstrip, usually 50 ohm, Z_{0f} is microstrip resonator characteristics impedance.

A. The Design of Microstrip Interdigital Filter:

Based on the above principles and formulas, the interdigital microstrip bandpass filter can be designed, with the center frequency of f_0 (L-Band Radar Band Center Frequency), 200 MHz Passband BW, max. Passband Insertion Loss of 1 dB, Rejections greater than 30 dBc at 1.5-BW away from f_0 . There is also a specification on the minimum return loss in the passband. A return loss of 26.4 dB (1.10 VSWR) corresponds to a prototype ripple level of 0.01 dB. A return loss of 20.8 dB (1.20 VSWR) corresponds to a prototype ripple level of .036 dB. Most mechanical filters with tuning screws can eventually be tuned to their designed return loss level. In printed filters, which are much harder to tune, we might design for 20-dB return loss and hope that we can achieve a minimum of 15 dB in practice. At the system level, it is important to have components with a minimum return loss around 15 dB to avoid mismatch ripple when components are cascaded.

The microstrip substrate used here is Rogers RT/Duroid laminate with a Relative dielectric constant of 2.2, with a thickness of 31 mil.

Instead of using the above mentioned design equations, Agilent Genesys was used for synthesizing the BPF. This leads to a 4th Order InterDigital BPF Design. Although the first iteration results as shown in Figure 1 appear disappointing, they are predictable and agree with results based on prior experience with this topology. The largest error is the tuning of the first and last resonators. It is well known in the filter design community that tapping has a significant effect on resonator tuning, and that the first and last resonators need to be considerably longer. However, it is not clear from these results what other corrections are necessary to the resonator lengths or spacings.

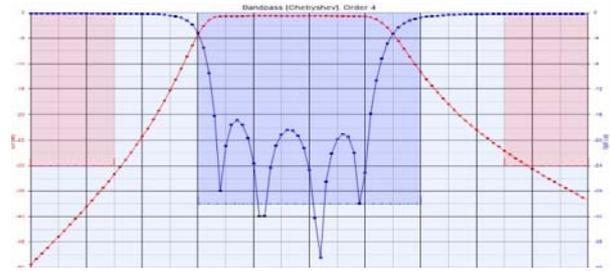


Figure 1: Simulated Result of Synthesized BPF in Genesys

B. The Optimization of Microstrip Interdigital Filter

For further optimization, the generated layout was exported to Agilent ADS. With some planar EM simulators, it would be tempting to parameterize this geometry and attempt to apply gradient optimization. Even considering the symmetry, there are two resonator length variables, two resonator spacing variables, and the tap position. Just computing the gradients to begin the optimization process would take a considerable amount of time. Figure 2 and 3 show the optimized Results.

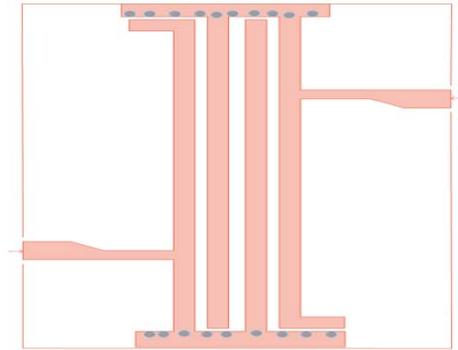


Figure 2: Optimized EM Model of BPF in ADS (30mm * 45mm)

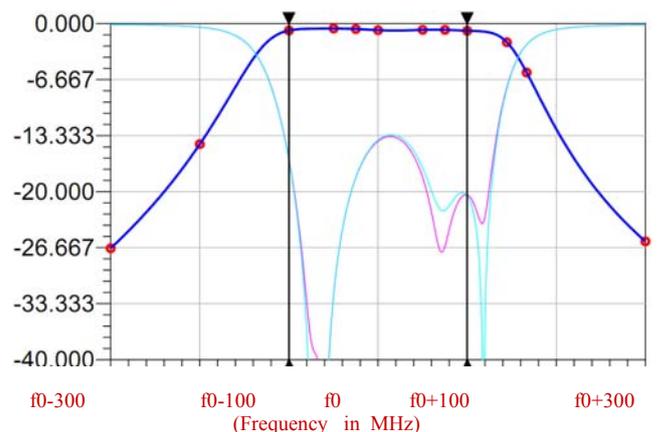


Figure 3: Simulated Result of Optimized BPF (fig 2) in ADS

III. ADJUST THE STRUCTURE OF THE CROSS-FINGER FOR MINIATURIZED MICROSTRIP FILTER DESIGN

A. The Design of Miniaturized Microstrip Interdigital Filter

But from Figure 2, it is evident that the optimized filter structure is not very compact. Through a large number of simulation experiments, by changing the geometric parameters of the coupling structure, the electrical performance of the filter is derived with the variation of physical parameters; it is observed that the center frequency is smaller as the resonator length is larger, but the scope of the passband has almost no effect. So, if we meander each resonator of 4th order Filter, keeping the total length of each Resonator same as before, it leads to a very small shift in Center frequency which can be compensated by some adjustments. It is crucial to note that the shape of Fig. 3 can be restored with some compromise in Passband Insertion Loss. But, by adjusting the coupling structure, the band-pass filter structure can be made more compact, with the performance in agreement with the design requirements. The following Fig. 4 and Fig. 5 show the miniaturized Microstrip Filter structure where each Resonator has been meandered to make compact structure.

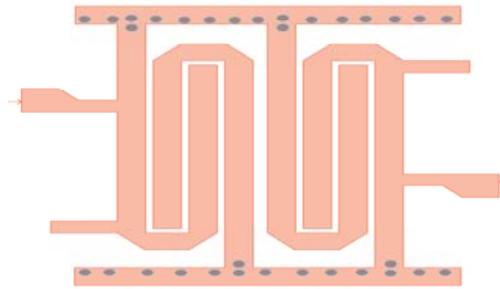


Figure 4: EM Model of Compact BPF in ADS (29 mm * 26 mm)

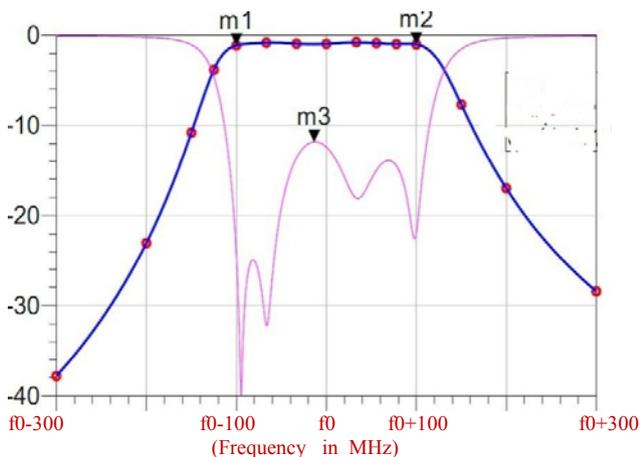


Figure 5: Simulated Result of Compact BPF (fig 4) in ADS

B. The Optimization of Miniaturized Microstrip Filter with Cover 'On' in 3D Simulator

It should be noted that all the above EM simulations performed in ADS do not include the housing effects. There are couplings from the filter to evanescent modes in the housing that can cause a significant shift in the realized bandwidth of the filter, if they are not accounted for in the design. Finally, in the finished circuit, there is a very limited amount of tuning that can be done to correct errors in design or fabrication. A significant bandwidth expansion is observed in the Housed Filter with the cover 'off' when compared to housing with cover 'on'. All these facts emphasize the need for a Full Wave 3D EM simulation. Hence, the above miniaturized BPF structure with the minimum height of Cover has been carried out in a 3D capable EM Environment like CST. All the optimization has been carried out in CST which makes use of a Transient Solver. Fig. 6 shows the 3D Model of BPF in CST environment and Fig. 7 shows a comparison between the measured and simulated results in CST after optimizations.

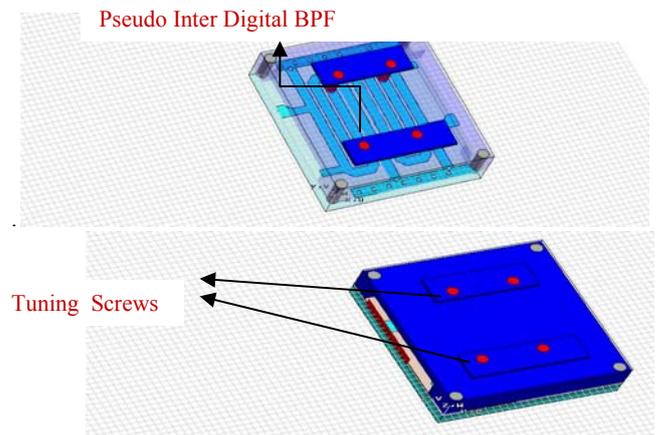


Fig 6: 3D EM Model of Compact BPF in CST (29 mm * 26 mm * 5 mm)



Fig 7: Simulated Result after optimization of BPF in CST

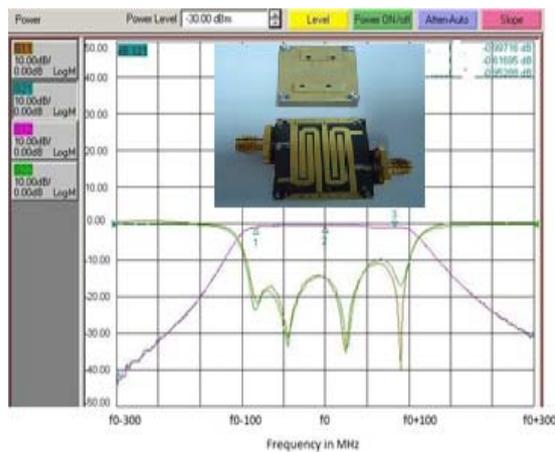


Figure 8: Measured Result of Realized BPF with Cover 'on'

IV. CONCLUSION AND FUTURE SCOPE

By adjusting the filter structure, the area of the improved filter is only 60% of that of the original design, thus achieving the purpose of miniaturization. Moreover, better than 30 dBc Rejection at f_0+300 MHz and f_0-300 MHz have been achieved with IL parameter better than 1 dB over Passband of 200 MHz (f_0-100 MHz to f_0+100 MHz). Little bit deviations occurred during manufacturing can be compensated by using 4 tuning screws manually.

This Filter can be used in Receiver Front end applications which require miniaturized Band Pass Filter with Low Insertion Loss and Good Rejection for out-of-band interference.

V. ACKNOWLEDGEMENT

We are grateful to Director, LRDE, Divisional Officer, RADL for providing this opportunity for development of this Miniaturized BPF. We are thankful to the RADL Technical Staff for their full co-operation. We are also thankful to MPD Division, MED Division of LRDE in realizing of this complete package. Last, but not the least we are thankful to all our colleagues whose precious inputs helped in the design and development of this module.

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