A Wide Band High Selectivity Combline Filter for ESM Application

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Abstract:
This paper presents a high selectivity combline band pass filter design with low insertion loss and very wide stop bands along with simulated and experiment results for Electronic Support Measure (ESM) application. The addition of small numbers of finite transmission zeros in the stop band and use of eleven resonators has been utilized to achieve the required filter response.

Key Words: Band Pass Filters, Combline, coaxial resonator.

I INTRODUCTION

Combline filters are popularly used as band pass filters in modern microwave and millimeter wave subsystems due to their compactness, excellent stop band, selectivity performance and ease of integration [1-2]. The conventional combline filter consists of an array of parallel resonators of metal bars, properly spaced, grounded at one end and loaded by lumped capacitors or open circuited at the other side. The capacitive end loading of the resonators give a useful size reduction compared with those that are based on a quarter-wave resonance.

The comblines are generally viewed as coupled TEM mode transmission lines. A schematic of a combline filter is shown in Figure 1 [3]. The coupling is a function of the resonator length, shape and spacing. Typical resonator shapes are flat striplines, round rods, or rectangular rods. Combline is a very popular filter structure because a moderate value of unloaded resonator quality factor may be achieved as more of the field is enclosed (and therefore low loss), and because a wide rejection band is indigenous to the structure by virtue of the wide separation in resonant modes.

All resonators are kept identical and resonating at the center frequency f_0. The coupling between the resonators results in a displacement Δf in the resonance frequencies. The coupling between resonators is predominantly magnetic in nature. All resonators are housed in cavity having a rectangular or circular cross section.

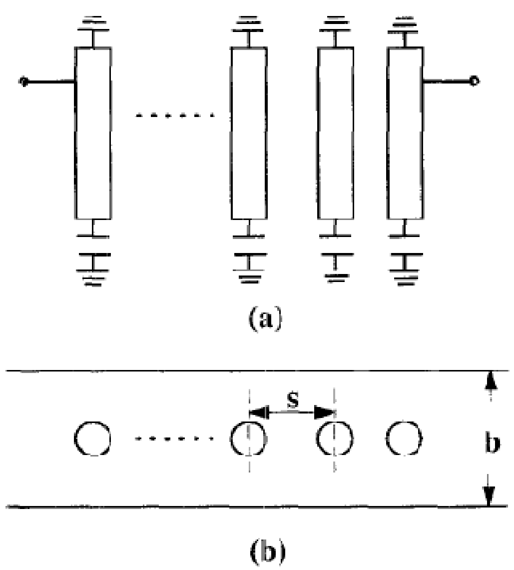

Figure1 Cornbline filter with (a) plane view (b) cross section view

The filter cavity itself should not be resonant or support waveguide modes close to desired pass band frequencies. It is preferable to employ direct tapping of the end resonators with input/output connectors, where the centre conductor of the coaxial connector is soldered to the end resonators [4].

II FILTER CONFIGURATION

The topology of a classic second-order combline filter is given in Figure 2. The equivalent-circuit network of the filter is also provided. As shown, the filter is made up of two identical transmission-line segments shortened to ground in one extreme and terminated in a lumped capacitor at the opposite end. The line-capacitor set corresponds to the filter resonator, modeled as the parallel connection of the corresponding capacitor and the equivalent distributed inductor of the transmission-line segment. The coupling between the resonator lines is merely inductive, and is approximated as a series distributed inductor connecting the resonators.

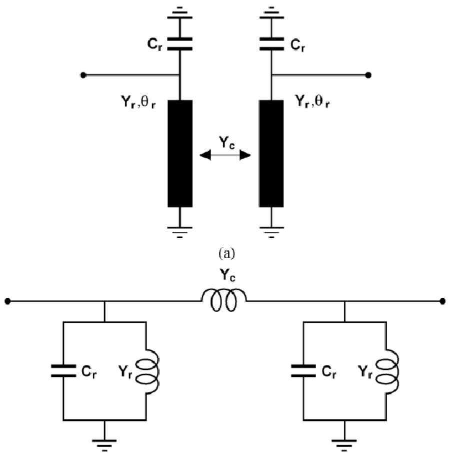

Figure 2 Second-order combline filter (a) topology (b) equivalent-circuit network

The design method of tunable filters can be broadly split into two steps. The first step consists of the suitable selection of the design parameters required to undertake the second step. These are design center frequency (f_0), resonator electrical length at f_0, filter bandwidth, and stop band rejection. The targeted design specifications are given in Table-1. The second step comprises the design and simulation of a TEM combline filter with a fixed center frequency making use of the method outlined in [2, 5-9]. The design was carried out by the expression proposed in [6]. With this approach the equivalent circuit of filter was developed so as to achieve the required percentage bandwidth. The characteristic admittances required for coupled-line structure can then be obtained using the expressions proposed in [10], assuming TEM approximation and negligible nonadjacent-line coupling [9].

Table I: Design Specifications

Parameter	**Specification**
Pass band (GHz)	10.0 – 14.0
Insertion Loss (dB)	< 1.3
Rejection (dB) in lower stop band (GHz)	> 65, DC to 8.5
Rejection (dB) in upper stop band (GHz)	> 65, 16.1 to 20.0
Return loss (dB)	> 12

The basic geometry of the filter consists of a cavity closed from all sides with eleven coaxial resonators as shown in Figure 3. The filter comprises of an array of equal-length parallel coupled cylindrical conductors, each of which is short circuited to ground at the same end and capacitive loaded on opposite ends. The geometry is symmetrical with respect to the center cylindrical resonator. The structure has direct coupling between the resonators (conductor rods), which results in reduction in size. Coupling depends on the distance between the rods and in particular increases as distance between them decreases. Two types of tuning screws, namely resonator tuning screws and coupling screws, have been used. The resonator tuning screws regulate the tuning centre frequency while the coupling screws placed between the resonators regulate the coupling and hence the bandwidth i.e. for greater penetration there is a correspondingly wider bandwidth. Hence when stronger couplings are generated wider bandwidths are produced. Narrow bandwidths for the filter are obtained with strong decoupling between the rods. Circular resonators are employed to achieve the required wide pass band at high frequency.

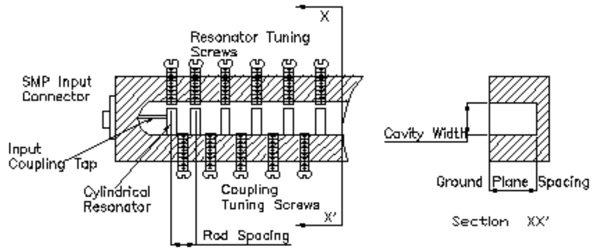

Figure 3 Mechanical structure of the Combline band pass Filter

The tuning screws are provided on "head-on" positions to resonator rods for adjusting ground capacitance. These resonating tuning screws are used in turn to adjust the resonating frequency of individual resonator. The filter input /output coupling is realized by direct tapping to the first and last resonator. The resonator length is kept typically $\lambda o/8$ at the primary pass band. This is accomplished so that the second pass band will be centered slightly over four times the frequency of the center of the first pass band. Practically due to non adjacent line coupling the filter response is asymmetrical and attenuation on high frequency side of the pass band is strong in comparison to the low frequency side. One method for correcting the attenuation slope asymmetry is the introduction of finite transmission zeroes below the pass band. The introduction of predominantly capacitive cross coupling between two adjacent resonators helps to produce attenuation poles in the lower side of the stop band. Interstage coupling screws at the center of adjacent resonators make the coupling predominantly capacitive within the band. In this manner a filter response with symmetrical upper and lower stop band has been achieved along with wide pass band.

A photograph of the fabricated tuneable filter prototype is shown in Figure 4. It can be observed that the overall filter circuit has been embedded in a brass box. The dimensions of the box are 74 (L) x12.8 (H) x14.5 (W) mm. A inside rectangular cavity of dimensions 3.4x8.4x6.0 mm has been used for realization of combline filter. The first waveguide mode (TE_{10}) cut-off is therefore 17.8 GHz and first cavity mode (TE_{011}) at 17.9 GHz, which is far from the pass band. A quarter wave resonator introduces its first spurious pass band at three times the center frequency ideally but depending on how the input and output is coupled to the waveguide mode (TE_{10}) one could expect spurious behaviour starting from 17.8 GHz. All 11 number of brass cylindrical resonators are identical, 1.6 mm in diameter and 3 mm long, resonating synchronously at the centre frequency of 12 GHz. Tuning screws has also been added. The first and last resonator are coupled to the input and output with taps at a location near to open end of resonator. These taps are extensions of the coaxial connector centre conductor. Each resonator is separated by distance calculated on the basis of coupling factors. The filter is symmetrical to centre resonator (6^{th} resonator). The inside cavity of the filter, all cylindrical resonators and tuning screws have been silver plated (5 micron thick).

III SIMULATION AND MEASUREMENTS

The combline filter was simulated using 3D structure simulator (HFSS) from Ansoft [11]. The simulated model of the combline filter is shown in figure 5. The simulated response of the filter is depicted in figure 6 below. It is observed that the simulated insertion loss is 1.04 dB (max) in the desired pass band with a ripple of 0.8 dB. The simulated rejection at the desired stop band frequencies of 8.7 GHz and 16.1 GHz is greater than 72 dB. The simulated return loss is better than 9.5 dB at the two ports. The simulated filter geometry was fabricated, assembled and tested for practical response. The filter was practically optimized for better return loss using tuning screws and their positions were locked using conductive epoxy. The measured insertion loss and return loss response of the designed band pass filter are shown in Figure 7. As is evident from the figure, an insertion loss of less than 1.0 dB with a ripple of 0.3 dB in the pass band has been achieved. A rejection in excess of 65 dB at 8.7 GHz and 16.1 GHz has been achieved with the proposed filter geometry. A return loss of better than 10 dB has been obtained at the two ports.

Figure 4 Fabricated filter prototype

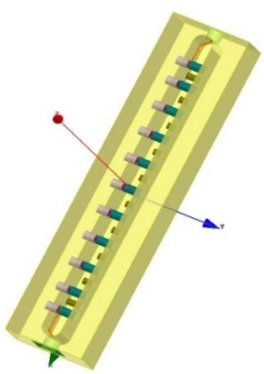

Figure 5 Simulated filter models with top cover plate removed

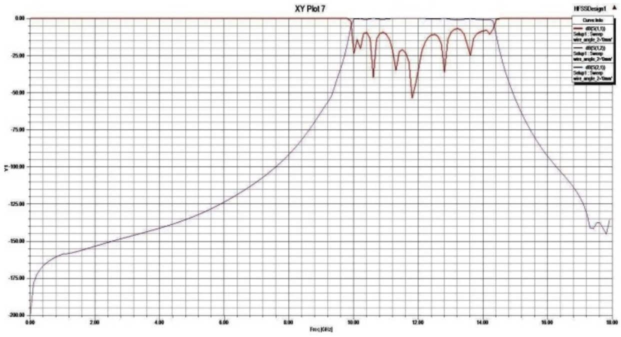

Figure 6 Simulated filter response

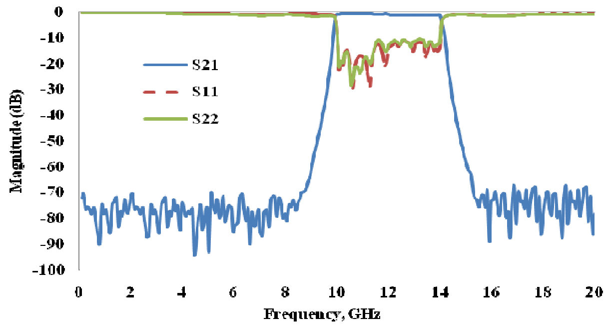

Figure 7 Measured filter response

IV CONCLUSION

A combline band pass filter has been designed and tested for a very wide pass band of 10 - 14 GHz with a rejection of greater than 65 dB in the stop band defined from 0.1 – 8.7 GHz and 16.1 – 20.0 GHz. A pass band insertion loss of less than 1.0 dB and attenuation greater than 65 dB over the specified stop band has been achieved experimentally. The tuning of required bandwidth has been accomplished by controlling the couplings of the filter, based on inserting inter stage coupling screws provided at the center of adjacent resonators in the same plane. The tuning screws have an effect on the inductive and capacitive cross coupling between the resonators. A symmetrical filter stop band has also been achieved by fine adjustments of these interstage coupling screws. The center-frequency tunability has been achieved by changing the capacitive end loading by moving the screws provided in the open-end plane of the resonators. The above features make it an ideal component for Electronics Support Measures (ESM) systems for band classification.

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