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Comparative Study of Band Pass Filters Used in Wireless Communication

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Abstract: Advances in microwave filter design methods has proved its significance for use in wireless communication systems. Modern wireless communication systems require microwave filters to have stringent specifications such as compact size, robust, conformal, light weight and more importantly cost effective while maintaining its electrical characteristics. Micro-strip filter design and reconfigurable filters present a better prospectus in this regards as it meets the specifications of modern wireless communication applications. Tunable filters can provide control over parameters such as frequency, bandwidth and selectivity while reducing the need of number of switches sandwiched between electrical components. Meta-materials have provided a new dimension for designing microwave filters.In this paper, we present a critical and through review on design methods for reconfigurable band-pass filters for next generation wireless technologies such as 4G, 5G and IOT.

Keywords: Band pass filter, Reconfigurable filter, frequency continuous tuning range (FTR), Q factor .

I. INTRODUCTION

Use of wireless communication systems has transformed our life style over the last few decades, and no mystery, with more advances in wireless communication system the next decade shall be revolutionary. Technologies such as 4G, 5G and IoT have already started impacting our life style through concepts of smart cities, smart grid systems and smart factories. Each wireless application demands different requirement based on the operational frequency, modulation schemes used, data rate, transmission bandwidth, power consumption and coverage area. A typical receiver in a wireless system is as shown below in Fig. 1.

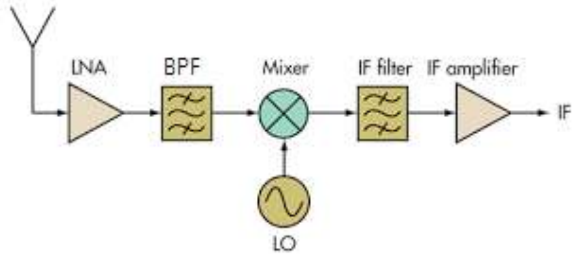


Fig.1. Typical block diagram of wireless receiver system

Design of all components becomes crucial for errorless and effective reception of the transmitted signal. The receiving antenna receives the signal while the low noise amplifier (LNA) amplifies the signal without amplifying the noise signal. The obvious application of the filter structure in such scenario is to reject the unwanted signal (the noise signal as well as the unwanted frequency signals) while permitting good transmission of wanted frequencies[1]. The most common filters deployed in various scenarios are low-pass, high-pass, band-pass or band-stop [2].

With rapid development in MMIC (Monolithic Microwave Integrated Circuits) and HIC (Hybrid Integrated Circuit technologies, development of filters having stringent specifications such as good counterfeit free response, fine/ ample bandwidth, good in band performance while maintaining compact size and low cost. Waveguide cavities have been used for the design of filters with good pass band and stop band roll off characteristics [2]-[5]. The requirement of high quality factor and low loss can be achieved by using substrate integrated waveguide (SIW) for design and development of high performance band-pass filters [7]-[8]. Dielectric resonator based filter offers advantages of compact size, high quality factor making it suitable candidate for propose and expansion of high performance RF/ Microwave filters [9]-[10]. Further development in filter microwave design based on concepts of single band-pass and differential band-pass filters has been illustrated in [11]-[12] using dielectric resonators. Micro-strip line based band-pass filters offer advantages such as light weight, compact, robust and conformal structure, low profile and easy integration with MMIC chips have been proposed in[13]-[14] as shown in fig.2.

(a) (b)

Fig. 2. a) Two pole dielectric resonator band-pass filter [11], b) Micro-strip line based band-pass filter [14].

The above mentioned filter designs have fixed characteristics such as band-pass frequencies and quality (Q) factor. However, modern communication systems demand filters to have variable characteristics so that the same filter structure can be used for various wireless applications. Reconfigurable filters have been grossing interest amongst researchers that can provide an effective solution to the demands of the next generation wireless technologies. In this paper a detailed literature review on recent developments in reconfigurable band-pass filters has been investigated.

II. CONTRIBUTIONS

The objective of this paper is to present the challenges in the design and analysis of band-pass filters specifically for next generation wireless applications and corresponding opportunities for innovative design solutions. The main contributions are as follows:

- Critical literature review for identifying current research developments inband-pass filter design.
- Identify gaps in research through detailed literature review and challenges in band-pass filter design for next generation wireless applications.
- Opportunities for RF engineers in developing innovative design solutions to meet specifications of band-pass filter.

III.RECONFIGURABLE BANDPASS FILTER DESIGN

As stated earlier, next generation wireless communication systems demand diversity in filter performance which can be achieved by using a reconfigurable filter. The term “reconfigurability” is defined as capability of filter to change its electrical characteristics (such as frequency, phase or Q-factor) by some means to accommodate the changing need of communication system. Traditional filter designed using waveguides, SIW and micro-strip line occupy more space on the circuit boards thereby demanding use of compact and high performance tuneable filters. To select a suitable reconfiguration technique RF engineers should take into consideration of following parameters: operating frequency, physical size, performance and power handling [15]. Reconfiguration in filter can be achieved by:

- Electrically using PIN diodes, RF diodes, MEMS switch or varactors.
- Optically using photoconductivity
- Physically using structure alteration
- Materially by changing substrate material or dielectric properties of materials (i.e., by using meta materials)

Most researchers have investigated tuneable band-pass and band-stop microwave filters using varactor diodes in [16]-[19] shown in fig.3. However, less investigation of low pass filter and high pass filter using varactor diode has been carried out due to it deficiency in practical realization of monolithic reconfigurable inductor solutions that increases design complexity for achieving good performance for the design. In general, researchers have devoted their research scope in designing reconfigurable band-pass and band-stop filters which frequency and bandwidth reconfigurable characteristics. Amongst most prominently used methods, λ/2 and λ/4 wavelength tuneable filters with varactor diodes and multi-mode filters have been commonly deployed due to its compact size and simplicity in tuning.

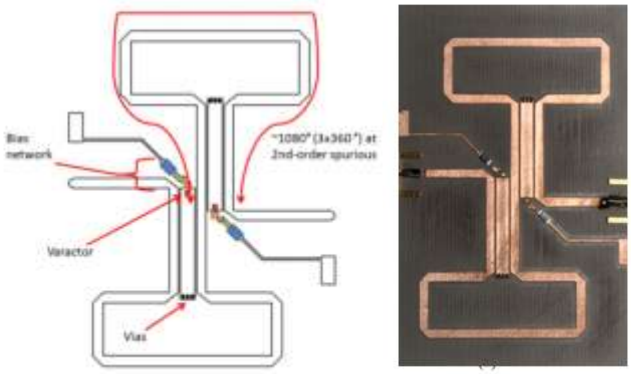
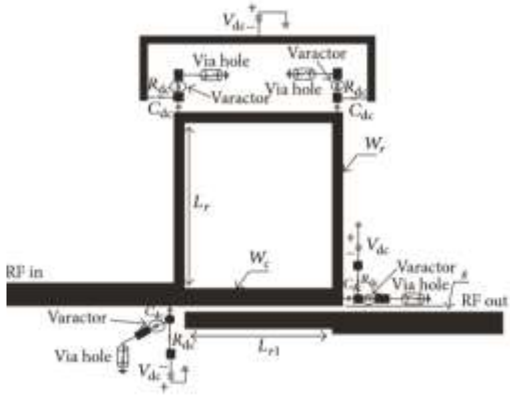
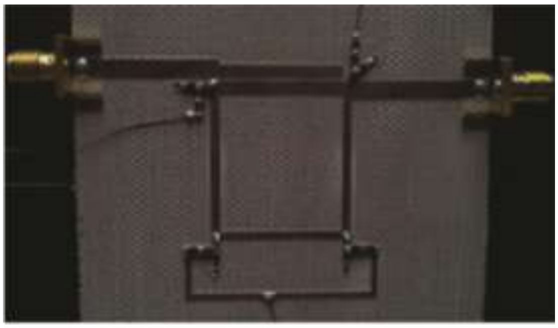


Fig. 3. Tunable band-pass filter using varactor diode [18]

The next generation wireless technologies such as 4G and 5G use carrier aggregation wherein several distinct RF carriers are allowed to be used in collaboration for the delivery and reception of data services. This method provides increased data rates in 4G and 5G technologies as compared to 3G. When several distinct RF carriers are used, a single band-pass filter or multi-mode band-pass filter cannot be deployed in this situation. Deploying several filters to filter each distinct frequency will utilize more space on the circuit board. Also increasing RF noise in communication systems is an alarming concern for RF engineers. A reconfigurable band-pass filter providing frequency reconfigurable characteristics over the desired frequency is a suitable solution for this scenario.
In Reference [20], a reconfigurable filter (tuned over 1.10GHzto1.38GHz) based on single-side-access topology is presented. The center frequency of the reconfigurable filter can be shifted at a desired frequency by changing the electrical length of the ring by using capacitive tuning elements have been investigated. A proper synthesis has been developed to determine the values of the capacitive elements. This synthesis can be extended further by researchers to develop reconfigurable filters of desired characteristics. Use of varactor diode to continuously tune the center frequency of the ring filter has been demonstrated as shown in fig.4.



(a)



(b)

Fig.4. A reconfigurable filter based on single-side-access topology presented in [20] a) Layout of the electronically reconfigurable ring band-pass filter using four Skyworks SMV 1800 varactors b) Fabricated prototype

In [21], a band-pass filter using tuneable active inductor (TAI) that provides wide frequency continuous tuning range (FTR) is presented. The proposed filter is realized using a differential TAI (DTAI) to provide coarse and fine tuning. The coarse tuning is achieved using a controllable current source while fine tuning is achieved through a variable feedback resistance. The band-pass filter is simulated using a 0.13µm CMOS technology and has an insertion loss of 23.62 to 33.45 dB over the tuneable frequency range of 1.16 – 3.27 GHz. The proposed band-pass filter has relative bandwidth of 1.3% - 3.4%.

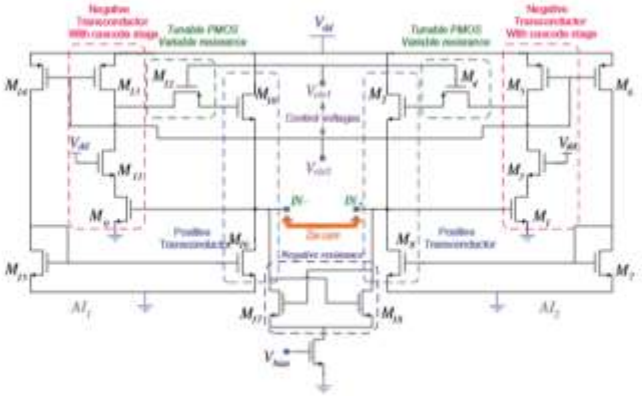


Fig. 5. Schematics of proposed differential TAI [21]

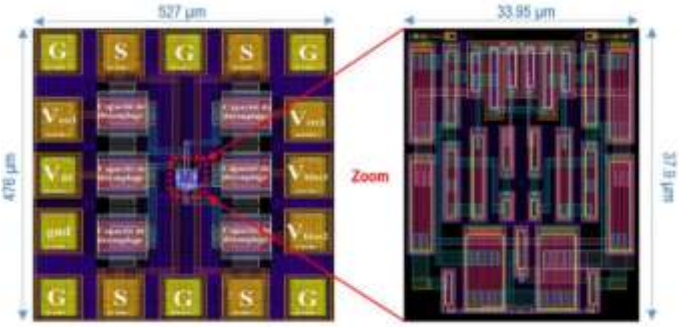
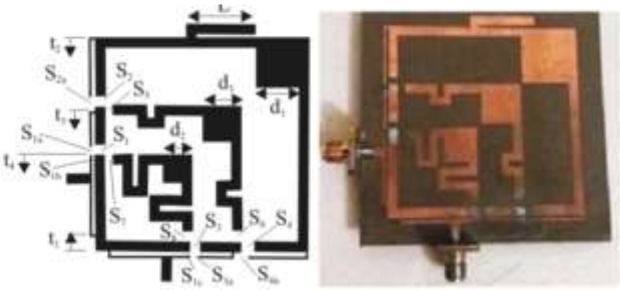
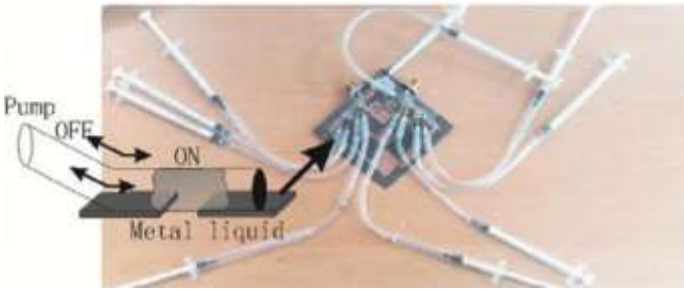


Fig.6. Layout of band-pass filter using tuneable active inductor (TAI)simulated using a 0.13µm CMOS technology [21]

In reference [22], a novel microfluidic based reconfigurable triple band filter operating over frequencies 1, 1.4 and 1.8 GHz has been investigated as shown in fig.7. The triple band filter based on dual mode ring resonators is reconfigured using metal-liquid switches for interconnecting different resonators and feed lines have been proposed. The metal liquid switches (metal liquid is forced in to active the switches) actives or deactivates the interconnection of resonators and feed lines thereby allowing tuning of center frequency of the filter as well as the external Quality (Q) factor.



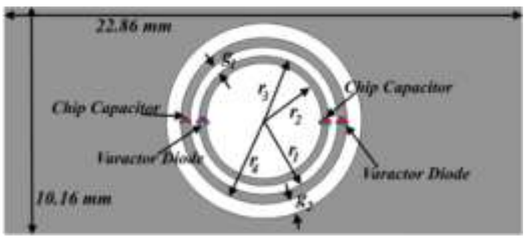
(a) (b)



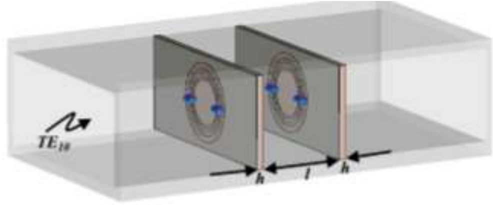
(c)

Fig. 7. A novel microfluidic based reconfigurable triple band filter [22]a) Proposed dual mode ring resonators configuration b) Fabricated prototype and c) Demonstration of use of metal liquid switches for achieving frequency reconfiguration

A dual mode dual band waveguide band-pass filter with tuneable over the frequency range from 8.12 - 8.58 GHz and 10.22 – 10.68 GHz is presented in [23] fig.8. Varactor diode and chip capacitor loaded planar split ring resonators in the form of filter are placed in a waveguide to provide the dual band operation. The proposed band-pass filter is compact, lightweight and provides dual mode, dual band frequency reconfigurable characteristics with insertion loss of 2.59 and 2.75dB, respectively.



(a)



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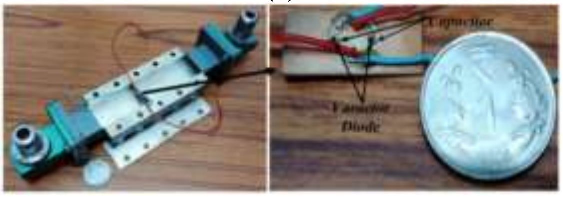

(c)

Fig. 8. Dual mode dual band waveguide band-pass filter [23] a) Proposed Varactor diode and chip capacitor loaded planar split ring resonators b) Placement of proposed ring resonator in waveguide c) Fabricated prototype with placement of ring resonator inside WR-90 waveguide.

In [24], a RF MEMS based electrically tunable waveguide filter with high Q and tuning characteristics is investigated for K band applications. High quality factor be achieved by using waveguide structures while high frequency tunability can be achieved by deploying radio frequency micro electromechanical systems (RF MEMS). In this paper, high frequency tunability of the order of 5% while Q factor of the order of 1000 can has been achieved using combination of waveguide and MEMS structures.

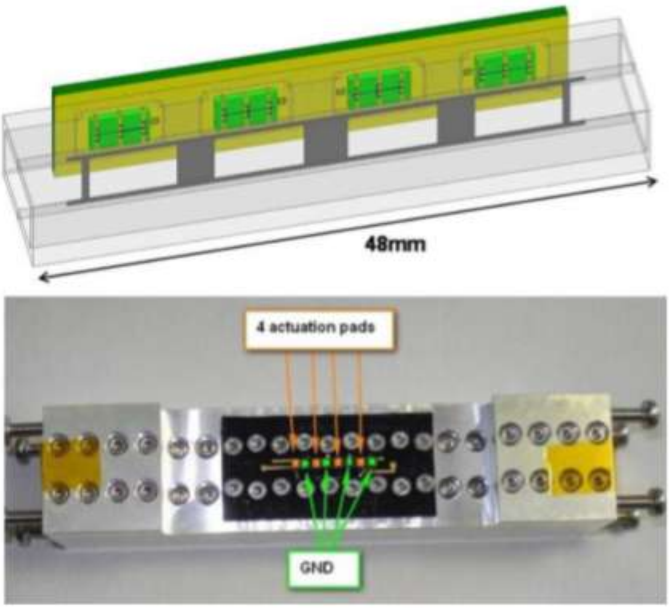

Fig. 9. HFSS simulation model and fabricated prototype of RF MEMS based electrically tunable waveguide filter [24]

So far electronically tunable reconfigurable filters have been investigated. Other techniques used to achieve reconfiguration consist of using optical switches. In reference [25], a UWB reconfigurable band-pass filter using optical switches has been investigated in [25]. A single optical switch activated using near infra-red light is deployed to select between either band-pass or band-stop response. When the optical switch is activated (in ON state) the filter circuit acts as a band-pass filter while in its deactivated state (OFF state) it acts as a band-stop filter.

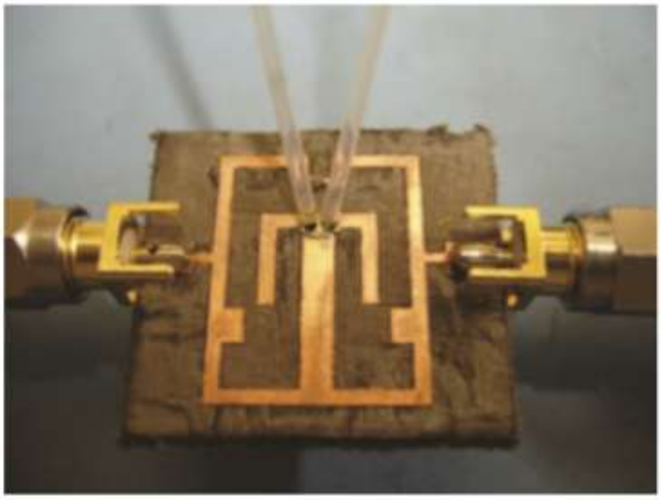

Fig.10. Fabricated prototype of optically reconfigurable Microstrip UWB Bandpass Filter [25]

IV.CHALLNEGES AND OPPORTUNITIES

a)Challenges: A critical literature review on recent advancements in design of reconfigurable band-pass filters has been presented in the previous section. Various methods to achieve reconfigurable characteristics using PIN diode, varactors, MEMS switches and optical switches have been investigated by researchers. While major focus of researchers is devoted in designing reconfigurable filter structures having less attention has been given to achieve other requirements of next generation wireless communication systems.

b) Opportunities: Meta materials exhibit numerous properties that have smooth path for innovative filter design solutions. The zero-index property of meta materials not only permits the development highly compact and efficient filters but also provides filters with reduced spurious radiation, high Q factor and low loss, thereby enhancing the performance in comparison to conventional material-loaded filters [26]-[27]. Using meta material in filter design can provide new innovative design solutions.

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