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Design of Microstrip Band-pass Filter from 2 GHz to 4.7 GHz for Biomedical Applications

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ABSTRACT

The paper's aim was to demonstrate the design methodology, fabrication of a genuine prototype, parameter analysis and measurement findings in comparison to modelling of a 5.8 GHz rectangular parallel linked microstrip patch antenna. The findings of the simulation research, practical measurement and antenna design calculations were given and contrasted. This study will be beneficial for producing a low-cost 5.8 GHz rectangular microstrip patch antenna and investigating the parameter studies. The shared knowledge was intended to make system features better. A significant part in wireless communication systems is played by band pass filters. It is necessary to filter sent and received signals at a specified frequency and bandwidth. In this study, Computer Simulation Technology (CST) was applied to build and simulate a microstrip parallel coupled-line band pass filter with a broad bandwidth of 1.25 GHz running at a centre frequency of 3.9 GHz. The suggested bandpass filter was set at 3.861 GHz by modifying the width between the linked lines, and at 3.926 GHz by adjusting the gap, with dimensions of 60 mm x 30 mm. The filter had a 1.25 GHz bandwidth with a -3 dB insertion loss, -17.3 dB return loss and a -2.2 dB bandwidth. The results addressed how the linked line's width and gap affect its centre frequency.

1. Introduction

In every microwave communication system, filters are crucial. Low-pass, high-pass and band-pass filters (BPFs) are only a few of the various types of filters that are employed in microwave systems. BPFs are the most commonly used filters in microwave systems and they should have excellent precision. They are employed in transmitters or receivers to filter out undesirable signals (frequencies). Numerous designs of a BPF have been developed as a result of the desire for a narrow bandwidth and low loss. Many factors should be taken into account while building a BPF, including

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bandwidth, low pass frequency, high frequency and centre operating frequency. As communication devices are getting smaller, there are additional design considerations because filters are also getting smaller.

Radio frequencies (RF) and microwave BPFs are essential parts used at the front end of transmitters and receivers in mobile and wireless communication systems [1]. Today's challenge is to construct compact BPFs with deep and severe rejection outside the pass band *via* the production of transmission zeros and attenuation poles in order to fulfil the requirements of current wireless communications [2]. Transmission line structures are frequently used to realise RF and microwave BPFs. The main benefit of traditional filters is their reduced need for space; nevertheless, a big component might actually take up room, therefore consideration should be given to the design of a compact size microstrip filter to facilitate simple installation [3,4]. BPFs are a crucial element that influence how well various communication systems work overall [5].

In mobile and satellite communications, metrology, radar electronic warfare and remote-sensing systems operate at microwave frequencies (1 GHz and above), microwave filters have two port elements (networks) that provide frequency selectivity [6,7]. Due to its ability to work across a broad frequency range, microstrip has gained a lot of praise in recent years for its usage in the design of integrated circuits and microwave components.

Additionally, because microstrip is simpler to manufacture, lighter, easier to integrate and less expensive, they may be readily included in communication systems or other systems of a similar kind for operation with other system components [8].

A nice place to start when designing a microstrip BPF with a low profile and tightened capacitive coupling is with a coupled-parallel line filter [9]. For narrow bands, these filters are simple to construct, but for wide bands, it becomes more difficult because additional parameters need to be taken into account. For Butterworth, Chebyshev and binomial [10], the needed design parameters of a BPF can be simply determined. The linked parallel line microstrip BPF is an excellent option to be appied if we operate at GHz frequencies.

The bandwidth of produced microstrip BPF is typically small. BPF however, have a number of drawbacks including the existence of erroneous bandpasses at the harmonics of the operating frequency. Despite that, the spurious bandpasses at the second resonant frequency of the microstrip-line resonator, frequently affects the performance of the microstrip BPF [11-13]. It worsens the upper stopband's performance. This issue arises because the even and odd mode propagation velocities in the heterogeneous dielectric media are unequal. The odd mode in a parallel-coupled microstrip line system moves more quickly than the even mode [14], hence its phase constant is smaller than that of the even mode. Consequently, the phase constant for the odd mode is smaller than that for the even mode. In addition for the odd mode, the electromagnetic energy concentrates along the metallic edges, whereas for the even mode it does so, near the central gap between the connected lines. Figure 1 depicts an example of a BPF.

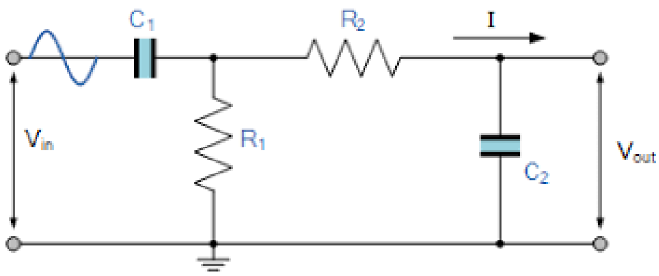

Fig. 1. An example of bandpass filter

2. Methodology
2.1 Design development

Due to its behaviour as a good resonator, a microstrip transmission line also known as a strip line, is now turned into a filter. In comparison to other types of filters, this micro strip line offers a better size and performance trade-off. In general, the procedures utilized in the production of printed circuit boards and microstrip circuits are fairly similar (PCB).

Its main benefit would be that it is mainly planar. The dielectric layer of thickness separates the broader ground plane from the conductive strip of width (W) and thickness (t) in the microstrip transmission lines (h) as in Figure 2.

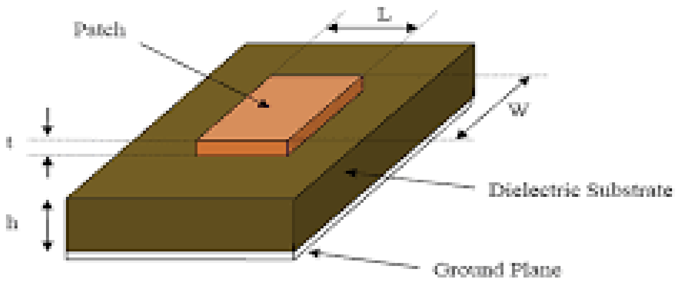

Fig. 2. Structure of a microstrip patch antenna

2.2 Antenna design

Step impedance, stub and linked line filters are components of a microstrip line filter [5]. Consider the parallel linked line BPF in Figure 3 below, where the half-wavelength line resonators are applied and are parallel to one another along their length. When compared to other filter configurations, this parallel coupled line structure with accepted resonator spacing resulted in a good coupling and offers the appropriate bandwidth [1]. The centre frequency of the bandpass response corresponds to the coupled line section for, which is equal to divided by two [5]. The width, gap, length and impedance are denoted as (W), (S), (l) and (Y0), respectively, in Figure 3.

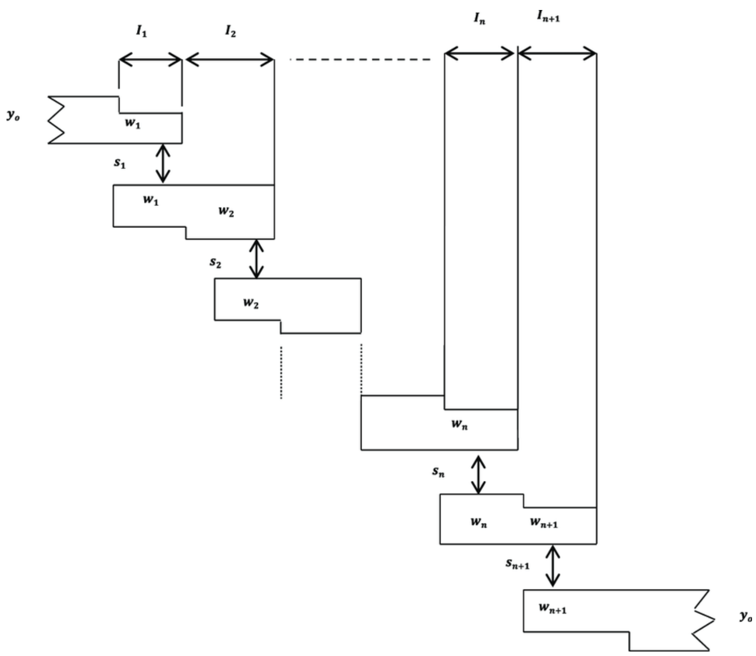

Fig. 3. General structure of parallel (edge)-coupled microstrip BPF

Based on the filter application in system design, the fractional bandwidth (FBW) is calculated using Eq. (1) below,

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \tag{1}$$

where, ω_1 and ω_2 denote the edges of the bandpass frequency. Then the odd and even resistance calculated by using Eq. (2), (3) and (4) [7] below:

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_0 g_1}} \tag{2}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2\sqrt{g_j g_{j+1}}} \tag{3}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}} \tag{4}$$

where, g_0, g_1 and $g_{(n+1)}$ are the elements of ladder type lowpass,

By using the J inverters obtained above, the even and odd type characteristic impedance of the coupled microstrip line resonators was identified by using Eq. (5) and (6) [7] below:

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \tag{5}$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \tag{6}$$

where Z_{0e} is an even characteristic impedance and Z_{0o} is odd characteristic impedance for j equals to 0 to n of elements. Prototype, $J_{(j,j+1)}$ are the characteristic admittances of J inverters and Y_0 are characteristic admittance of terminating lines.

3. Results and Discussion

The calculated both even and odd characteristic impedance is shown in Table 1 below where i represent the stage order. Start Line Calc in Agilent Technologies' Advanced Design System (ADS) software was used to determine each stage's width, spacing and length using even/odd characteristic impedance. The typical assumption for the characteristic impedance, Z_0 was 50 Ohms. Each stage length was a guided wavelength (g), even though it was 90 degrees longer electrically (Eeff). Table 2 displays the calculated width, gap and length of each stage. The list of parameters and specifications are presented as in Table 3 and 4, respectively.

Table 1
Dimensions of width, gap and length

Stage (i, i + 1)	Z_{0o} (Ω)	Z_{0e} (Ω)
0,1	38.95	71.90
1,2	45.87	54.94

Table 2
Calculated dimensions of width, gap and length

Stage	Width (W)	Gap (S)	Length (L)
0	2.71	-	6.42
1	2.30	0.48	6.63
2	2.63	2.64	5.75

Table 3
Parameter list

Name	Expression	Value
ch_part_cut_ang	= 30	30
ch_part_cut_len	= ch_part_len	2.59807621135332
ch_part_len	= 2.598076211353316	2.598076211353316
ch_part_wid	= parts_wid_2	1.5
gap_1	= 0.16	0.16
gap_2	= 0.29	0.29
gap_3	= 0.29	0.29
gap_4	= 0.16	0.16
ground_thickness	= 0.035	0.035
line_thickness	= 0.035	0.035
parts_len_1	= 20	20
parts_len_2	= 10	10
parts_wid_1	= 3	3
parts_wid_2	= 1.5	1.5
sub_len	= 60	60
sub_thickness	= 1.52	1.52
sub_wid	= 30	30

Table 4
Parameters and specifications

Parameters	Specifications
Frequency range	3.25-4.5 GHz
Center Frequency (Δf)	3.9 GHz
Bandwidth (BW)	1250 MHz
Insertion Loss (IL)	-2.2 dB
Return Loss (RL)	-17.3 dB
Impedance (Z_0)	49.8 Ω

3.1 CST design and simulation

The ground plane for the proposed linked line band pass filter is made of copper annealed, and the substrate is made of FR-4 lossy, which has a dielectric constant of 4.3 and a thickness of 1.52 mm. It is modelled using CST Studio Suite 2019 and has a rectangular shape with measurements of 60 mm x 30 mm. Figure 4 depicts the design from a viewpoint. It was decided to keep the distance between the linked lines on the port side constant throughout the design, and these distances are designated as g_1 and g_4, respectively. Throughout the design, the gaps g_2 and g_3 are likewise kept constant. To lessen filter waves, a 2.4 mm thin edge was added and blended at a 30 degree angle. The connected line's width and gap are parametrically examined in this research.

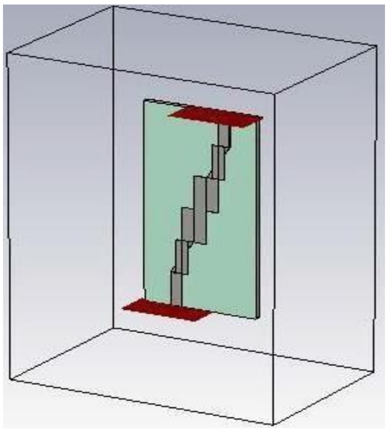

Fig. 4. Modeling of BPF on CST

Figure 5 illustrates the suggested design filter with all dimensions in millimetres and the angle measured in degrees. Figure 6 to 8 depicts the fabricated BPF in CST and its parts. The real fabricated design of BPF is shown in Figure 9. In Figure 10 and 11 however, it depicted the simulation results for S- and S1,2 parameters respectively using CST. Then, the 3D BPF design was shown in Figure 12, also using CST.

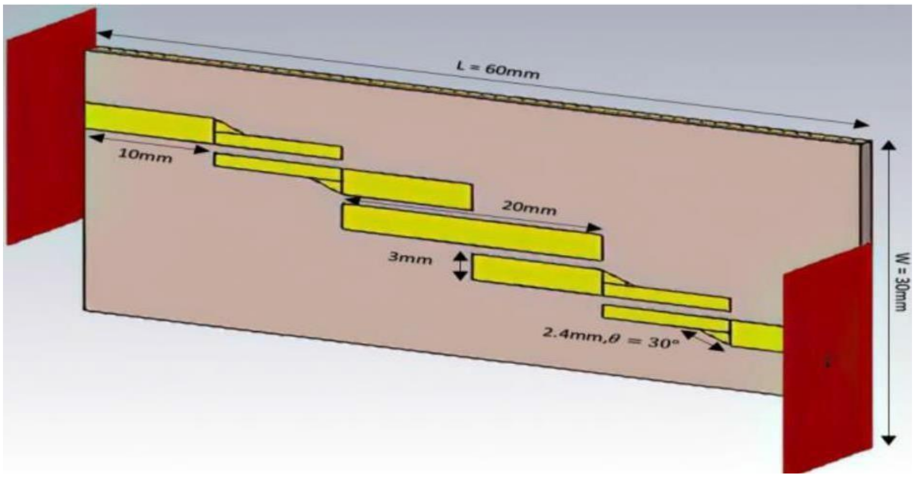

Fig. 5. Proposed BPF

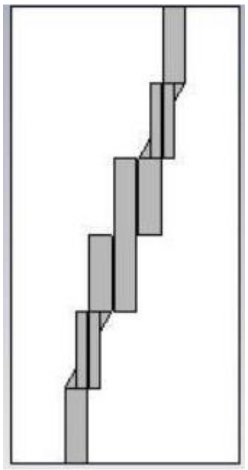

Fig. 6. The fabricated BPF in CST

Fig. 7. Fabrication part a

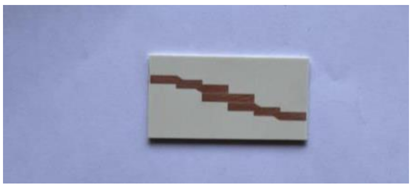

Fig. 8. Fabrication part b

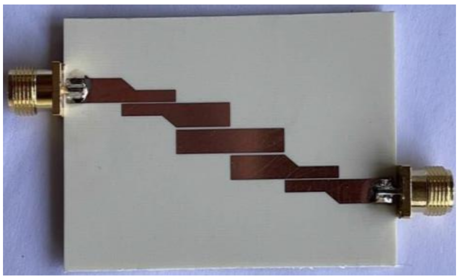

Fig. 9. Real fabricated design of BPF

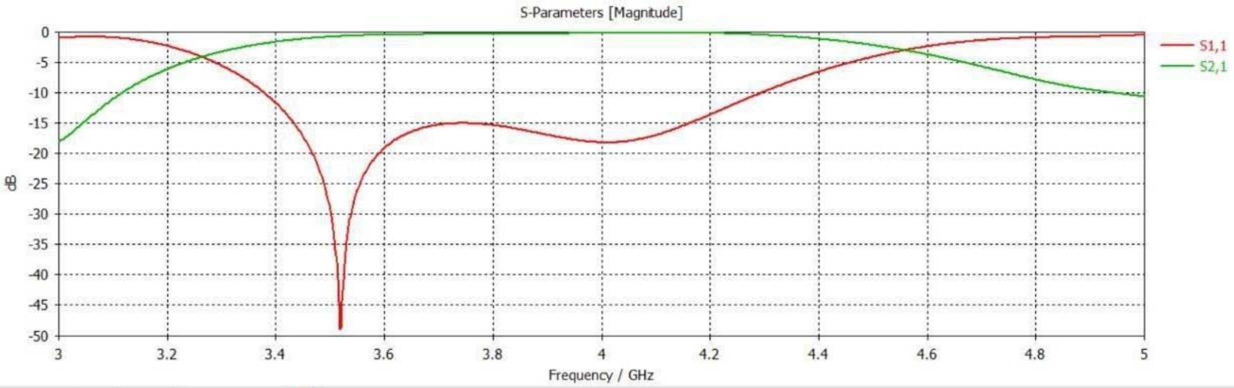

Fig. 10. Simulation results for S-Parameters using CST

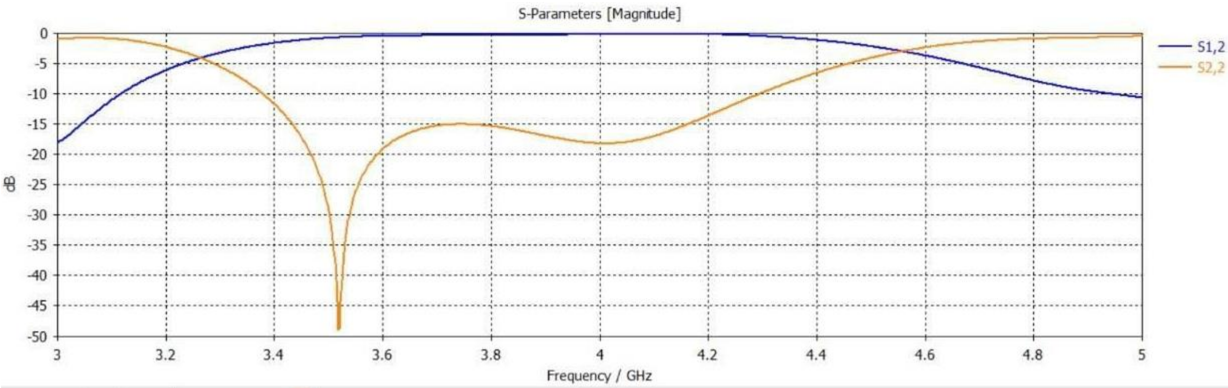

Fig. 11. Simulation results for S1,2 parameters using CST

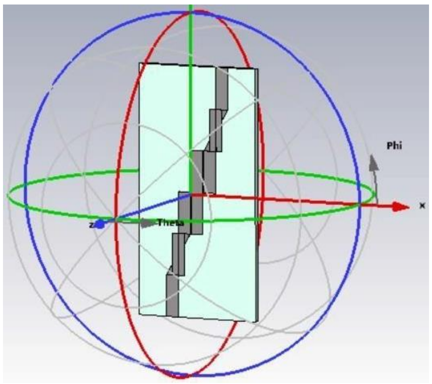

Fig. 12. 3D BPF design using CST

3.2 Applications

The increasing need for small, straightforward and effective transceivers continues to have an impact on radio frequency (RF) and microwave (MW) applications. Such devices must have planar antennas and filters since they significantly affect how well wireless communication networks function as a whole. In wireless systems of the present and the future such as green RF front ends and wideband applications, RF interference is a significant issue. Microstrip BPFs are widely used in a number of applications, especially in RF and MW wireless communications because of their efficacy in reducing interference and noise signals. The bulk of microstrip filter downsizing methods focus on identifying, managing or improving these characteristics. Several design techniques, including the combine, open-ring, coupled-line and stepped-impedance resonator (SIR), are introduced in the literature as well.

3.2.1 Biomedical applications

A microstrip BPF operating from 2 - 4.7 GHz, with a 1.8 V supply voltage and 180 nm CMOS, N-well technology; a BPF was utilized for a variety of biomedical applications, including EEG, ECG and EOG. This filter was simulated using Cadence Spectre simulator. The BPF was created with multiple bandwidth ranges for diverse biomedical device applications, according to simulation findings. Wearable sensors are frequently employed to track patients' medical and physical states and can give healthcare users quantifiable data.

Biosensors based on standard CMOS technology are often employed in biomedical applications. Commonly, the front-end stage is an amplifier. The bio-signal from the electrodes can be processed by the analogue front end (AFE), which can also increase the desired signal. Before the analogue to digital converter samples the signal, the required frequency is filtered out (ADC).

The input offsets off the signal by the amplifier in biomedical and communication applications must frequently be suppressed using a very low-frequency pole, which necessitates a large R-C time constant. Large resistors take up a lot of chip space and are typically difficult to manufacture. In order to replace extremely high resistances, a switched-capacitor approach was adopted that employed periodic switching of the connections of on-chip and small-valued capacitors. It may be created in such a way.

Table 5
Bio-signals and their corresponding frequency range

Signals	Frequency range (Hz)
Electroencephalogram (EEG)	0.1-100
Electrocardiogram (ECG)	0.01-300
Electrooculogram (EOG)	0.1-15
Electromyogram (EMG)	20-30000

4. Conclusion

Microstrip antennas have a wide range of uses, including for radar, power dividers, phase shifting, band passes and mobile and satellite communications. Additionally, demonstrating how to manufacture phase shifters, BPF and power dividers utilize CST MWS and microstrip antennas. The comparison of their results revealed that they are nearly identical. CST were used to create and simulate a parallel coupled line microstrip BPF by altering the coupled lines' width, gap and centre frequency. The frequency was 3.9 GHz. The filter was created and modelled. Utilizing FR-4 as the top layer and copper annealed as the ground plane the substrate, with an insertion loss of -2.2 dB and return loss of -17.3 dB at 1.25 GHz bandwidth. Using the results from the simulation, future research will consider a filter to be made, and additional tests will be conducted to be accomplished by modifying the filter's design parameters for industrial applications e.g. WiFi, WLAN and etc.

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