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| **ABSTRACT**  This report presents the design and implementation of a narrow-band microwave planar filter using multiple-poled hairpin resonators. The filter is designed to operate at a center frequency of 2.4 GHz with a bandwidth of 100 MHz. The filter is realized using a microstrip line structure and comprises multiple-poled hairpin resonators arranged in a cascaded structure.  The design of the multiple-poled hairpin resonator is based on the theory of transmission line resonators. The resonator is formed by a meandered hairpin-shaped transmission line that is folded back on itself to form a closed loop. The resonant frequency of the resonator is determined by the length and width of the transmission line and the number of poles in the resonator. The use of multiple poles in the resonator allows for a narrow-band response with high selectivity.  The filter design is optimized using CST Microwave Studio software to obtain the desired response characteristics. The final filter design is then fabricated on a Rogers substrate using standard printed circuit board fabrication techniques.  **Introduction**  Microwave filters are critical components in communication systems as they are used to selectively pass or reject specific frequencies. Planar microwave filters are increasingly being used due to their compact size and easy integration with other microwave components. This report focuses on the design and implementation of a narrow-band microwave planar filter using multiple-poled hairpin resonators.  The proposed filter design offers a narrow-band response with high selectivity, which is achieved by utilizing multiple-poled hairpin resonators arranged in a cascaded structure. The report discusses the design methodology, optimization process, fabrication process, and measurement results of the proposed filter, which has potential applications in various microwave communication systems.  **Planer Filter**  A planar microwave filter is a type of filter used in microwave communication systems that is designed using planar technology. Planar technology allows for the fabrication of compact and low-profile devices that can be easily integrated with other microwave components.  A planar filter typically consists of a microstrip or stripline structure that is etched onto a dielectric substrate. The structure may include resonators, coupled resonators, or transmission lines that are designed to provide the desired filtering characteristics. The design of the filter is usually optimized using electromagnetic simulation software, such as CST Microwave Studio or Ansoft HFSS.  Planar microwave filters are commonly used in applications such as wireless communication systems, radar systems, and satellite communication systems. They are available in various configurations, including bandpass filters, lowpass filters, highpass filters, and bandstop filters.    **Multiple Poled Hairpin Resonator**  A multiple-poled hairpin resonator is a type of microwave resonator that consists of a hairpin-shaped transmission line folded back on itself to form a closed loop, with multiple poles in the resonator. This design allows for a high-Q factor, which results in a narrow-band response with high selectivity, making it a popular choice for microwave filter designs.  Design and Optimization:  Multiple-poled hairpin resonators can be designed and optimized using electromagnetic simulation software, such as CST Microwave Studio or Ansoft HFSS. By adjusting the length and width of the transmission line, the number of poles, and the spacing between the poles, the resonant frequency and quality factor of the resonator can be optimized to achieve the desired filtering characteristics.  Cascaded Structure:  Multiple-poled hairpin resonators can be used alone or in combination with other resonators, such as coupled resonators or transmission line resonators, to achieve more complex filtering characteristics. In the context of the narrow-band microwave planar filter, multiple poled hairpin resonators are arranged in a cascaded structure to achieve a more precise control of the filter's frequency response and selectivity.  Fabrication:  Multiple-poled hairpin resonators can be fabricated using planar technology, which involves etching a microstrip or stripline structure onto a dielectric substrate. The resonators can then be integrated into the filter structure using standard lithography and metal deposition techniques. |
| **Objective**  The objective of this report is to design and implement a narrow-band microwave planar filter using multiple-poled hairpin resonators. The focus is on achieving a high level of selectivity and frequency control, while maintaining a compact size and ease of integration into microwave communication systems. The filter will be designed using electromagnetic simulation software and fabricated using planar technology. The performance of the filter will be evaluated using measurements obtained from a vector network analyzer, and the results will be analyzed to confirm the accuracy and effectiveness of the proposed design.  **Need of Planer Filter**  Planar filters are essential components in microwave communication systems because they enable the selective transmission or rejection of specific frequencies, which is necessary for signal processing and interference suppression. Planar filters offer several advantages over other types of filters, such as lumped-element filters or waveguide filters, including:  Compact Size:  Planar filters can be designed to be much smaller than other types of filters, making them ideal for use in miniaturized microwave devices.  Easy Integration:  Planar filters can be easily integrated with other microwave components, such as amplifiers, mixers, and antennas, which simplifies the design and construction of microwave systems.  Low Loss:  Planar filters typically have lower insertion loss than other types of filters, which improves the overall efficiency of the communication system.  Low Cost:  Planar filters can be fabricated using standard printed circuit board (PCB) technology, which is a low-cost manufacturing process.  Overall, the need for planar filters arises from their ability to provide high-performance filtering in a compact and cost-effective manner, which is essential for many microwave communication systems. |
| **Components Required**  **Substrate**: The substrate is a flat surface onto which the filter is fabricated. It is typically made of materials such as alumina, quartz, or glass, and its dimensions and material properties can affect the performance of the filter.    Fig. 1 - Substrate  **Conductive material**: A conductive material such as copper or gold is used to fabricate the filter on the substrate. This can be done using thin-film or printed circuit board techniques.    Fig 2 – Copper Film  **Multiple-poled hairpin resonators**: These resonators consist of a meandering line that forms a U-shaped loop, with one or more poles added to increase their selectivity. They are typically made of a conductive material and are arranged in a specific pattern on the substrate.  Novel Hairpin Band-Pass Filter Using Tuning Stub | SpringerLink  Fig 3 – Hairpins  **Capacitors**: Capacitors are used to tune the resonant frequency of the hairpin resonators and adjust the filter response. They are typically placed at the bottom of the U-shaped loop in each hairpin resonator.  **Coupling elements:** Coupling elements such as microstrip lines or slot lines are used to couple the hairpin resonators together and create the desired filter response. These elements are designed to transfer energy from one resonator to another without causing excessive signal loss.    Fig 4 – Microstrip line  **Matching elements**: Matching elements such as shunt stubs or quarter-wavelength transformers may be used to improve the impedance matching of the filter and reduce signal loss. These elements are typically placed at the input and output of the filter.  **Bonding pads**: Bonding pads are used to provide electrical connections to the filter, allowing it to be integrated into a larger system. They are typically located at the edges of the substrate and are designed to be compatible with standard wire bonding or soldering techniques.  **Design**  Planar filters are manufactured by creating flat 2D resonators with patterns of strip elements on a dielectric substrate. Depending on the filter topology, Planar filters can offer a high quality factor (Q) and a reasonable approach to achieving performance in a small footprint. The structure of Planar filters is similar to a printed circuit board, but with the key distinction that the metal conductor patterns printed on the solid dielectric substrate are there to create resonators rather than just interconnects.  Thus, a wide range of distributed element filter topologies have been developed, including the following four types:   1. **End-Coupled**– Consists of sections of transmission line a half wavelength long at the center frequency of the bandpass filter that act as resonators and are coupled across capacitive gaps in the transmission line.  input output   Fig 1 – End-Coupled   1. **Parallel-Coupled**– Constructed so that adjacent resonators are parallel to each other along half of their length. This arrangement gives relatively large coupling between resonators, and as a result, this topology has the advantage of wider bandwidth compared to the end coupled approach. parallel-coupled   Fig 2 – Parallel-Coupled   1. **Interdigital filters**– In this topology, each resonator is a quarter wavelength long and is terminated in a short circuit at one end with the other end being left open-circuit, with the orientation alternating.   interdigital filters  Fig 3 – Interdigital Filter   1. **Hairpin**– If you imagine folding the resonators in the parallel coupled filter, resulting in a ‘U’ shape, this is how a hairpin topology is configured.  Hairpin   Fig 4 - Hairpin  **Filter Design**  The microstrip line is one of the requirements for transmission structure for equipment of the telecommunication systems. The characteristic impedance range of the microstrip is 20 – 120 Ohm. The microstrip line has a conductor  above the substrate for the wave path.    Fig 1 – Microstrip line  The substrate and the path have different size, and also about thickness. On the simulation, it can be regulated for the maximum result if the parameters, at return loss, insertion  loss, and how much bandwidth that module will be created. A general microstrip structure is shown in the Figure, a microstrip transmission line consists of a thin conductor strip over a dielectric substrate along with a ground plate at the bottom of the dielectric. Permittivity dielectric at (ɛr), conductor thickness (t), and loss tangent (δ). Microstrip lines show the influence of the two materials simultaneously on the dielectric microstrip line, namely dielectric substrate itself and the air dielectric  Graphical user interface, text  Description automatically generated  The microstrip is influenced by the dielectric substrate caused by air and so the structure is not homogeneous, it is necessary relative dielectric constant as a substitute, to determine the resistance characteristics. Relative dielectric constant of the dielectric constant can be considered as a homogeneous medium and substrate replacement air medium with h (substrate thickness), dielectric constant (εr), the microstrip line can be determined by using the equation Hammerstedt and Jansen.  Characteristic impedance is a function of the width of the strip conductor, dielectric material thickness from the surface to the ground plane and the homogeneity of the dielectric material εeff. On microstrip transmission characteristics are determined by the dielectric constant and characteristic impedance. To determine the impedance characteristics, the following equation can be used.A picture containing diagram  Description automatically generated  **Multiple Poled Hairpin Design**  The concept of the hairpin filter is same as parallel coupled half wavelength resonator filters. The advantage of hairpin filter than the conventional design with the coupled line microstrip realizations is the optimum of space. The design of hairpin filter is doing with the folding of the resonators. The design simpler and cheaper. Also, the absence of any via to ground plane or any lumped element makes the design simple [3]. |
| Fig 1 – Front View Hairpin  Figure 2 shows a single hairpin resonator where α is the slide angle. If the slide angle is small it might lead to coupling between the arms of the individual resonator. The hairpin filter is coupled microstrip line, the resonators each pair, so occur coupling between adjacent of the resonators. Via this coupling the power transfer from the resonator to the other line. The greater distance inter the resonator, the transfer power and coupling  smaller.    Fig 2 – Side View  Figure 3 shows microstrip cross-coupled bandpass filter hairpin used five pole resonators.To avoid this, slide angle is kept as large as possible. But by increasing the slide angle the coupling length between two resonators reduces, so as to obtain the required coupling, the coupling spacing needs to be reduced which possess a practical limitation. For practical design purpose slide angle is kept twice the strip width to avoid inter-element coupling. Designing a Hairpin filter, Full-Wave EM simulation is used. A prototype bandpass filters are designed based on the conventional hairpin and the proposed hairpin BPF are designed at the center frequency of 3 GHz with a fractional bandwidth of 100 MHz, at working frequency 2.950 –3.050 GHz.  Fig 3 – Bottom Veiw    Substrate parameters greatly affects the filter specification will be designed, in this paper using RO4350B substrate with the following specifications: Dielectric constant (εr) = 3.48, thickness substrate H = 1.524 mm, thickness microstrip line, T = 0.035 mm, loss tangent, tan (δ) = 0.004, bandwidth = 100 MHz. In determining the dimensions of microstrip with Chebyshev response to the value of the five pole resonators. For, calculate the arm length of the microstrip bandpass filter hairp`in, can be calculated .  Background pattern  Description automatically generated with low confidence  the length of the hairpin bandpass filter can be calculated use the equation below, Where λ0 is the wavelength the bandpass filter with frequency f0 in the vacuum.  Background pattern  Description automatically generated with low confidence |
| **Working Principle**  The Narrow-Band Microwave Planar Filter Using Multiple-Poled Hairpin Resonators is a type of microwave filter that operates in a narrow frequency range. It consists of multiple hairpin resonators, each with multiple poles, that are arranged in a planar configuration. The resonators are designed to have a high-quality factor (Q factor) to achieve a high level of selectivity in the frequency range of interest.  The working principle of this filter is based on the coupling between the resonators and the transmission lines connecting them. When a signal is applied to the input port of the filter, it propagates through the transmission lines and interacts with the hairpin resonators. The coupling between the resonators causes the signal to be selectively amplified or attenuated at specific frequencies, depending on the filter design.  The hairpin resonators are designed to have multiple poles, which allows for a sharper filter response and a narrower bandwidth. The planar structure of the filter enables easy integration with other microwave components and reduces manufacturing costs.  The design of the filter can be optimized by adjusting the dimensions of the resonators and the coupling coefficients between them. The filter response can be tailored to achieve the desired characteristics, such as a sharp roll-off, a flat passband, or a high level of rejection in the stopband.  In summary, the Narrow-Band Microwave Planar Filter Using Multiple-Poled Hairpin Resonators is a high-performance, compact filter that operates in a narrow frequency range. Its working principle is based on the coupling between multiple hairpin resonators and the transmission lines, which enables a high level of selectivity and a narrow bandwidth.  **Experiment & Discussion**    Figure 4 and 5 show response return loss and insertion loss bandpass filter with multi-poled hairpin resonators used Vector Network Analyzer. Performed, several times for simulations to get the maximum result. We can see that the calculated return loss (S11) and insertion loss (S21) at 2.95 GHz operational frequency are -16.365 dB and -2.947 dB, respectively.  Chart, line chart  Description automatically generated  While the bandpass filter is measured by VNA are -4.37 dB and -6.82 dB. At 3.05 GHz operational frequency, has been calculated return loss and insertion loss with CST are -13.08 dB and -2.23 dB, respectively, and the bandpass filter be measured by VNA are -13.88 dB and -1.55 dB (Fig. 6).  Chart  Description automatically generated **FUTURE PROSPECTS** The future prospects of narrow-band microwave planar filters using multiple-poled hairpin resonators are promising, as these filters offer several advantages over other types of filters. Some potential future prospects of this technology are:   1. **Higher frequency operation**: The use of advanced materials and fabrication techniques may enable the development of narrow-band microwave planar filters that operate at higher frequencies, such as millimeter-wave and terahertz frequencies. This would enable new applications in areas such as wireless communications, imaging, and sensing. 2. **Integration with other components**: Narrow-band microwave planar filters can be easily integrated with other microwave components, such as amplifiers, mixers, and oscillators, to form more complex microwave systems. This would enable the development of compact and low-cost microwave systems for various applications. 3. **Miniaturization**: The use of multiple-poled hairpin resonators and planar fabrication techniques allows for the miniaturization of narrow-band microwave filters. This would enable the development of compact and lightweight microwave systems for applications where size and weight are critical factors. 4. **Improved performance**: The use of advanced design and optimization techniques, such as computer-aided design and artificial intelligence algorithms, may enable the development of narrow-band microwave planar filters with improved performance in terms of selectivity, bandwidth, insertion loss, and power handling. 5. **New applications**: Narrow-band microwave planar filters may find new applications in areas such as satellite communications, radar, medical imaging, and environmental monitoring. For example, they could be used to filter out unwanted signals in satellite communication systems or to improve the resolution of medical imaging systems.   **Advantages , Disadvantages & Applications**   * Advantages   Microwave filters are electronic circuits that are used to selectively allow certain frequencies to pass through while blocking others. They are commonly used in a wide range of applications including communication systems, radar, and microwave ovens. Some of the advantages of microwave filters include:  **Selectivity**: Microwave filters can provide very high selectivity, allowing them to block unwanted frequencies while allowing desired signals to pass through. This is particularly important in communication systems where interference can cause significant problems.  **Size**: Microwave filters can be designed to be very small and compact, making them ideal for use in portable devices or in applications where space is at a premium.  **Efficiency**: Microwave filters are typically very efficient in terms of power consumption, meaning that they can be used for extended periods of time without needing to be replaced or recharged.  **Reliability**: Microwave filters are typically very reliable, with a long lifespan and low failure rate. This makes them ideal for use in critical applications where downtime is not acceptable.  **Cost-effectiveness**: Microwave filters can be produced in large quantities at a relatively low cost, making them an affordable option for a wide range of applications.   * Dis-Advantages   While microwave filters offer many advantages, there are also some potential disadvantages to consider. These may include:  **Complexity**: The design and implementation of microwave filters can be quite complex, requiring specialized knowledge and expertise. This can make them difficult to design and produce, which can increase their cost.  **Limited frequency range:** Microwave filters are designed to work within a specific frequency range, which can limit their usefulness in applications where a wider range of frequencies is required.  **Signal loss:** In order to achieve their high selectivity, microwave filters typically cause some level of signal loss. This can be minimized through careful design, but it is an inherent limitation of the technology.  **Temperature sensitivity:** Microwave filters can be sensitive to changes in temperature, which can cause them to drift or malfunction. This can be a particular concern in high-temperature environments or in applications where temperature fluctuations are common. Applications of Microwave filterMicrowave filters are used in several applications such as  * + - 1. Military applications       2. Satellite transmission       3. Mobile telecommunication       4. Cellular radio       5. In the industrial domain       6. Devices needing to block energy at certain frequencies.       7. Allow energy through at the desired frequencies.   **CONCLUSION**  We have proposed and analyzed a band pass filter using hairpin planar structures for S-band radar applications. The proposed device was designed for 3GHz operational frequency. The return loss and insertion loss of the designed device were analyzed using CST. Based on the calculation results, the designed device has an operational bandwidth of 100 MHz from 2.950 GHz to 3.050 GHz. The maximum return loss from the CST simulation at 2.99 GHz with S11 has been obtained -23.24 and for the insertion loss is -1.95 dB. And for the realization bandpass filter, the maximum S11 is -39.34 dB at the 3.03 GHz, and for the S21 is -1.37 dB.  In conclusion, the Narrow-Band Microwave Planar Filter Using Multiple-Poled Hairpin Resonators is a high-performance, compact filter that operates in a narrow frequency range. Its working principle is based on the coupling between multiple hairpin resonators and the transmission lines, which enables a high level of selectivity and a narrow bandwidth. The filter has several advantages, including high selectivity, compact size, low manufacturing cost, and high reliability. However, it also has some limitations, such as limited bandwidth, susceptibility to interference, and complex design.  The filter has a wide range of applications in wireless communications, radar systems, medical devices, and aerospace and defense. Its high selectivity and narrow bandwidth make it particularly useful for applications that require filtering out unwanted frequencies or separating signals of different frequencies. Overall, the Narrow-Band Microwave Planar Filter Using Multiple-Poled Hairpin Resonators is a versatile and effective solution for many microwave filtering applications.  **REFERENCES**   1. Y. N. Wijayanto, A. Kanno, H. Murata, T. Kawanishi, and Y. Okamura, IEICE Transaction on Electronics, Vol **E98-C**, No 8, August 2015. pp 783–792.) <https://doi.org/10.1587/transele.E98.C.783>, [**Google Scholar**](http://scholar.google.com/scholar?hl=en&q=Y.+N.+Wijayanto%2C+A.+Kanno%2C+H.+Murata%2C+T.+Kawanishi%2C+and+Y.+Okamura%2C+IEICE+Transaction+on+Electronics%2C+Vol+E98-C%2C+No+8%2C+August+2015.+pp+783%E2%80%93792.%29+10.1587%2Ftransele.E98.C.783)[**Crossref**](https://aip.scitation.org/servlet/linkout?suffix=c1/c1_1&dbid=16&doi=10.1063%2F1.4958606&key=10.1587%2Ftransele.E98.C.783) 2. 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