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STATE OF ART ON MICROSTRIP RESONATORS, FILTERS, DIPLEXERS AND TRIPLEXERS

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Abstract

In today's world, communication is essential for various aspects of life. From military operations and medical systems to community networks, communication plays a crucial role in ensuring the smooth functioning of these applications. With the advancement of technology, communication has become more efficient and has significantly reduced the barriers of distance, bringing people and nations closer together. One of the key components of modern communication systems is microstrip devices. These devices are used in a wide range of applications, including filters, diplexers, and triplexers. Filters are used to selectively allow certain frequencies to pass through while blocking others, making them essential for signal processing and interference reduction in communication systems. Diplexers and triplexers are used to combine or separate multiple signals, allowing for more efficient use of the available frequency spectrum. This article aims to provide an overview of the state-of-the-art microstrip devices used in communication systems. It will review previous studies and advancements in the field, providing insights into the latest developments and technologies. By understanding the current state of research and development in microstrip devices, engineers and researchers can gain valuable knowledge to improve the performance and efficiency of communication systems. Furthermore, the article will explore the potential applications of microstrip devices in various communication systems, such as satellite communications, wireless networks, and radar systems. Understanding the capabilities and limitations of these devices will be crucial for *optimizing their performance in different scenarios. Overall, this article will serve as a comprehensive resource for anyone interested in the role of microstrip devices in communication systems. Delving into the scope of filters, diplexers, and triplexers, will provide valuable insights into the advancements and potential future developments in this important area of technology.*

Keywords: Microstrip, Bandpass Filter, Diplexer, Triplexer

I. Introduction

Modern communication systems rely heavily on microwave filters, which allow for frequency selectivity in radar, mobile communications, satellites, and other forms of modern communication. Two common types of microwave filters used to combine signals of different frequencies are diplexers and multiplexers. A multiplexer is a passive multiport device that consists of a series of filters joined at a common junction. A multiplexer's principal function is to merge or divide signals across different frequency bands. Essentially, multiplexers are passive multiport devices that consist of a common junction, a string of filters, and one or more input/output pairs. A multiplexer's principal function is to merge or divide signals across different frequency bands. The first one is the most basic type of multiplexer. A diplexer is a device that uses communication channels to combine two separate filters into one. It has recently become quite popular in wireless communication systems such as cellular networks, broadband wireless, satellite, and radio. Microwave diplexers allow two transmitters to use a single antenna with minimal signal interference, as an example.

Having just one antenna reduces the overall size and weight of a gadget. Diplexers and multiplexers have both seen significant technological advancements thanks to the expansion and improvement of standards. A diplexer allows two antennas to share a single port while using distinct frequencies [XXV], [X], [XLVI]. A variety of applications, including transceivers, automobile radars, and imaging systems, have made use of millimeter-wave devices, thanks to the appealing characteristics of millimeter-wave frequency ranges. These features are characterized by improved spatial resolution, quicker data rates, less spectrum congestion, and secure channels [I]. Multiplexers are commonly used in the RF front ends of both transmitters and receivers. Microstrip quadruplexes, microstrip diplexers, and microstrip triplexers are all examples of planar microstrip multiplexers that are becoming more popular due to their tiny size, low integration cost, and great applicability [XVI]. An essential component of the diplexer, the filter has the ability to alter the incoming and outgoing signals, eliminate undesired ones, and reduce interference. This means that the filter of the diplexer greatly affects the overall communication setup's efficiency [XXV]. There are a lot of papers on multiband filters, although most of them focus on creating multiband bandpass filters. Multiband lowpass-bandpass filters are necessary for certain applications, such as mixers, to isolate DC, IF, and other important frequencies. This helps to simplify the system and improve its reliability [I]. Additionally, diplexers are utilized in communication systems to either combine or split signals with distinct fundamental frequencies. For clarity, the diplexer separates the signals from the two frequency bands, applies a filter to them, and then recombines them into one channel while preventing crosstalk. Two independent channel filters plus a common input make form the diplexer. By joining the two-channel filters' shared input, a three-port circuit is created. The antenna, transmission, and reception ports make up a diplexer's three terminals. A diplexer uses two filters to separate the transmission and reception signals. Because they function on two frequency ranges, diplexers are used to split the signals that are transmitted and received [XXV], [XXXV]. Wireless communication technologies such as LTE, Bluetooth, Wi-Fi, and WiMAX require transceivers that can handle many bands or modes. Using multiplexers is essential for building multiband transceivers [I]. Broadband wireless Internet, mobile phone networks, radio waves, and technologies based on satellites all come under this umbrella. By utilizing many ports on the same network, signals of varying frequencies can be mixed or separated. Some examples of communication systems that rely on the microwave switch are switched beam-forming arrays, multi-in, time-division multiplexing, multi-out, and many more [XXVIII]. To improve the electrical performance of a microwave system, filtering structures are frequently cascaded with transmission lines. This tactic worked well for prehistoric primitive forms of communication. But, to handle the ever-expanding spectrum environment and the ever-increasing range of communication modalities, contemporary communication systems have increased both the quantity and complexity of microwave front-end components. Over time, the shortcomings of conventional design approaches, such as oversized circuits, high impedance matching losses, and astronomical production costs, have been more and more exposed [XXVIII]. Wide passbands, small size, good isolation, and low insertion loss are desirable qualities of multiplexers, which are necessary for the development of multi-band wireless communication systems, which is something that many people are interested in. More efficient multiplexers are in high demand. Consequently, multiplexer research and development has been introduced in a plethora of published articles. One common component of multiplexers is the stepped impedance resonator, or SIR [II]. Modern communication networks and testing equipment often use planar and nonplanar diplexers as an initial step in the signal processing chain to divide a broadband input signal into two independent subbands. A diplexer, which allows a single antenna to function as both a transmitter and receiver, is another viable alternative. Another benefit of diplexers is that they reduce the quantity of radio frequency components needed for subchannels when only one receiving mode is involved. Diplexers are often made with a combination of band-pass filters or two low-pass and high-pass filters. Circulators, E-and-H-plane power dividers, Y-junctions, and T-junctions make up the bulk of these filters' combining circuits. Because of their numerous benefits, including their small size, easy manufacture, and integration possibilities, microstrip planar diplexers have been the subject of intense research in the last several years [II]. Different types of diplexers were introduced according to the channels they used: Several studies have made available diplexers with six, four, two, or eight channels [XVI]. In state-of-the-art multi-channel communication systems, multiplexers and diplexers, two varieties of multi-channel microstrip devices, are highly sought after. Overused frequency ranges have had their unwanted communications filtered out using them. Among the many types of multiplexers, triplexers have the unique ability to toggle between three distinct signals. Due to their compact size and high efficiency, microstrip triplexers have lately risen in popularity as a component for mobile and multichannel wireless systems [VIII]. To separate useful signals from overlapping ones and eliminate background noise, microstrip triplexers have become standard equipment in modern communication networks. Therefore, it is important to minimise physical dimensions and insertion losses while designing a high-performance microstrip triplexer [XXV]. Triplexers typically include multiple resonators and an input junction matching portion. When resonators are utilized to block out unused channels, the matching network guarantees strong input matching and great port-to-port isolation [XI]. Triplexers have shown to be a dependable substitute for improving triband communication networks. A common design element of triplexers is a combination of bandpass filters and matching circuits, which allows them to isolate the output from any other operating bands and maintain strong matching within each band [XV]. This allows them to produce band pass output at three separate frequencies.

II. Microstrip Filter

You can see the microstrip layout in Figure (1). A ground (conducting) plane is located at the substrate's base, and a conducting strip with dimensions (t) and (W) is located on top of the dielectric [XXV], [II].

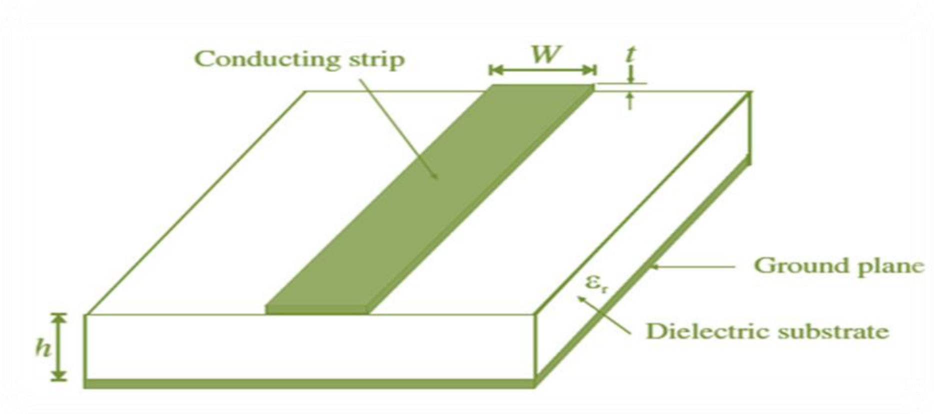

Fig. 1. Microstrip structure [XXV]**.**

Resistance (R), shunt conductance (G), inductance (L), and capacitance (C) are lumped elements that must be evenly distributed along the full length of the transmission line, as shown in Figure (2) [XXV], [II].

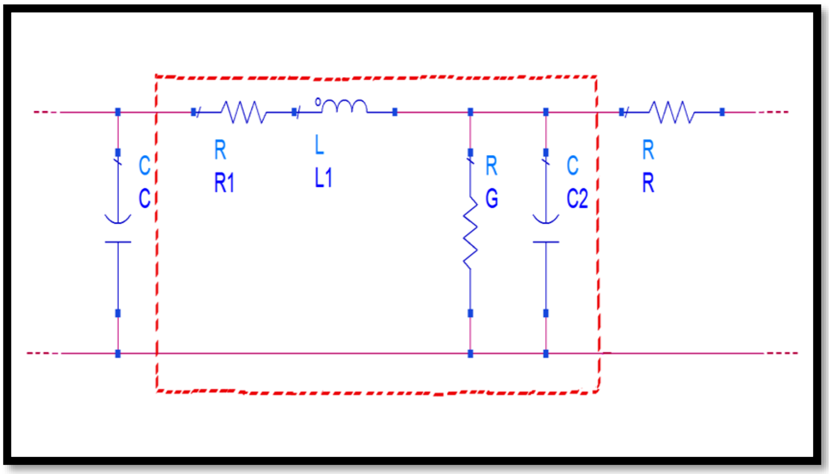

Fig. 2. C, L, R, and G are elements of the transmission line.

III. Microstrip Resonators

In a filter design, microstrip components can be either lumped (like inductors and capacitors) or quasi-lumped (like stubs and short line segments). As a general rule, distributed elements like half-wave and quarter-wavelength line resonators are employed. When deciding on a component type, quality considerations (allowed losses), fabrication techniques, operating frequencies, and power management, it is crucial to select the correct filter [XXV], [II].

From lumped to quasi-lumped to patch to distributed-line resonators, microstrip resonators come in a variety of shapes and sizes.

Resonators with lumped or quasi-lumped capacitors and inductors that exhibit both shapes are theoretically feasible. At higher frequencies, these components are rendered useless. It is useful to be able to make microstrip structures immediately from equivalent circuits that use inductors and capacitors.

"Distributed resonators" are resonators where the electric and magnetic fields are spread out throughout the resonant part of the building. A microstrip line section is the most basic type of distributed microstrip resonator.

When the guided wavelength at frequency zero is g0, we say that the resonator has a quarter-wavelength dispersed line. If you want a different kind of resonator—say, a series LC resonator—you can always use an open-circuit or short-circuit variant of this device. The g0-g2 resonator is another resonator that can be used to construct microstrip filters. Radiation losses, conductor losses, and dielectric dissipation losses are the primary problems with scattered line resonators.

Distributed line resonators also come in ring form. A simple transmission line generates the resonator within a specific frequency range. Accordingly, the electrical length at resonance frequency determines whether the resonator's circular path forms a standing wave pattern.

Patch resonators have recently risen to prominence in the field of microstrip filter design due to their superior power handling capacity and reduced conductor losses compared to conventional microstrip line resonators. Some examples of patch resonators' shapes are triangles and circles, which are chosen according to their intended use. A sample of each of these is shown in Figure 3.

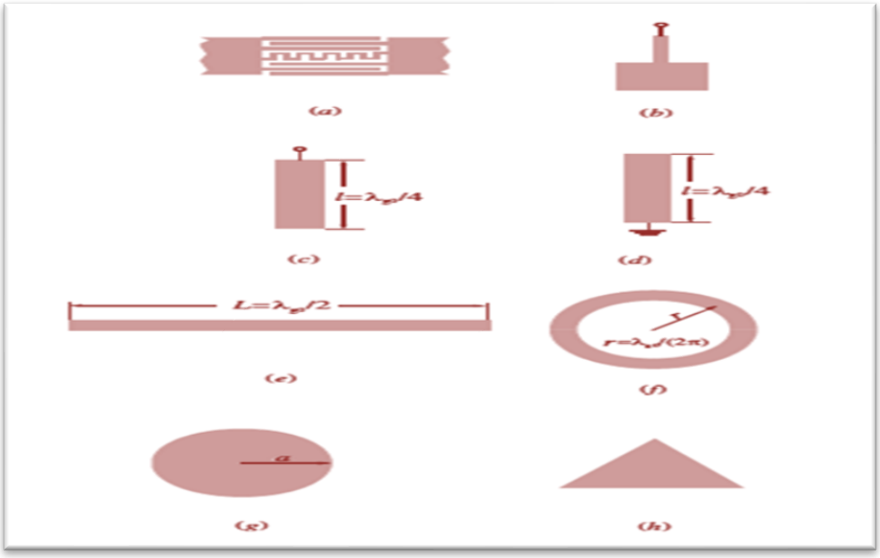

Fig. 3. Several structures for microstrip resonators

IV. Transmission Line Resonator and SIR

TEM mode transmission line resonators, such as coaxial, strip, and microstrip resonators, are used in transmission lines. The dielectric substrate material for the Uniform Impedance Resonator (UIR) must have high permittivity, low loss tangent, and temperature stabilization. UIRs are widely used due to their basic form and ease of use. To avoid spurious responses at integer multiples of the critical frequency, capacitance loads can be added to the open terminals of the resonator. At extremely high frequencies, there are fewer spurious frequencies to deal with, and they are shifted from multiple integers of the fundamental frequency. The structure difference of a $\lambda_{g0}/2$ resonator is depicted in Figure 4. The capacitor-loaded UIR has an electrical length of $2\theta_1$ and a characteristic impedance of Z_1. The loading capacitance for this resonator can be determined based on the half-wavelength UIR [XXV].

$$C = Y_1 \tan\theta_2/\omega_0 \tag{1}$$

where

$$\theta_2 = \pi/4 - \theta_1,\ Y_1 = 1/Z_1 \tag{2}$$

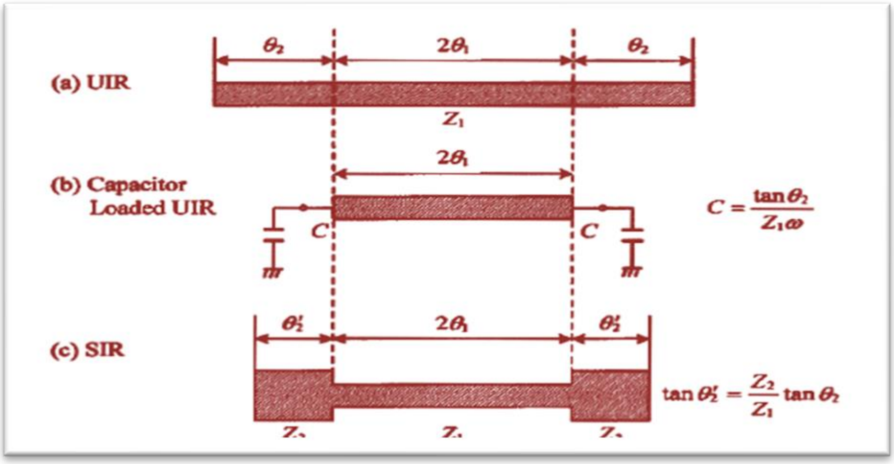

Fig. 4. Structure variation of a half-wavelength resonator. (a) UIR. (b) Capacitor loaded UIR. (c) SIR.

As shown in Figure (4b), capacitors are used in place of the transmission line components with electrical lengths of θ_2 according to Figure (4a). The compactness and ability to eliminate spurious response are two advantages of a capacitor-loaded UIR.

It is challenging to stratify the capacitance-loaded UIR because the lumped-element capacitance experiences a noticeable rise in capacitor loss as the resonant frequency approaches 1 GHz. Consequently, tweaking the frequency is necessary in this case.

To compensate for the loaded capacitance, an open-circuit transmission line can be employed. Additionally, it is not always necessary to construct a transmission line with a characteristic impedance at Z 1. As shown in Figure (4 c), a characteristic impedance that was at $Z_2 = (1/Y_2)$. When $Y_2 \tan\theta_2^{`} = Y_1 \tan\theta_2$. Every component has the potential to resonate at the same frequency. Then, $\theta_2<\theta_1$ if Z_2 is smaller than Z_1. This allows for a shorter resonator. To showcase other characteristics, like a small variation in resonance frequency and low-loss characteristics, UIR's design eliminates capacitors. This gadget eliminates the shortcomings that were previously mentioned by utilizing a capacitance-loaded design (4 b). Figure (4 c) shows that the characteristic impedance of the SIRs varies significantly from one another [XXV].

V. SIR Structure

Figure 5 displays SIR, TEM, or quasi-TEM components with two or more varying characteristic impedances. Figures (5 a, b, and c) show examples of a λg⁄4, λg⁄2, and λg-type resonator, respectively, illustrating the structural changes in the stripline arrangement. Based on the TEM/semi-TEM mode resonance condition, additional transmission-line structures, such as coplanar and coaxial-line, are tolerated, in addition to the illustrated stripline shape. Due to the open-ended nature of the λg⁄2-type SIR as shown in Figure (5 b), short-circuited structures have also been made available [XXV], [II].

Characteristic impedances for SIR components are denoted by Z1 and Z2, while the electrical lengths of transmission lines between the short and open-circuited ends are denoted by θ1 and θ2, as shown in Figure (5).

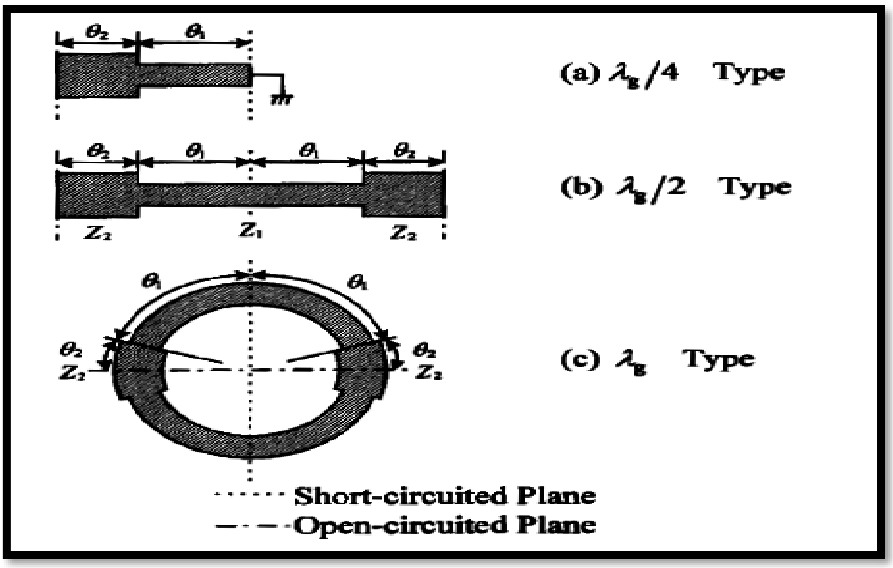

Fig. 5. A structure for basic SIR. (a) 1/4 wavelength $(\lambda_g/4)$. (b) 1/2 wavelength$(\lambda_g/2)$. (c) Unitary wavelength (λ_g).

The weighty parameter about the properties of SIR is indicated by R_z which is the transmission line impedance Z_2 and Z_1 ratio as follows [XXV]:

$$R_z = Z_2/ Z_1 \qquad \text{Impedance ratio} \qquad (3)$$

VI. Diplexers

Wireless communication systems have been introduced, and they have made significant progress during the last years, been rapidly developed, wireless internet, such as Wi-Fi and WiMAX, mobile wireless communication systems, and 3G, 4G, and 5G innovations have also been developed. As a result of these fast advancements, more robust radio frequency components were needed. At this point, satellite systems have shifted their focus away from static communications and toward remote sensing, navigation implementations, and mobile applications [XXV], [XXVIII]. As most communication systems demand lightweight, low-cost, high reliability, and higher frequency electronics, diplexer has become a core component in many communication systems. As seen in (Figure 6), the application of diplexer technology is quite commonplace in radio base stations as well as radio devices.

To allow for the use of a single antenna in the broadcast and receive paths of two distinct frequency bands, a diplexer is equipped with three ports. In fact, can be described as a device that has three ports, which are used to combine two networks into a single, shared port [I]. Therefore, the diplexer is less expensive than other devices that connect through separate channels [XXVIII].

The diplexer can be used as a transmitter or receiver, and it also features an antenna port [II]. In addition, it consists of a power divider as well as two filters meeting standard standards for selectivity and isolation. Both filters are coupled to their respective ports; one at the transmitter's end and the other at the receiver's. The antenna and the two filters are linked via the third port [XVI]. Filters have to have a small insertion loss and a significant return loss for robust impedance matching of high-frequency selectivity and connector components. This is necessary to prevent interference. If the filter has a high-frequency selectivity, then it can be established that the guard band between each channel is low, which determines that the frequency can be used effectively[VIII]. In recent years, designers have been working with a variety of various topologies in an effort to develop microstrip diplexers for use in contemporary microwave transceivers [XXV].

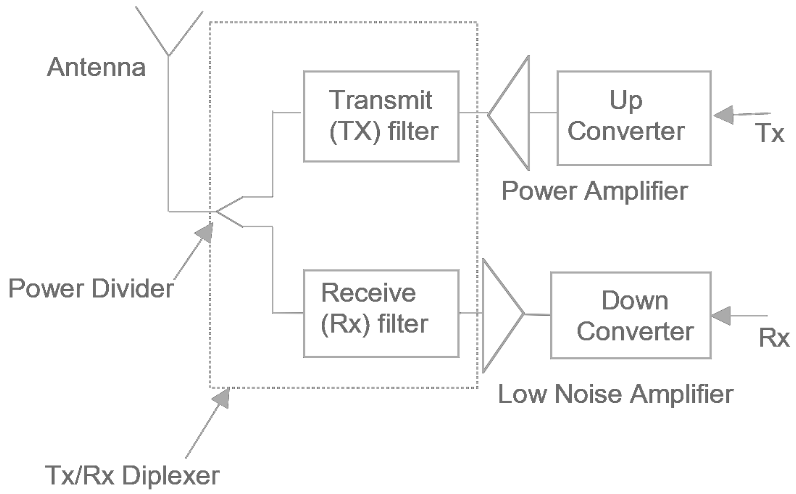

Fig. 6. Utilization of Diplexer Technology in Base Stations.

Diplexers have a wide range of applications in modern communication systems, including:

1. Wavelength Division Multiplexing (WDM) Systems: Diplexers are used to combine or separate multiple optical signals at different wavelengths, allowing for the transmission of multiple data streams over a single optical fiber.

2. Fiber to the Home (FTTH) Networks: Diplexers are used to separate upstream and downstream signals in FTTH networks, enabling bidirectional communication over a single fiber.

3. Optical Networking Equipment: Diplexers are used in optical networking equipment such as transceivers, switches, and routers to enable the transmission and reception of multiple signals over a single optical path.

4. Telecommunication Systems: Diplexers are used in telecommunication systems to combine or separate different frequency bands for voice, data, and video transmission.

5. Satellite Communication Systems: Diplexers are used in satellite communication systems to combine or separate different frequency bands for uplink and downlink signals as in Figure 7.

Overall, diplexers play a critical role in enabling the efficient transmission and reception of multiple signals in various communication systems.

Fig. 7. Diplexer Switch Satellite+ Cable TV Antenna HD DTV Digital Combiner FTA

A diplexer with two channels and separate bandpass filters (BPFs) was suggested in the paper [V]. The BPF of both channels is generated on a via-free composite right/left-handed transmission line using a newly proposed CMOS-based right-angled corner-modified split ring resonator (RAC-MSRR). A tiny, low-insertion-loss microstrip diplexer with high isolation (BPFs) is constructed by combining two connected line bandpass filters in the article [XXXVIII]. An additional 'zero' in the lower BPF transmission can be achieved by tuning a coupling capacitance in the higher channel. Using a stub-loaded square ring resonator, a compact wide-band diplexer (SLSRR) was introduced in paper [XXV]. An SLSRR's passband bandwidth and center frequency are both adjustable by simple changes to the stub length. In the first transmission route, a 50% FBW covering the frequency range of 3.23 to 3.38 GHz is used. At its core, the channel operates at 4.3 GHz.The second channel averages 2.3 dB insertion loss and has an FBW of 51.4%. A novel diplexer capable of switching between frequencies of 1.8 and 2.4 gigahertz is proposed in the article [XXIX]. It is compact, has a simple architecture based on linked microstrip lines, and has minimal insertion loss. Using a pair of matching stubs and a series of connected lines, channel-selecting filters, and T-junctions are not necessary. The development of a circuit prototype and its subsequent testing have been completed. Every single one of the measurements lines up perfectly with the forecasted outcomes. A proposed switchable filtering diplexer that makes use of a repurposed resonator is detailed in the paper [XLI]. In contrast to the previously reported state-of-the-art, the manufactured device not only achieves a reduced size but also a lower insertion loss. The occupied area measures 12 * 20 mmm. By adjusting the bias state of the diode, the resonant frequency of the switchable resonator can be altered. There is no longer any requirement for an external matching circuit thanks to a diplexer that was built and proposed in the paper [XLIII]. With the help of the impedance transformations offered by the J-inverters and the allocation of TZs at the opposite channel's center frequency, excellent passband selectivity and great isolation are achieved. Through testing, it was shown that diplexers A and B possess isolation properties above 40 dB. An alternate method for creating a small, high-rejection diplexer using hybrid resonator (HR) bandpass filters was suggested in the paper [XXXIX]. Less space is needed in the RF module's shielding box for the proposed HR because it only requires two lines. Its good selectivity, great isolation, and ease of integration with preexisting planar printed circuits make it an attractive option.

A tunable TZ-based technique that permits both high signal isolation and a wide stopband is proposed in the article [XXII]. To minimize the size of a dual-mode resonator and its associated harmonics, a high selectivity microstrip diplexer with a stepped-impedance opened-end construction is employed. For top-notch signal isolation in the 1.95 GHz and 2.14 GHz upper- and lower-stopband regions, transmission zero control and even-odd mode are employed. In their publication [XL], the researchers describe the construction of a new type of microstrip diplexer that is both electrically small and has excellent isolation. Radio occultation has been widely used for planetary atmosphere analysis. With a balanced design that incorporates two intrinsic filters, numerous gearbox zeroes are possible, leading to a small stopband and good port isolation. The distance is more than 27 dB at both frequencies. The article [XIV] suggests a small and straightforward lowpass/dual-band-bandpass filter design that lets the transmission zero, center frequency, and 3-dB bandwidth be fine-tuned. The article [XIV] offers some advice on how to construct a novel small lowpass and dual-band bandpass filter out of metamaterials by utilizing a folded coupled line and an open-ended L-shaped stub. There aren't many designs out there that can provide two separate filtering responses. By connecting two unit cells with a strip, a different bandpass response was achieved. A physical component of the specified filter structure can be adjusted individually to alter the position of TZs frequencies and 3-dB bandwidth characteristics. According to the proposal in [VI], a microstrip diplexer with two adjacent channels at 1.67 GHz and 1.88 GHz is possible. By connecting two open-loop meandrous resonators with spiral cells, the suggested diplexer's construction can be put to use. It was from an LC model that the new resonator was conceived. Even though the bandwidth is somewhat small, the insertion loss in the first band is just 0.43 dB, and in the second band, it's only 0.35 dB. Since its 1.67 GHz and 1.88 GHz channels are quite near together, it finds usage in FDD systems and GSM applications. A small diplexer filter with low-pass (LP) and bandpass (BP) functions that exhibit the required response characteristics has been designed, produced, and studied in detail in reference [XXXIV], [XLIX]. A main resonator and a suppressor resonator are the two primary components of an LP filter. In terms of bandwidth, the computed BP filter excels at 0.2

GHz with a center frequency of 2.42 GHz, a smaller stopband bandwidth of 4.68 GHz, and a bigger bandwidth of 7.35 GHz. This long-awaited LP/BP filter has finally been constructed and evaluated, and the results from both the simulations and the physical construction are in excellent agreement. The design, manufacturing, and evaluation of an LP/BP diplexer with the necessary responses are detailed in [XXVI]. This diplexer consists of an LP filter and a BP filter. Confirming the computed bandwidth of 0.2 GHz for the BP filter centered at 2.42 GHz, the measured bandwidths of the lower stopband (2 GHz) and upper bandwidth (4.68 GHz) are in agreement. The proposed low-pass filter makes use of a primary resonator and a single-resonator suppressor design. The frequency at which 3 decibels of gain are no longer present is 1.46 GHz, while the transition band is 0.29 GHz. The microstrip diplexer validated by measurements from Rohde & Schwarz, the ZVL20 Network Analyzer, was suggested in [III] as having low insertion loss, high selectivity, and outstanding isolation. Good insertion losses of around 1.6 dB and 1.3 dB for the two channels are provided by the structure, which has fractional bandwidths of 2.8% and 3.2%, respectively. The researchers have suggested a high-isolation diplexer with a wide stopband in the publication [XLII]. To begin, we need to create a composite resonator with an isolation level of 40 dB. Second, the device's common port can be used to construct a lowpass filter (LPF) by providing a broad passband. A switchable response diplexer is built by lastly including PIN diodes in the circuit. All areas have a suppression level above 20 dB. A highly effective microstrip diplexer has been developed and built as described in the paper [XXXVII]. For 5G communications below 6 GHz and Wi-Fi communications at 5 GHz, it runs at 3.5 GHz. Both channels have insertion losses of 0.5 dB, which is much lower than the competition. We highly recommend this structure for fifth-generation applications and wireless communications. The authors of this paper [XVIII] offer a simple approach to microstrip diplexer design. The square open-loop resonators are the band-pass filters upon which the microstrip diplexer is built. Radio Frequency Identification systems are perfect for these filters because of the 2.45 GHz frequency they use. The results show that the diplexer provides minimal insertion loss, great isolation, and outstanding selectivity despite its small size. The researchers define diplexers, three-port dual-filter circuits that enable two independent frequency channels to use an antenna simultaneously, in paper [XXXI]. But this technology can work with many transmitters on separate bands, so long as the signals sent and received are inside their respective frequencies. The use of SIR in conjunction with UIR makes fractal filters possible while drastically reducing the complexity of both modelling and manufacturing. Diplexers, triplexers, and quadruplex components can make use of kappa substrate due to its extremely low loss tangent value. In their investigation, the researchers [XIII] suggested a small structure with almost no insertion loss when the system is in operation. The Ansoff HFSS, a dedicated programme for modeling three-dimensional electrodynamic processes, was used to conduct all of the experiments. In the diplexer, you'll find two filters that operate at separate frequencies. The experiments showed that the first usable band was at 358 MHz and the second at 680 MHz. On paper, a dual-channel miniature microstrip diplexer has been developed [XVII]. There is just one junction between the two bandpass filters, which operate on separate frequency bands. The following components are essential to every BPF: a feed line for input and output, a resonator with meandering lines, a resonator with step impedance, and a resonator with uniform impedance. The filter is equipped with three feed lines, SIR and UIR elements, and a meandering line resonator. Here in [VII], we see a high-performance microstrip diplexer that makes use of linked triangle microstrip cells. It is completely compatible with L-band networks using frequencies of 1 GHz and 1.3 GHz. There is an improvement of over 0.21 dB in the channels' insertion losses and over 25 dB in their return losses. With 40 dB of channel isolation, this device is top-notch. One more perk of this diplexer is the 40 dB of channel isolation it provides. In the article [XLVIII], an ADS simulator is used to study and propose a dual-channel diplexer that uses connected open-loop microstrip resonators. The device's insertion loss values at the first load are (1.8 dB) and the second load is (1.0 dB), according to the simulation results. About 35 dB-isolated channel bands were created using microstrip open-loop resonators and source-load coupling lines. To accommodate cellular system frequencies ranging from 900 to 1800 MHz, a planar diplexer was developed in [XLV]. The researchers were able to decrease the footprint of hairpin resonators by 40% compared to their unloaded counterparts by adding external capacitors. Because the resonators take up less room in this arrangement, the researchers can potentially free up 40% of their present area. The configuration outperformed its predecessor in terms of port isolation, channel isolation, and stopband rejection. In reference [XXIV], a diplexer was introduced that makes use of a common stub-loaded resonator SIR to manage several TZs. To make the separation of the two channels more distinct and selective, several TZs are made. As examples, we show the design, construction, and testing of a device that can operate at 2.22 and 2.95 GHz. It possesses qualities such as total isolation, great selectivity, and low loss. The diplexer described in the literature [XXIV] contains two tri-band bandpass filters (BPFs), two feeding lines fashioned like hooks, and two meander transmission lines. The design of the BPFs is based on SLSIRs or tub-loaded stepped-impedance resonators. The first load uses two meander networks at 1.46/1.74/2.96 GHz, whereas the second load uses 0.89 / 2.40/3.15/4.40 GHz. Experimental and computational findings bolster the suggested diplexer. A diplexer, which integrates two separate filter types into one, was suggested in [XXXIII]. These filters were designed using microstrip line coupling techniques. The 3.5 GHz band filter made use of a folded coupled line resonator, whilst the 2.3 GHz band filter employed a coupled open loop ring resonator. Table 1 clarifies the difference between diplexer and duplexer.

Table 1: The Difference Between Diplexer and Duplexer.

Diplexer	Duplexer
Diplexer is a 3-port RF device that offers two signal pathways to be used on the same antenna or transmission line.	3-port RF device, splits antenna signals into two channels based on direction.
The diplexer works well with large frequency ranges.	The frequency bands will possess very nearer frequency bands.

Used in telecommunications, where various modulation schemes and carriers share the same antenna.	A duplexer can be used in radar and radio communication systems where the high-power transmitter signals need to be isolated but operate on the same antenna.

VII. The Standards of WLAN Systems

A wireless local area network (WLAN) connects multiple devices in a single, enclosed location, such as a house, office, or school, through the use of wireless distribution. Users can only take advantage of this if they are physically within the designated coverage area. Current WLANs are based on the IEEE 802.11 standards, which were created by the Institute of Electrical and Electronics Engineers. "Wi-Fi" is the most common name for these standards as in Table 2.

Using the 5, 3.6, 2.4, and 60 GHz frequency bands, the Physical Layer and Media Access Control protocols of IEEE 802.11 allow for WLAN communication. All told, these bands span 80 GHz. As far as the IEEE 802 standards are concerned, their development and upkeep. Given that the standard has been around since 1997, with several revisions following its first introduction.

For their half-duplex through-the-air broadcasts, all modulation schemes in the IEEE 802.11 family employ the same protocol. Standardization began with the IEEE 802.11-1997 standards, but it wasn't until the 802.11 b specification came out that the technology took off. Table 1 provides an overview of the IEEE 802.11 standard family.

Table 2 : The Family of IEEE 802.11 Standards Is Presented.

Electrical and Electronics Engineers (IEEE) 802.11	Frequency (F)	Max Speed (MS)	Compatible
802.11-(a)	5 Gigahertz	54 Mbit /s	Non
802.11-(b)	2.4 Gigahertz	11 Mbit /s	Non
802.11-(g)	2.4 Gigahertz	54 Mbit /s	802.11-(b)
802.11-(n)	2.4 Gigahertz, 5 Gigahertz	600 Mbit /s	802.11-(a/b/g)
802.11-(ac)	5 Gigahertz	1.3 Gbit /s	802.11-(b/g/n)

VIII. Triplexer

A sample of a triplexer is shown in Figure 8 to help clarify the idea. The paper [VIII] lays out the steps used to design and test a new planar four-port microstrip triplexer that can operate at 1.5, 2.5, and 3.35 GHz. Spiral arrangements of small patch cells are part of the suggested layout. Measured insertion losses are greater than 0.7 dB, but simulated losses are less than 0.4 dB. A groundbreaking new triplexer design is suggested for usage in the article [XLIV] using suspended line technology integrated into the substrate. The 0.8 GHz, 2.5 GHz, and 5.8 GHz channels of the triplexer each have low insertion losses of 1.4 dB, and the three ports are well-isolated from one another. Incorporating a T-junction into the triplexer allows for a separation of more than 35 dB between the high-pass filter (HPF) and the two low-pass filters (LPFs). The suggested idea is further enhanced by employing a suspended, patterned substrate to decrease loss. In [XXV], the authors suggest a microstrip triplexer for use in WiMAX and other wireless networks. With a measured g at 2.3 GHz, the new 3.2-3.6 GHz resonator is 0.35 g0.26 g in size. In addition to that, insertion losses of 0.78 dB, 1.1 dB, and 0.62 dB were detected. To adjust the resonance frequencies, they used a newly created LC equivalent model of the resonator. For usage in multi-band wireless transceivers, the article [XV] details the construction of a compact inline triplexer. There is just one feeding line and three bandpass filters interdigitalized. Each band pass filter has a transmission zero in each of the other working bands to ensure optimum segregation. This is a prototype triplexer that has been tested and works at 2.3GHz, 3.4GHz, and 5.6GHz. The findings from the full-wave electromagnetic modelling match the data quite well. In their study [XXXII], the researchers introduced a triplexer that utilizes E-stub-loaded composite right-/left-handed (ESL-CRLH) resonators in conjunction with a quasi-lumped impedance matching network. The triplexer's three filter channels—at 1.86, 2.41, and 3.25 GHz—have minimal in-band insertion losses and great port-to-port isolation. Modern multi-standard communication systems can legitimately use it. An eight-state lowpass-bandpass triplexer integrated switch with two BPCs and one LPC that may be toggled on and off is suggested by the authors of [XXVIII]. A combination of the lowpass transformation method with the conventional theory of coupled-resonator filter design yields an optimal set of parameters that are then used in the LPC design. Because the proposed architectures permit lower sizes and higher frequencies, modern integrated circuit design can benefit from their portability. To link the three resonant modes of the open stub DSLR, the even-and-odd-mode method was employed. The triplexer, which is ideal for mobile communication applications, consists of three sets of hairpin resonators connected to the DSLR resonator at 1.8, 2.1, and 2.6 GHz. An examination of a four-port triplexer using a common resonator (DSLR) is presented in the publication [IV]. A narrowband triplexer with six poles and high-tolerance switches (HTS) is designed, with eight different operating modes that can be achieved by implementing switches in each channel. The study [XXIII] details the construction of a compact, switchable, narrow-band, high-temperature superconducting triplexer that is based on a three-mode common net-type resonator. A novel microstrip triplexer with tuneable resonance frequencies is designed in the paper [IX] by combining the properties of steps, linked lines, and spiral cells. At 2.67 GHz, a microstrip triplexer can handle 4G LTE, and at 3.1 GHz, it can support WiMAX. It is suitable for usage in frequency division duplex systems due to its proximity to resonance frequencies. Investigating the proposed resonator's LC equivalent circuit lowers its insertion loss. Also, by arranging the linked lines and step impedance structures correctly, the return losses can be optimized. Avoiding loading effects and fitting resonators for many bands within the footprint of a single-band resonator are two design challenges. To overcome these limitations, stub-loaded resonators are utilized, which display a diverse range of small-band loading effects. All of the circuits that are currently being proposed have been successfully built by the researchers in [XXXVI] using RO4003C substrates. By integrating the matching circuit inside the resonator, the suggested SLR D and SLR T eliminate the requirement for an external matching circuit and provide the band matching conditions needed to minimize loading effects. The overall design of a triplexer consists of microstrip transmission lines and resistor model components, such as the input matching impedance section, the power combiner section, and the isolation section. All three triplexers' input impedances, as well as their insertion and return losses and isolation, have been confirmed in [XI] at 0.915, 1.8, and 2.45 GHz. A sample of a triplexer is shown in Figure 8 to help clarify the idea.

Fig. 9: A sample of a triplexer for dish network

IX. Comparison between Diplexer and Triplexer

Diplexers and triplexers are both types of passive electronic devices used in telecommunications and radio frequency (RF) systems to combine or separate different frequency bands. While they serve similar purposes, there are key differences between the two that make them suitable for different applications. Diplexer: A diplexer is a passive device that allows two different frequency bands to be transmitted and received over a single transmission line. It combines the signals from two different frequency bands into a single output or separates a combined signal into its original frequency bands. Diplexers are commonly used in applications where two frequency bands need to be transmitted or received simultaneously, such as in satellite communications, cellular networks, and radio systems. Diplexers typically consist of three ports: two input ports for the different frequency bands and one output port for the combined or separated signal. They use filters and impedance-matching networks to ensure that the signals from each frequency band do not interfere with each other. Triplexer: A triplexer is similar to a diplexer, but it is designed to handle three different frequency bands instead of two. It combines or separates three different frequency bands into a single output, allowing for more efficient use of transmission lines and antennas. Triplexers are commonly used in applications where multiple frequency bands need to be transmitted or received simultaneously, such as in multi-band cellular networks, wireless communication systems, and radar systems. Triplexers typically consist of four ports: three input ports for the different frequency bands and one output port for the combined or separated signal. Like diplexers, they use filters and impedance-matching networks to ensure that the signals from each frequency band do not interfere with each other. Comparison: The main difference between diplexers and triplexers is the number of frequency bands they can handle. Diplexers are designed for two frequency bands, while triplexers are designed for three frequency bands. This means that triplexers are more suitable for applications that require the simultaneous transmission or reception of three different frequency bands, while diplexers are more suitable for applications that only require two frequency bands. In terms of complexity and cost, triplexers are generally more complex and expensive than diplexers due to the additional components required to handle the third frequency band. However, both diplexers and triplexers are passive devices, meaning they do not require external power sources and are relatively simple to install and maintain. In conclusion, diplexers and triplexers are both important components in RF systems, allowing for the efficient transmission and reception of multiple frequency bands. The choice between the two depends on the specific requirements of the application, with diplexers being suitable for two-frequency band applications and triplexers being suitable for three-frequency band applications.

X. Challenges and Critical Points of Diplexer and Triplexer

The challenges and critical review of diplexers and triplexers include:

1. Size and complexity: One of the main challenges in designing diplexers and triplexers is achieving a compact size while maintaining the desired performance. The use of fractal geometries has helped in reducing the size, but there are still challenges in integrating multiple filters into a single device without increasing complexity.

2. Bandwidth and isolation: Another challenge is achieving wide bandwidth and high isolation between the different channels in the diplexer or triplexer. This becomes more critical in 5G communication systems where the frequency bands are closely spaced, requiring high isolation between the channels.

3. Insertion loss and power handling: Diplexers and triplexers introduce insertion loss in the signal path, which can affect the overall system performance. Additionally, they need to handle high power levels without significant degradation, which can be challenging to achieve.

4. Manufacturing and cost: The manufacturing process for diplexers and triplexers, especially those using fractal geometries, can be complex and costly. Finding cost-effective manufacturing techniques while maintaining high performance is a critical challenge.

5. Integration with other components: Integrating diplexers and triplexers with other components in the communication system, such as antennas and amplifiers, can be challenging due to impedance matching and space constraints.

In terms of critical review, while diplexers and triplexers offer the advantage of combining multiple channels into a single device, there are still limitations in terms of performance, especially in terms of insertion loss and isolation. Additionally, the use of fractal geometries has shown promise in reducing size and improving performance, but there is still a need for further research and development to address the challenges mentioned above. Overall, diplexers and triplexers are essential components in modern communication systems, but ongoing research is needed to overcome their limitations and improve their overall performance.

XI. Fractal Microstrip Diplexers and Triplexers

Fractal microstrip diplexers and triplexers are essential components in modern communication systems, allowing for the simultaneous transmission and reception of multiple signals on the same antenna. These devices are crucial for increasing the capacity and efficiency of wireless communication systems. In this report, we will discuss the design, characteristics, and applications of fractal microstrip diplexers and triplexers [XX], [XXXXIII], [XXX], [XXVII], [XII], [XIX].

Fractal microstrip diplexers and triplexers are based on the use of fractal geometries in the design of microstrip filters. Fractal geometries are known for their self-similarity and space-filling properties, which allow for the miniaturization and broadening of bandwidth in microwave circuits. These properties make fractal microstrip diplexers and triplexers highly attractive for modern communication systems.

One of the key advantages of fractal microstrip diplexers and triplexers is their compact size and broad bandwidth. Traditional microstrip filters are limited in terms of bandwidth due to their size and structure. However, by using fractal geometries, the size of the filter can be significantly reduced while maintaining a bandwidth. This makes fractal microstrip diplexers and triplexers ideal for applications where space is limited and high data rates are required.

In addition to their compact size and broad bandwidth, fractal microstrip diplexers and triplexers also offer excellent performance in terms of insertion loss, return loss, and isolation between channels. These characteristics make them suitable for high-frequency applications such as satellite communication, radar systems, and wireless networks.

In brief, fractal microstrip diplexers and triplexers offer significant advantages in terms of compact size, broad bandwidth, and excellent performance characteristics. These devices have been widely studied and applied in various communication systems, making them essential components for modern wireless communication technologies.

XII. Optical Diplexers and Triplexers

The main difference between microstrip and optical diplexers and triplexers lies in the medium through which the signals are being transmitted. Microstrip diplexers and triplexers are designed for use in radio frequency (RF) and microwave communication systems, where signals are transmitted through electrical conductors such as coaxial cables or printed circuit boards. These devices are typically used in wireless communication systems, radar systems, and satellite communication systems. On the other hand, optical diplexers and triplexers are designed for use in optical communication systems, where signals are transmitted through optical fibers. These devices are used in WDM systems, FTTH networks, and other optical networking equipment to combine or separate multiple optical signals at different wavelengths. In summary, the main difference between microstrip and optical diplexers and triplexers is the medium through which the signals are transmitted - electrical conductors for microstrip devices and optical fibers for optical devices [L], [XXXXVIX], [XXI].

XIII. Conclusion

In conclusion, microstrip resonators, filters, diplexers, and triplexers play a crucial role in modern communication systems by allowing multiple channels to be combined into a single device. However, several challenges need to be addressed to improve their performance and overall effectiveness. These challenges include size and complexity, bandwidth and isolation, insertion loss and power handling, manufacturing and cost, and integration with other components.

To address these challenges, further research and development are needed to explore new design techniques and manufacturing processes that can improve the performance of microstrip resonators, filters, diplexers, and triplexers. This may involve exploring new materials, innovative geometries, and advanced manufacturing techniques to achieve compact size, wide bandwidth, high isolation, low insertion loss, and high power handling capabilities. Additionally, efforts should be made to integrate diplexers and triplexers seamlessly with other components in the communication system to ensure optimal performance.

Generally, while diplexers and triplexers have their limitations, they are essential components in modern communication systems. By addressing the challenges and limitations through ongoing research and development, it is possible to improve their performance and make them more effective in meeting the demands of 5G and future communication systems. Therefore, continued investment in research and development in this area is recommended to overcome the challenges and improve the overall performance of diplexers and triplexers.

Conflict of interest

There was no relevant conflict of interest regarding this paper

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