Microstrip Triplexer Design: A Review

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***Abstract*—Radio Frequency communication systems were developed in the past decades and many designs are involved in triplexer development. The previous designs focused on various purposes, new techniques, and applications in order to overcome the existing limitations. This manuscript presents several reviews for the past triplexer designs and techniques used in RF communication systems in order to propose a novel design and an improvement concept, and reduce limitation gaps of triplexer design for future research work.**

***Index Terms*—Diplexer; Matching Network; RF Microwave Filters; Triplexer.**

I. Introduction

Many triplexer designs have been made over several years in order to fulfil the requirements of modern RF communication systems which are demanded to support the multi-band and multi-services provided by the regulations (WIFI, Broadband, WiMAX, WLAN etc.) [1]. Furthermore, the objective of designing the triplexer is to support large coverage areas compared to conventional triplexer reported in [2]. In the phase of developing the triplexer, RF communication systems have come out with various techniques and improvements in order to cope with the environment. Many designs were introduced into various structures such as in microstrip transmission line [3]-[4], low temperature co-fired Ceramic (LTCC) [5][6], waveguide [7], electromagnetic band-gap (EBG) [8][9] and even designed in antenna structures [10][11].

Traditionally, the triplexer is measured based on the frequency band, insertion loss, isolation, bandwidth, and fractional bandwidth for its performances. However, in modern RF communication systems, they are very demanding in triplexer development which needs to be more flexible in frequencies, have high performance with low cost, complexity in design with a compact size, and easy to implement in RF communication systems [12][13].

Figure 1 shows the block diagram of a WiMAX tri-band Front-end Module which was used in LTCC technology for WiMAX applications. The module consists of the transmitter and receiver paths which operate simultaneously.

This paper covers the conceptual design of triplexer in section II. Following this is Section III for the realisation of the triplexer design and continuing with Section IV on a brief of tunable and switchable triplexer available. Finally, Section V summarises the paper.

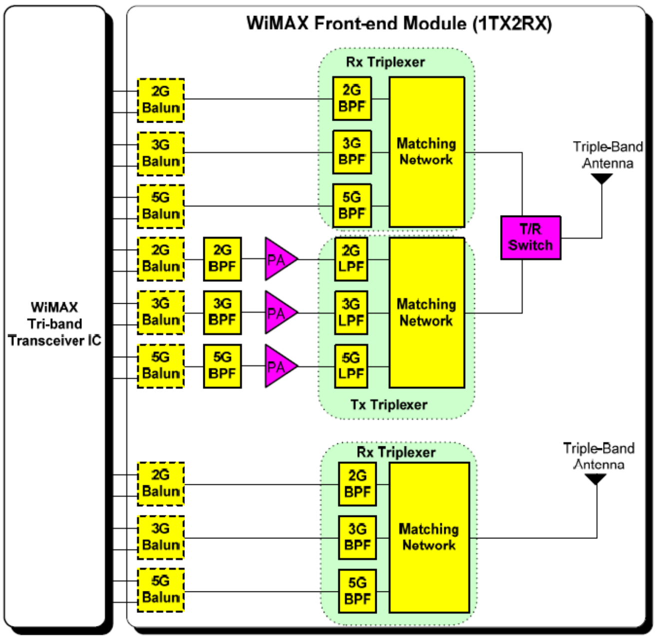

Figure 1: Block diagram of WiMAX tri-band model[2]

II. Design Concept of Triplexer

While developing the RF communication systems, triplexer is basically the improved version of diplexer which majors in separating, combining, and selecting the radio frequency signals from a transmitter to the receiver as demonstrated in [14][15]. In the same vein, the operation of the triplexer is similar as a multi-band filter operation [16][17]. The difference between multi-band filter and triplexer is the number of network ports. Triplexer has a four-port network with a combination of three bandpass filters with a matching network, while the multi-band filter only has a two-port network. The most critical parameter is the isolations between the frequencies.

In addition, there are various triplexer configuration types used in RF communication systems. Figure 2 (a) shows a basic triplexer configuration type which is commonly used in receivers. The most important highlight is the arrangement of the bandpass filters and matching network. Most of the designs developed are referred as type A with the matching network is allocated first before the bandpass filters. The other configuration type used in RF communication is type B as shown in Figure 2 (b). The matching networks are allocated after the bandpass filter. The design in [18] was a diplexer based on a dual-band filter. Nevertheless, the triplexer can be realised using the same concept with the addition of a third matching network.

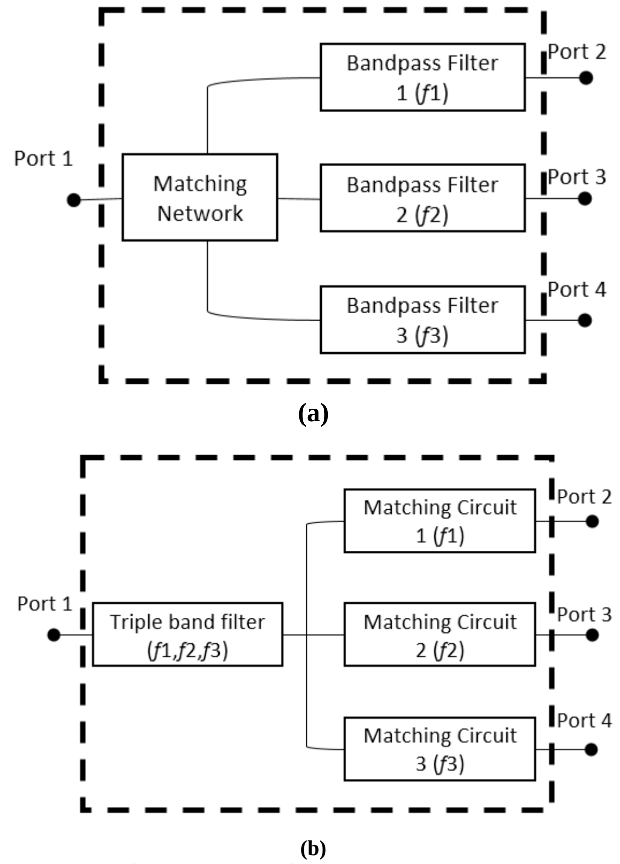

Figure 2: Configuration Types of Triplexer (a) Type A (b) Type B [19]

The design in [20] was consistent with the agreements of past designs by [21]-[22], in which the designed triplexers were referred as passive triplexers since they were operating at fixed parameters such as frequencies, bandwidth, and elements. Based in [23][24], the design also refers to the same concept to prove the functionality and concept applied to the triplexer. An example of a passive triplexer is shown in Figure 3.

Matching networks also play an important role in separating or selecting the desired frequencies while designing the triplexer. They contribute to the overall performances such as enhancing the response efficiency, low insertion loss and high isolation [25]. Microstrip non-uniform transmission lines were introduced as a matching method for the triplexer. This matching method is more efficient and has low group delay variations. However, in the matching network techniques, there were many approaches made besides using the conventional power divider. As reported in [26], there are various types of power divider such as quadrature hybrid, 180-degree ring hybrid, Wilkinson power divider, and 3dB quadrature hybrid coupler. In [27], a 18-degree ring hybrid was used for connecting microstrip passbands. This type of matching is also known as the rat-race or ring-manifold. It provides high isolation between output ports. However, there is a limitation in terms of size. Therefore, a new design was proposed that had the same concept as the 180-degree ring hybrid as referred by [28]. The design was basically the combination of the coupler technique and the ring hybrid. This technique was able to reduce the size of the matching network but the result was approximately the same compared to the conventional method. The challenging phase while developing this matching network is the matching phase between the couplers.

In spite of the development of the passive triplexer, interestingly, these designs are a variety to the passive triplexer design [29][30]. These designs upgraded the triplexer into a different technique; tunable as an extension to the potential of the design and better coverage area.

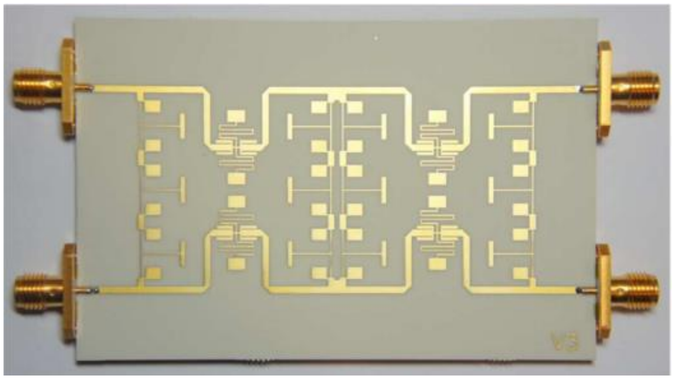

Figure 3: Passive Triplexer[20]

Accordingly, the tunable techniques attempt to enlarge the usage of the triplexer since the technique can be maximised to revamp many standards with a single triplexer design. Due to these acceptances, various tunable elements were produced and introduced into the RF communication systems such as semiconductor (P-I-N diode and varactor diode) [31]-[32], RF microelectromechanical systems (MEMS) [33], piezoelectric transducer (PET) [34][35], and ferroelectric materials [36].

Summarising all the points, this manuscript presents an exhaustive review of past designs and a direction for better understanding in triplexer design concepts, thus improving future triplexer developments.

III. REALIZATION OF MICROSTRIP TRIPLEXER

In the early milestones of RF communication systems, the communication systems relied on the waveguide, wired line, and coaxial lines as mediums to transmit powers [31]. Although the mediums have been widely used in radio frequency microwave, there are still challenges and limits in terms of cost, size, and complexity to realise the design concept. Therefore, as an alternative, the microstrip transmission line technology has been introduced to the RF communication systems. The microstrip transmission line provides many options and forms to be used as another medium since the microstrip transmission line is primarily being used in designs because of minor cost, fabricated by UV lithography techniques, and easily miniaturised [37].

In addition, the microstrip transmission lines can be applied and merged with both passive and active microwave components. These agreements are supported by studies presented in Table 1 which applied the microstrip transmission lines in passive triplexer design. The triplexer is particularly analysed based on the design techniques and matching techniques used, hence the overall performances of the triplexer. The sequences are arranged from the latest to oldest designs.

A triplexer with high isolation was presented in [14], which was embedded with a lowpass-bandpass filter. Stepped-impedance stubs were used to produce absolute selectivity and defected ground structures were used to support the transmission line impedance performances. The triplexer was designed based on hybrid structures combined with three different filter topologies. From the basic concept of the design, the stubs were important components to generate transmission zero and high isolation in selecting the frequencies. The frequencies were operating at 1 GHz, 2.35 to 2.35GHz, and 5.61 to 5.99 GHz and the insertion losses were 2.1 dB and 2.5 dB. The minimum isolations for all passbands were better than 40dB

The authors in [1] proposed an enhanced isolation triplexer from [14]. The triplexer consisted of T-shaped short-circuited resonators as the resonant elements and short-circuited parallel-coupled lines as the coupling medium. The authors proved that the concept of impedance matching could improve the performance of the isolation by placing the embedded open-ended stubs along with the main transmission path of each channel. These techniques are purposely to create a zero transmission and also require imaginary input admittance at operation frequencies. The above design made by the authors operated at 1.5 GHz, 1.7 GHz, and 1.9 GHz. The isolations were greater than 50 dB. In addition to the performance of the triplexer, the authors performed the triplexer on a roger substrate, RO4003c with 0.813 mm-thick (ε_r = 3.55, tan δ = 0.0027). The insertion losses of the triplexer were 4.94 dB, 5.82 dB, and 5.95dB, respectively.

The design in [24] was a microstrip triplexer with high isolation. The triplexer was an integration of multimode resonators, stepped-impedance resonators, and distributed coupling method. The triplexer was built on an RO400C with a dielectric constant of 3.55 and loss tangent of 0.0021. Initially, the concept was used to design a diplexer with multimode resonators; the first channel was the odd mode while the second channel was the even mode. This technique proved that the parameters of the shunt stub can control the frequency resonant to achieve the fundamental frequency. In addition to the concept of the triplexer design, the extended channel was added at the same feeding line. The third channel was meant for distributed coupling to enhance the overall performance of the triplexer. Figure 4 shows the proposed triplexer.

The performance of the triplexer indicated that the fractional bandwidth for operating frequencies was less than < 10%. The insertion losses of each channel were 2.7, 2.5, and 1.8dB for 3.2, 3.7, and 4.4 GHz, respectively. The isolation achieved was greater than 35dB.

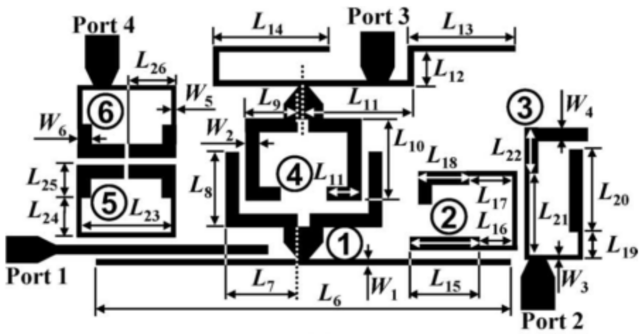

Figure 4: Proposed Triplexer[24]

However, many evidences of the matching network have been developed for the triplexer. [25] was more focused on the matching of the triplexers. The filters were integrated at the feeding line by using the non-uniform microstrip transmission lines. The performances of the triplexers were categorised based on the placement of the non-uniform microstrip transmission line between the filter and feeding line. Moreover, the addition of non-uniform microstrip transmission line affected the efficiency and group delay of the triplexer. The triplexer had three different passbands operating at the frequencies of 1.92 to 2.17, 2.3 to 2.5, and 2.5 to 2.69 GHz. The responds were smaller than 3 dB for the insertion losses of each filter while the isolations were larger than 35 dB. Figure 5 shows the proposed triplexer.

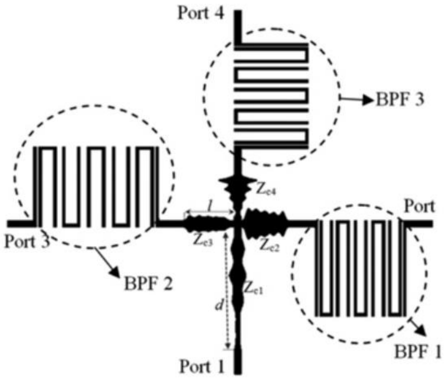

Figure 5: Proposed Triplexer in [25]

Authors in [38] designed a flex-rigid printed circuit of triplexer demonstrated with four metal layers in the rigid part as shown in Figure 6. The triplexer was developed on substrate Pyralux polyimide and designed from the frequencies of 6 to 9 GHz. The method used on the triplexer was based on the manifold principle which was similarly introduced in [27]. However, it was slightly different in the operation system; in this design, the manifold system used vertical transmission-lines and coupling to passbands in order to provide better input impedance. The significance of the method was to miniaturise the structure of the triplexer. Even though the flex-rigid technology is complex in structure, it provides flexibility, high performances, and low cost in manufacture. A good agreement in performance of the triplexer was recorded where the insertion losses were from 3.41 to 4.10 dB, including the isolation that occurred at the boundary of the neigbouring sub-band at 45 dB. In the same basis of concept used in [38], [23] used a coupling technique on resonators but in a different approach.

Interestingly, the design in [15] was more focused on the arrangement of the resonators which were twisted and coupled to exhibit better filter characteristics in electrical coupling and magnetic coupling, thus enhancing the matching of the filter impedance. The triplexer was fabricated on RO4003 with dielectric constant of 3.55 and loss tangent of 0.0027. The result of the triplexer was presented at the operating frequencies of 2.15, 2.95, and 3.80 GHz. The insertion losses were 2.9, 2.2, and 1.7 dB respectively, while the isolation among the filters was greater than 20 dB.

Table 1
Bandpass Microwave Passive Triplexers Design

No	Year	Filtering Techniques	Matching Techniques	Frequency	Isolation	Insertion Loss
[39]	2016	Resonators with open loop	Coupling	1.8/3.1/4.4 GHz	>21.5 dB	1.97, 1.99 and 2.3 dB
[40]	2016	A plane type with three bandpass filter based on LC circuit	Power Divider	1.2/1.9/2.75 GHz	>15dB	1.78/-5/-10 dB
[1]	2015	T-shaped short-circuited resonator and short-circuited parallel-coupled lines.	Power Divider	1.5/ 1.7/1.9GHz	>50dB	: 4.94, 5.82, 5.95 dB
[8]	2015	Electromagnetic band-gap (EBG) on coupled-line structures in microstrip	Coupling	900 Mhz /2.4/5.5 GHz		0.7, 1.7, 1.5 dB
[14]	2015	A low pass bandpass triplexer consists of one low pass and 2 band pass channels. The techniques used are SIR and DGS	Coupling	1/2.4/5.8 GHz	>40 dB	0.8, 2.1 and 2.5 dB
[15]	2014	A modified conventional split ring resonator.	Power Divider	2.15/2.95/3.80 GHz	<20 dB	2.9, 2.2, 1.7db
[25]	2013	Hairpin resonators with MNTL matching.	Power Divider	1.92–2.69 GHz	>35 dB	0.04 to 0.055 dB
[20]	2013	Two folds' symmetry using tri-operational mode synthesized transmission lines.	Hybrid Junction	0.7/1.85/3.55 GHz	28, 74, 52 dB	0.5,0.5,1.1dB
[38]	2013	Using flex-rigid technology with parallel passband filters	Edge coupling	6.5/7.5/8.5 GHz	>45 dB	3.41-4.10dB
[21]	2012	Consist of three pairs of stepped hairpin passband filter	Star-Junction	3.4/3.9/4.6 GHz	>18 dB	2.2/2.3/2.3dB
[41]	2011	Lump elements passbands mount on multi-layer LTCC	Coupling	2.4/3.5/5 GHz	>30 dB	1.5 dB
[4]	2011	Compact dual band quasi-elliptic passband filters with additional third filter after tri-mode resonator	Net-type Junction	1/1.25/1.5 GHz		2.7/1.8/3.2 dB
[23]	2008	Using λ/4 transmission line coupled side by side with parallel coupler	Coupling	3.432/3.960/4.488 GHz	>23 dB	1.7-2.5 dB
[2]	2008	Using second order coupled resonator	Conjugated matching	2.5/3.5/5.55 GHz	>23 dB	1.6/2.1/1.3 dB
[3]	2007	Using cascaded resonators with SIR and UIR.	Coupling	2/4/6 GHz	>53 dB	0.7/1.75/2.55 dB

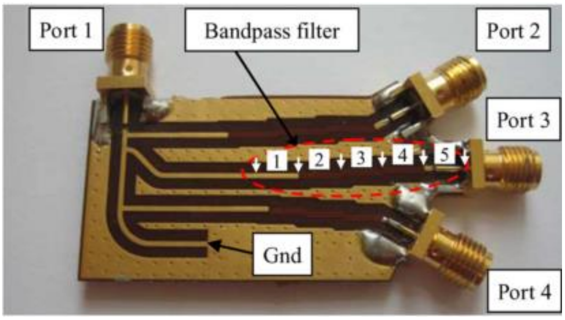

Figure 6: Flex-rigid Printed Triplexer in [38]

IV. SWITCHABLE AND TUNABLE TRIPLEXER

Tunable or switchable triplexer is also considered as an important trend to RF communication system development based on the capability to discriminate multiple frequencies with an individual system. The tuning mechanism majors in three types of classes; magnetic, electronic, and mechanical [43]. In addition, the tuning mechanism can also be used as the switchable method in designing active triplexer [35].

Generally, by observing the preliminary design of the tunable triplexer, it is very difficult to obtain an absolute performance due to the diversity of the bandwidth since the tuned frequencies depend on matching networks. Besides, the biasing voltage applied to the biasing networks at the resonators can also be another factor which affects the overall performance of the triplexer.

The design in [29] demonstrated the tuning method implementing a switchless bank of the three tunable bandpass filters which were able to cover a large tuning range. The operating frequencies of these three bandpass were at 2.74, 3.03, and 3.37 GHz. The insertion loss obtained was 0.5 dB while the isolation of the tunable triplexer was better than 50 dB. The triplexer was fabricated by using Roger TMM3 which utilised a 0.5 mm thick piezoelectric as a tuning element. The technique used to achieve the response was by placing the input feedlines at the backside of the filter, thus producing an external coupling. In the tuning process, the design still maintained low insertion loss bandwidth at approximately -3 dB. Yet, there were certain obstacles that occurred during the matching process. The individual feeding line needed to be matched with the tuning range in order to minimise insertion losses. The tunable triplexer is depicted in Figure 7.

As referred in [30], it was observed that the design also implemented the tuning method with a novel compact size and constant fractional bandwidth tunable triplexer. The triplexer consisted of three frequency channels operating at 1.45, 2.15, and 2.75 GHz. The triplexer was fabricated on

Roger 6010 while the tuning elements used in the triplexer were silicon varactors. The triplexer showed satisfactory results in terms of performances with insertion losses of 2.8 – 4.1, 3.1 – 4.7, and 4.0 – 4.7 dB for each of the frequencies. The responses were within the tuning range. The isolation of all channels was better than 25 dB in the overall tuning states. The limitations occurred when the tuned-channels got closer to each other, thus resulting in a mismatch of the designs. To overcome the situation, the number of order and Q factor of each filter needed to be increased.

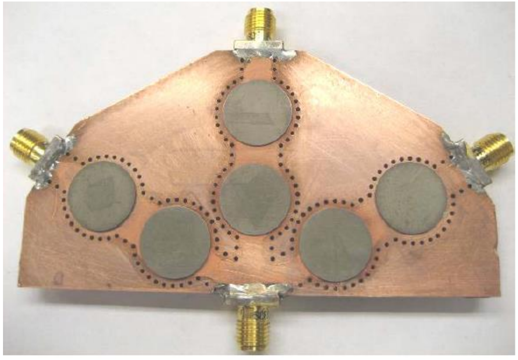

Figure 7: Tunable Triplexer Proposed in [29]

As proposed in [44], the switchable triplexer with impedance matching circuit was used in the triplexer. The circuit consisted of the п-networks and L-network was integrated with three different passbands which operated at the frequencies of 1.2, 1.3, and 2.4 GHz. The proposed triplexer fabricated by using ARIon DiClad 880 showed the insertion loss of -1.74, -2.6, and -3.1, dB respectively. The isolations recorded also showed an impressively high and wide bandwidth which was suitable for the high data-rate RF communication systems.

Table 2 shows the previous designs of active triplexer in the RF communication systems. The sequences are arranged from the latest to oldest.

Table 2
Bandpass Microwave Active Triplexers Design

No	Year	Filtering Techniques	Matching Techniques	Performance
[30]	2016	Dual mode second-order bandpass filters and	Coupling	Freq: 1.45/2.15/2.75 GHz Isolation: >25 dB IL: 2.8-6.6 dB
[44]	2016	Consist of two п-network and one *L*-network of QE-BPFs	Switchable Impedance matching	Freq: 1.2/1.8/2.4 GHz Isolation: >52 dB IL: 1.74/2.6/3.1 dB
[29]	2009	A filter-bank with switchless concept for passband filters	Power Divider	Freq: 1.7/2.4/3.4 GHz Isolation: >32 dB IL: 2.89-3.92 dB

V. Conclusion

In conclusion, this paper presents a review of the preliminary designs implemented in the development process of the triplexer. Various types of matching and filtering techniques were used to adapt the RF communication systems. The designs were mostly fabricated in a microstrip medium due to the easiness of the fabrication process, light in weight, low-cost manufacture, and easy to apply on any other front-end. However, there are still design gaps during the development process of the triplexer which need to be overcome through time. Therefore, this manuscript purposely reviewed the literature to keep a better understanding and introduce a new concept in the design trends of triplexer. This review can also be a reference for future researchers who are interested in developing and improving the triplexer in order to achieve better performances and various operation applications in the RF communication system.

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