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Review Article

Quasi Yagi Antennas for State of the Art Applications

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Abstract *- This paper presents a detailed review of the latest developments in the design of quasi Yagi antennas, which are suitable for a wide range of wireless applications, including wireless local area networks (WLAN), radio frequency identification (RFID), radio wave detection and ranging (RADAR), medical imaging, airborne, Wi-Fi, Wi-MAX, RF energy harvesting, wireless power transfer (WPT), sensor nodes, access points, and indoor tracking applications. The paper analyzes important parameters of the quasi Yagi antennas in terms of impedance bandwidth, gain, front to back (F/B) ratio, cross-polarization level etc. Further, the quasi-Yagi geometries are reviewed and analyzed concerning their design features such as miniaturization or size reduction, beam scanning/pattern reconfiguration ability, simplification of feed, and combining the filtering and radiation characteristics (filtenna), multiple-input multiple-output (MIMO) and reduction of mutual coupling. Among the Yagi antennas reviewed here, the best performance parameters obtained by the researchers so far are an impedance bandwidth of nearly 122%, a peak gain of nearly 13dB, more than 20dB front-to-back ratio and an excellent cross-polarization ratio of -25dB. The limitations of the reported works on Yagi antennas have been discussed and presented.*

Keywords *- 5G, Microstrip antenna, MIMO, Quasi yagi, RFID.*

1. Introduction

Modern wireless applications need an antenna with a small size, good gain, pattern diversity with a wide frequency range of operation [1-4]. Further, some specialized applications like aircraft and missiles need unidirectional radiation patterns, and for such applications, the Yagi-Uda antenna is the best choice [5-7]. The conventional Yagi-Uda antenna was first proposed by Yagi [7, 8] that produces a pencil beam with an excellent gain in the range of 10-20dB. It is well known that the basic structure of the Yagi antenna has three primary elements, viz., a dipole (usually λ/2 in length), a reflector and one or more directors. The use of a reflector ensures the unidirectional radiation (end-fire radiation), and one or more directors will contribute to enhancing the gain of the Yagi antenna. Closed spacing between the elements helps in increasing the gain of the antenna.

Further, a balance to unbalance (BALUN) transformer plays an important role in matching the folded dipole and feed line impedance. Since the dimensions and spacing between elements function design a wavelength, the conventional Yagi antenna exhibits a narrow band performance. Further, the conventional Yagi antenna is large and unsuitable for wireless mobile applications documents.

[1]On the other hand, in 1991, Haung and Densmore [9] proposed a printed microstrip Yagi antenna termed quasi Yagi antenna, which is suitable for mobile wireless applications. It clubs the advantages of Yagi antennas with advantages of microstrip antennas such as low profile, lightweight, and ease of fabrication. However, the printed microstrip Yagi antenna offers poor gain and narrow bandwidth [7-20]. Therefore, several researchers have addressed these issues and reported numerous innovative techniques to improve the performance parameters of the quasi Yagi antenna.

In this work, various quasi Yagi antennas reported in the literature suitable for a wide range of wireless applications have been reviewed and analyzed. Applications and their limitations have been discussed in the subsequent sections of the paper. Section 2 briefs about the basic structure of the quasi Yagi antenna. Various feeding techniques available & their performances are also discussed here. Recent advances in the development of quasi Yagi antennas are covered in Section 3. Finally, the summary and limitations in the development of Yagi antennas are covered in the conclusions part (Section 4) of this work.

2. Basic Quasi Yagi Antenna and Feeding Network

The conventional Yagi or Yagi-Uda is a three-dimensional antenna with limited applications due to size constraints. However, the microstrip Yagi antenna has combined advantages of the microstrip and Yagi antenna. Hence microstrip Yagi antenna is a promising candidate for low profile and lightweight wireless applications. The geometry of a typical Yagi antenna is shown in Fig. 1 [21]. It may be noted that all geometries covered here use one of the feeding techniques such as microstrip to coplanar stripline (MS to CPS) [22] or CPW feed [23-26] or tapered microstrip line feed structures [27-29]. However, a few geometries use slightly modified feeds of the basic feed structure like coupled slot line feed [31], coplanar stripline feed [32, 33] and simplified tapered line feed [34] etc. All these feeding structures are presented in Section 2.1.

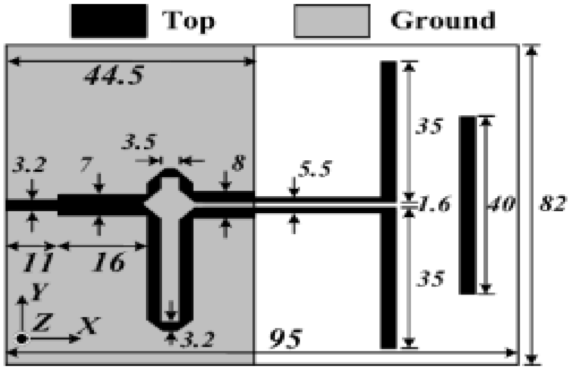


Fig. 1 A typical quasi yagi antenna [21]

2.1 Feeding Techniques

The impedance matching between the driven element and the feed line is crucial in Yagi/quasi-Yagi antennas design. A BALUN is used to achieve good impedance matching between the active element and feed line. The use of BALUN ensures enhanced bandwidth with good gain. However, the design of BALUN is a complicated one to the design of Yagi antennas. Hence, the researchers have made several efforts to make the BALUN design simple or avoid the BALUN structures, such as replacing the BALUN with CPW feed, tapered microstrip line, etc. Quasi yagi antennas with different feeding techniques are shown in Fig. 2 (a) -(f). Microstrip to CPS transition is achieved with the help of a BALUN structure shown in Fig. 2(a). In another effort, a coplanar waveguide feed [36] is used for feeding the dipole element (Fig. 2(b)).

On the other hand, Fig. 2 (c) [32] shows the feeding of the Yagi antenna with coplanar stripline. A simple microstrip line is tapered and used as a BALUN in work reported in [29]. This line feeds the monopole element. In another work [34], a simplified feed similar to a coaxial probe feed is proposed and is shown in Figure 2(e). At the same time, Fig. 2 (e) [35] is another simplified feed where two opposite planes are used for feeding. The top plane acts as a signal line, and the bottom line acts as the ground. The performance of Yagi antennas with these feeds is summarized in Table 1. From Table 1, it may be noted that the monopole element has a driven Yagi antenna with a tapered microstrip line feed that is simple to design and offers the best performance. For example, the antenna [28] has the optimum performance parameters such as maximum impedance bandwidth of 114.0%, a peak gain of 6.9dBi, 9.2dB front-to-back ratio and a good cross-polarization ratio of -20dB.

3. Recent Progresses in Yagi Antennas

This section covers the recent developments in the field of Yagi antennas. Researchers have made numerous efforts to address a variety of issues including developing dual [34], multi-band [13], wideband Yagi antennas [10, 11, 16, 29], pattern reconfigurable antenna [2, 35] switched beam/beam scanning antennas [39], simplified feeding structures [35], MIMO Yagi antennas [16, 30, 40-42], high gain 3D printed Yagi antennas [43], double-layer yagi antennas for bandwidth and gain enhancement [44], gain reconfigurable [45], multiple driven yagi antenna (SRR) [46], metamaterial structure-based Yagi antennas [47-50], filtering-radiating antennas [32, 51-52], dual-wideband multi resonant antenna [53], phased-array Yagi antenna [54], defective ground structure (DGS) Yagi antenna [15], dielectric resonator Yagi antennas [55] and mutual coupling reduction [56] etc. In addition to the performance improvement, almost all the cases reported here have focused on the design of miniaturized and compact Yagi antennas.

Further the reported Yagi antennas cover the wide range of state of the art wireless applications including wide fidelity (Wi-Fi) & worldwide interoperability for microwave access (Wi-Max) [42, 57], millimetre wave [54], tera Hertz (THz) [10, 58], long term evolution (LTE) [37] and 5G applications [40, 41, 44, 54, 58], energy harvesting applications [45, 50, 59, 60], Cubesat (multi frequency tilt) [61], RF-ID [62-64], UHF-ISM band applications[63], Wearable [64], and WLAN [42, 66-68] and dedicated short range communications (DSRC) [68]. Further a few researchers have focussed on an indoor application like indoor wireless power transfer [69], indoor location tracking systems [70], and indoor access points [71].

3.1 Active Element Shapes

In this section, Yagi antennas with different shapes of actives elements are reviewed. Researchers have published the results with both monopole and dipole driven elements. Of the two elements, Yagi antennas with monopole show a good performance over their counterparts.

3.1.1 Quasi Yagi Antenna with Monopole Driven Element

Authors of [11, 12, 21, 27-30] have presented Yagi antennas with monopole as a driven element. It has a microstrip line fed monopole on one side and the other side, passive elements. With these arrangements, authors have claimed that it replaces the use of complicated BALUN. The geometries of quasi Yagi antennas with monopole as a driven element are shown in Fig. 3. The Yagi antenna [29] offers an impedance bandwidth of 117.3% with a centre frequency of 3.7GHz. The corresponding gain, front-to-back ratio, and cross-polarization ratio are 6.4dB, 8dB, and -25dB respectively. Another work presented in [28] has similar performance, i.e., it has an impedance bandwidth of 114% for a centre frequency of 3.8GHz. It has a gain of 6.9dB and a front-to-back ratio of 9.2dB.

The antenna has a cross-polarization of -20dB.

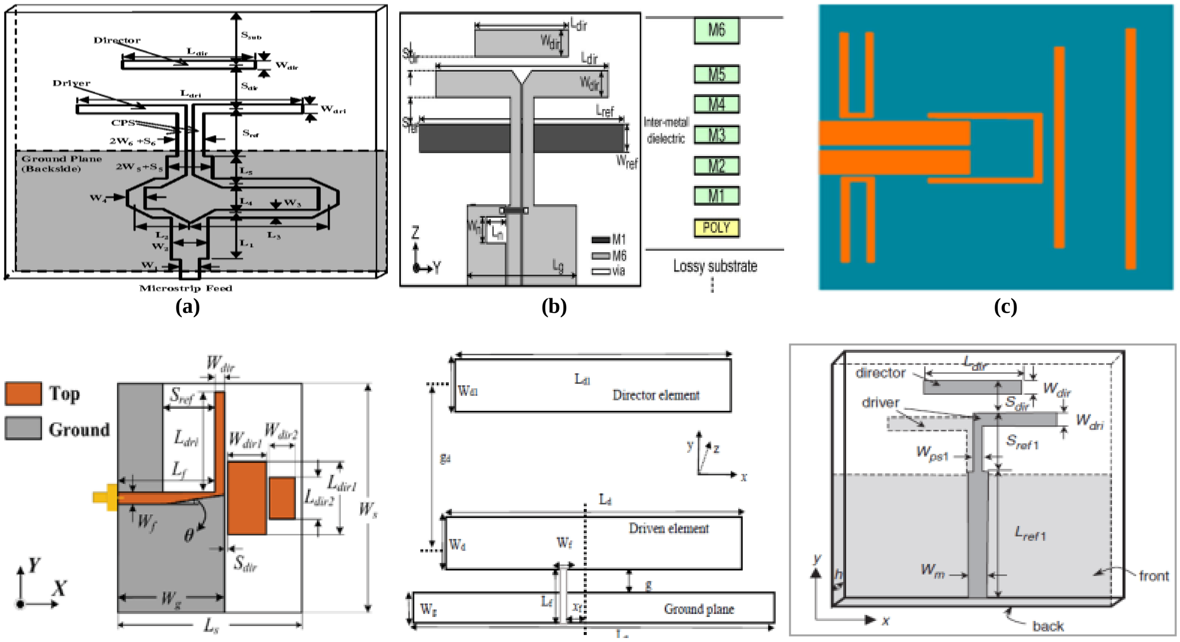
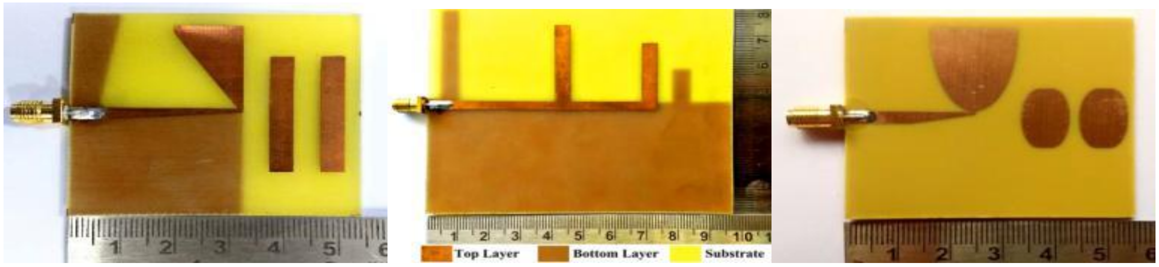


Fig. 2 Quasi-Yagi antennas with a variety of feeding techniques. (a) Microstrip to CPS BALUN [19] (b) CPW feed [36] (c) CPS feed [32] (d) Microstrip feed with tapered BALUN [29] (e) A simple microstrip feed [34] (f) A simplified MS feed [35]

Table 1. Performance of Yagi antennas with different feed configurations

Ref.	Feed type	Driven element type	Operating frequency (GHz)	BW (%)	Peak gain (dBi)	Front to back ratio (FBR) (dB)	Cross polarizarion ratio (dB)
[11]	Tapered microstrip line	Half bow-tie monopole	2.31	63.54	5.8	10	-25
[12]	Microstrip Line	Series fed double monopole	2..25	70.20	5.3	10	-20
[21]	Microstrip Line	Monopole	1.93	47.6	4.1	22.7	--
	Microstrip (MS) to coplanar strip (CPS) BALUN	Conventional dipole	1.87	20.3	4.7	20.6	--
[22]	Microstrip (MS) to coplanar strip (CPS) BALUN	Conventional dipole	2.27	43.17	--	15	--
		Log periodic	2.33	42.06	--	15	-
		Patch	2.19	41.20	--	22	--
		Meander	2.53	18.18	--	22	--
[28]	Tapered microstrip line	Semi-elliptical monopole	3.80	114.0	6.9	9.2	-20
[29]	Tapered microstrip line	Single monopole	3.70	117.3	6.4	8	-25
[32]	Coplanar strip feed(CPS)	Dipole	4.0	18.5	5.8	--	--
[34]	Microstrip feed	Dipole	2.45	--	8.2	18	-13
[35]	Simplified MS feed	Dipole	8.0	40.0	--	15	-20
[36]	Coplanar waveguide (CPW)	Dipole	60.0	16.66	-10.0	9	--
[72]	Microstrip to slotline	Horn shape	2.425	80.4	4	10	--



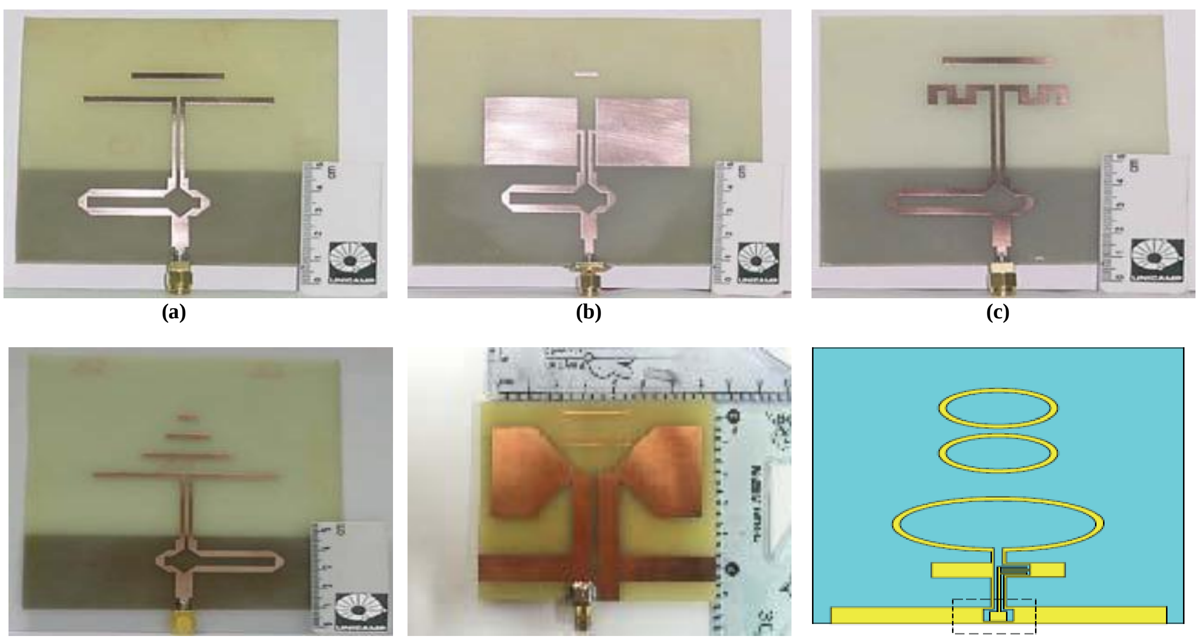
(a) (b) (c)

Fig. 3 Geometries showing different shapes of monopoles used in quasi-Yagi antenna. (a)Half bow-tie monopole [12] (b) Series fed double monopole [11] (c) Semi-elliptical monopole [28]

3.1.2 Quasi Yagi Antenna with Dipole Driven Element

Authors of [8, 9, 18, 24-27] have presented Yagi antennas with dipole as a driven element. The only drawback of the Yagi antenna with dipole as an active element is the use of a balance to unbalance transformer (BALUN). However, some efforts have been made in [72] to reduce the complex design of BALUN. Here a CPW feed is used in place of a microstrip feed. The geometries of quasi Yagi antennas with dipole as a driven element are shown in Fig. 4.

Among the Yagi antennas with dipole as a driven element shown in Fig. 4 (a) to (f), dipole Yagi, patch Yagi, and multi-directors Yagi have a maximum impedance bandwidth of 49.35% [19]. On the other hand, driven elements with meander lines and loops have the least impedance bandwidth of less than 25% [19, 70].



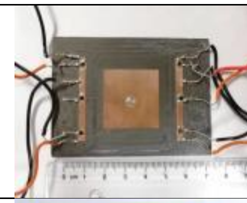
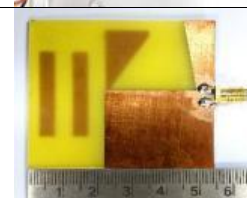
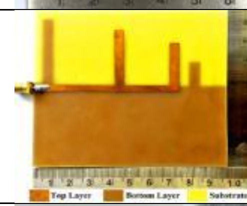
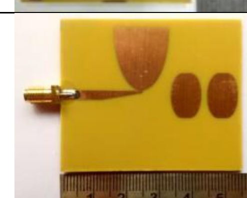
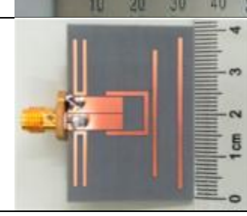
(a) (b) (c) (d) (e) (f)

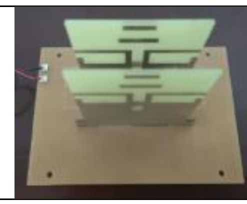
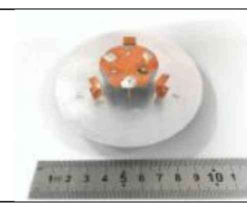
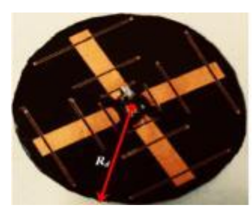
Fig. 4 Geometries showing different shapes of dipoles used in quasi-Yagi antenna. (a) A simple dipole [22] (b) microstrip patch [22] (c) Meander line [22] (d) Log periodic dipole array [22] (e) Bow tie [72] (f) Loop [73]

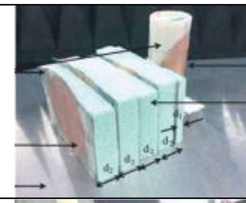
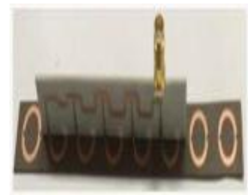
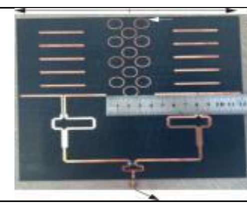
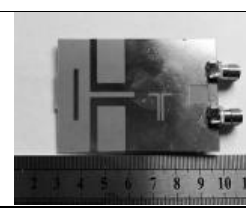
3.2 Performance Enhancement & Size Reduction Techniques

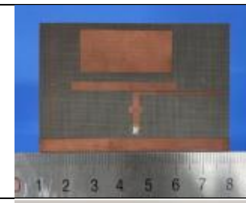
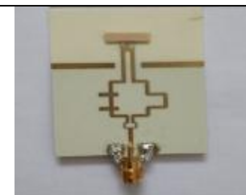
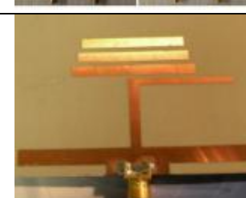
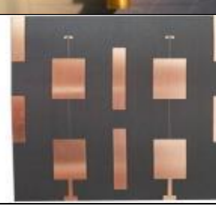
This section covers quasi Yagi antennas, which focus on improving antenna performance. These include enhancement of bandwidth, gain, efficiency, reduction of mutual coupling in the arrays, and reduction of the antenna's physical size. Antennas related to these contributions are summarized in Table 2. Analysis and discussion of these works are summarized in Section 4.

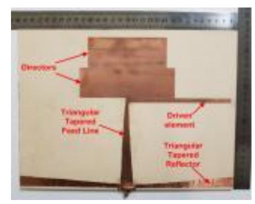
Table 2. A list of Yagi-Uda antennas that focus on performance enhancement & size-reduction

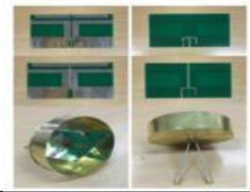
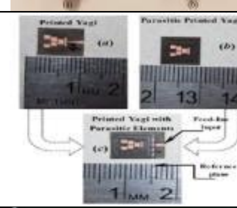
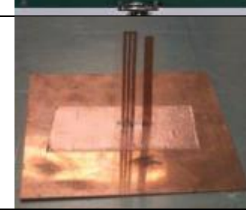
Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[5]	♦ Pattern reconfigurable Yagi-Uda antenna ♦ Seven switchable beams ♦ Antenna size:75mm x70 mm	♦ Operating frequency:3.6GHz ♦ Impedance bandwidth:150MHz ♦ Peak gain:6.5dB ♦ Front to back ratio:-- ♦ Cross polarization--	♦ Wi-Max	
[11]	♦ Compact printed quasi Yagi antenna ♦ Half-bow-tie monopole element is used as the driven element ♦ Antenna size:$0.41\lambda_0$ x $0.41\lambda_0$	♦ Operating frequency:2.31GHz ♦ Impedance bandwidth:63.54% ♦ Gain:5.8dBi (peak) ♦ Front to back ratio:10dB ♦ Cross polarization level:-25dB	♦ Multiple beam arrays ♦ Wideband phased arrays ♦ Power combining	
[12]	♦ Compact printed quasi Yagi antenna ♦ Series fed double monopole driven element ♦ Antenna size:$0.72\lambda_0$ x $0.64\lambda_0$	♦ Operating frequency:2.25GHz ♦ Impedance bandwidth:70.2% ♦ Gain :4.7-5.3dBi ♦ Front to back ratio:10dB ♦ Cross polarization level:-20dB	♦ Base station ♦ 2.45GHz based systems	
[20]	♦ A planar quasi Yagi antenna using LPDA driven element ♦ T simple tapered microstrip to stripline transition BALUN ♦ Antenna size:$0.41\lambda_0$ x $0.54\lambda_0$	♦ Operating frequency:1.45GHz ♦ Impedance bandwidth:41.4% ♦ Gain :6.5±0.5dBi ♦ Front to back ratio:20dB ♦ Cross polarization level:--	♦ RFID ♦ Portable direction finding ♦ Spectrum monitoring	
[28]	♦ UWB printed monopole driven quasi Yagi antenna ♦ Semi elliptical driven element ♦ Antenna size:55mm x 55mm	♦ Operating frequency:3.8GHz ♦ Impedance bandwidth:114% ♦ Gain :6.9dBi (peak) ♦ Front to back ratio:9.2dB ♦ Cross polarization level:-20dB	♦ Unidirectional wireless systems	
[30]	♦ A compact UWB three elements MIMO quasi Yagi antenna ♦ Three monopole driven elements ♦ Antenna size:45mm x 55mm (single element) (Area:$0.21\lambda_0^2$)	♦ Operating frequency: 3.8GHz ♦ Impedance bandwidth:118.7% ♦ Gain : 5.6 dBi (peak) ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ Multi functional wireless systems	
[31]	♦ Printed quasi Yagi antenna with coupled slot line feed ♦ 1x2 CPW to the slot-line divider for excitation ♦ Antenna size:17mm x 34.5mm	♦ Operating frequency:9.25GHz ♦ Impedance bandwidth 41.5:% ♦ Gain :2-8.6dBi ♦ Front to back ratio:-- ♦ Cross polarization level:--	♦ General wireless applications ♦ RADAR	
[32]	♦ Wideband dipole Yagi antenna ♦ Coplanar stripline feed ♦ Combination of filter and antenna for radiation ♦ Antenna size:$0.56\lambda_0$ x $0.4\lambda_0$	♦ Operating frequency: 4GHz ♦ Impedance bandwidth:18.5% ♦ Gain:5.8dBi ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ 5G	

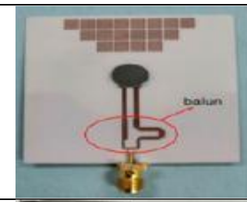
Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[34]	♦ Uniplanar MSA based quasi Yagi antenna ♦ Simple microstrip feed ♦ Antenna size:$0.47\lambda_0$ x $0.13\lambda_0$	♦ Operating frequency:2.45GHz ♦ Impedance bandwidth:-- ♦ Gain :6.7 dBi (8.2dBi with additional director) ♦ Front to back ratio: 18dB ♦ Cross polarization level:-13dB	♦ RF front end circuits	
[35]	♦ A simple feed-based quasi Yagi antenna ♦ Two parallel (opposite plane) strips for feeding ♦ Antenna size:$2\lambda_0$ x λ_0	♦ Operating frequency: 8GHz ♦ Impedance bandwidth:40% ♦ Gain:-- ♦ Front to back ratio: 15dB ♦ Cross polarization level:-20dB	♦ Phase arras	--
[37]	♦ Dual band quasi Yagi antenna ♦ Optimized gain ♦ Closely spaced two drive elements ♦ Antenna size: $0.66\lambda_0$ x $0.69\lambda_0$	♦ Operating frequency: 1.8GHz & 2.6GHz ♦ Impedance bandwidth:10.5% & 4% ♦ Gain :6 & 7.7dBi ♦ Front to back ratio:22, 18.4 ♦ Cross polarization level:--	♦ LTE	
[38]	♦ Printed Yagi antenna array ♦ Pattern reconfigurable ♦ Feed structure with varying phases. ♦ Antenna size--	♦ Operating frequency:4.35GHz ♦ Impedance bandwidth:75.9% ♦ Gain: 6dBi ♦ Front to back ratio:-- ♦ Cross polarization level:-15dB	♦ --	
[39]	♦ Yagi antenna for mm-wave communication ♦ Switched beam with high gain characteristics ♦ Antenna size:29mm x 79mm	♦ Operating frequency: 24GHz ♦ Impedance bandwidth:6.5% ♦ Gain :7.97dBi ♦ Front to back ratio:-- ♦ Cross polarization level:--	♦ 5G ♦ Milli-meter wave applications	--
[40]	♦ Quasi Yagi antenna with vertical poles. characteristics ♦ MIMO with pattern diversity ♦ Antenna volume: $\pi\lambda_0$ x $0.33\lambda_0$ x $0.14\lambda_0$	♦ Operating frequency:3.55GHz ♦ Impedance bandwidth:14% ♦ Gain:8.2dBi ♦ Front to back ratio:-- ♦ Cross polarization level:-20dB	♦ 5G (N78 band)	
[41]	♦ Circular array configuration using quasi Yagi antenna. ♦ Beamforming MIMO antenna ♦ Antenna size: $1.87\lambda_0$ x $2.15\lambda_0$	♦ Operating frequency:28GHz ♦ Impedance bandwidth: 47% (broadband and 15% for dual-band) ♦ Gain :8.9dB (peak) for single band and 7.9dB (peak) for dual-band ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ 5G	
[42]	♦ MIMO Yagi antenna with dumbbell defected ground ♦ Loop excitation ♦ Antenna size: 50mm x 80mm	♦ Operating frequency: 2.4GHz, 5.32 GHz ♦ Impedance bandwidth: 38.72% ♦ Gain :4.7dB (peak) ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ WLAN ♦ Wi-Fi ♦ Wi-Max ♦ Medical	

Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[43]	♦ A new Yagi antenna with large bandwidth ♦ 3D printed ♦ Antenna volume:30cm x 30cm x 5cm	♦ Operating frequency: 5GHz ♦ Impedance bandwidth:39% ♦ Gain :13dBi (peak) ♦ Front to back ratio: --- ♦ Cross polarization level:-10dB	♦ 5G (N79)	
[44]	♦ Octagonal microstrip Yagi antenna ♦ Double layer ♦ Antenna size:39mmx70mmx34.075mm	♦ Operating frequency: 5.8GHz ♦ Impedance bandwidth: 14.6% ♦ Gain :13dBi (peak)for double layer ♦ Front to back ratio:-- ♦ Cross polarization level:-10dB	♦ --	
[46]	♦ Split ring resonator based Yagi antenna ♦ Multiple driven elements ♦ Antenna size:Array 1: $2.54\lambda_0$x0.25 λ_0 ♦ Array 2: $3.18\lambda_0$x$0.25\lambda_0$	♦ Operating frequency: 2.45GHz ♦ Impedance bandwidth:6.6% ♦ Gain :11.7dBi (array 1); 12.4dBi (array 2) ♦ Front to back ratio: 13.4dB & 14.8dB ♦ Cross polarization level:--	♦ Wi-Fi	
[48]	♦ Compact Yagi antenna with SRR and bent arms ♦ High gain antenna ♦ Antenna size:60mmx90mm (straight arms) ♦ Bent arm: 60mm x 75mm (0.49 λ_0x$0.61\lambda_0$)	♦ Operating frequency: 2.45GHz ♦ Impedance bandwidth:16.32% ♦ Gain :6.58dBi ♦ Front to back ratio:-- ♦ Cross polarization level:--	♦ Point to point wireless communicatio n	
[49]	♦ High gain quasi Yagi antenna ♦ Split ring resonator for miniaturization ♦ Antenna size: 200mm x 207mm	♦ Operating frequency: 2.45GHz ♦ Impedance bandwidth:16.3% ♦ Gain :12dBi ♦ Front to back ratio:-- ♦ Cross polarization level:--	♦ Wireless power transfer	
[50]	♦ Dual band high gain Yagi antenna ♦ Split ring resonators for high gain ♦ Antenna size:95mm x 80mm	♦ Operating frequency:1.8 & 2.45GHz ♦ Impedance bandwidth:11.11% & 6.53% ♦ Gain :6 dBi & 5.8dBi respectively ♦ Front to back ratio:14dB & 15dB ♦ Cross polarization level:--	♦ Energy harvesting	
[51]	♦ Filtering-radiating Yagi antenna ♦ Low cross-polarization ♦ Common mode suppression ♦ Antenna size: --	♦ Operating frequency: 3.76 & 4.15GHz ♦ Impedance bandwidth:18.5% ♦ Gain :4.17 & 5.82dBi ♦ Front to back ratio: -- ♦ Cross polarization level:-24dB	♦ Balanced wireless systems	

Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[52]	♦ Compact quasi Yagi antenna ♦ Wideband filtering response ♦ Double side printed driven dipole ♦ Antenna size: 70mm x 49 mm ($0.53\lambda_0$x$0.37\lambda_0$)	♦ Operating frequency: 2.3GHz ♦ Impedance bandwidth:30.4% ♦ Gain:5.04 to 6.36dBi ♦ Front to back ratio: 19dB ♦ Cross polarization level:-28dB	♦ --	
[53]	♦ Printed quasi Yagi antenna ♦ Dual driven elements ♦ Multi mode operation ♦ Compact and dual wideband operation ♦ Antenna size: $0.058\lambda^2$ (area)	♦ Operating frequency: 1.1 & 3.7GHz ♦ Impedance bandwidth:44% & 115% ♦ Gain :2.6 to 4.2dBi & 2 to 5.2dB ♦ Front to back ratio: 8.3dB ♦ Cross polarization level:-28dB	♦ Short range wireless	
[54]	♦ Phased array quasi Yagi antenna ♦ Eight elements of compact antenna ♦ Antenna size:-- ♦ Beam scanning: 0 to 75^0	♦ Operating frequency: 26GHz ♦ Impedance bandwidth: 7.69% ♦ Gain : 10.5 to 12dB ♦ Front to back ratio: -- ♦ Cross polarization level: --	♦ 5G cellular	--
[55]	♦ Dual-wideband quasi Yagi antenna ♦ Dielectric resonator-based ♦ Antenna size:34mm x 30mm (substrate/resonator size)	♦ Operating frequency: 10.46GHz ♦ Impedance bandwidth: 21.7% ♦ Gain : 8dBi ♦ Front to back ratio: -- ♦ Cross polarization level: -18dB	♦ --	
[56]	♦ Mutual coupling reduction in quasi Yagi antenna array ♦ Hybrid-wideband decoupling ♦ Antenna size:59.6mm x 45mm.	♦ Operating frequency: 7.6GHz ♦ Impedance bandwidth: 92.1% ♦ Gain: 8dB ♦ Front to back ratio: -- ♦ Cross polarization level: -- ♦ Mutual coupling coefficient: -20dB	♦ Multi bands and wideband array	
[57]	♦ Broadband quasi Yagi antenna. ♦ Multi directors ♦ Antenna size: - -	♦ Operating frequency: 3.05GHz ♦ Impedance bandwidth:50 % ♦ Gain : 5dB (flat) ♦ Front to back ratio: -- ♦ Cross polarization level: --	♦ Wi-Fi ♦ Wi-Max	
[59]	♦ Compact and collinear-array quasi Yagi antenna. ♦ Beams: 2 ♦ Antenna size: 49mm x 190.5mm($0.4\lambda_0$x1.55 λ_0)	♦ Operating frequency: 2.45GHz ♦ Impedance bandwidth:13.46 % ♦ Gain : 8.9 to 9.24dB ♦ Front to back ratio: -- ♦ Cross polarization level: --	♦ Wireless energy harvesting	
[60]	♦ Dual output quasi Yagi antenna ♦ Simultaneous information & power transmission ♦ Antenna size:	♦ Operating frequency: 1.8 and 2.4GHz ♦ Impedance bandwidth: % ♦ Gain : -3.17 & 1.84 dB (@2.45GHz) ♦ Front to back ratio: -- ♦ Cross polarization level: -15dB	♦ RF energy-harvesting	

Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[61]	♦ Yagi antenna for cubesat ♦ Multiple frequency tilt angles operation ♦ Antenna size:100 x 98mm	♦ Operating frequency: 1.3, 2.4 and 3GHz ♦ Impedance bandwidth: % ♦ Gain 8.167 at 2.4GHz, 5.278 at 1.3 GHz and 6.12 at 3GHz: ♦ Front to back ratio: dB ♦ Cross polarization level: dB	♦ Cubesat	
[63]	♦ Wearable Yagi antenna ♦ Meta surface enabled ♦ Antenna size: $0.25\lambda x 0.25\lambda$	♦ Operating frequency: 915MHz ♦ Impedance bandwidth: % ♦ Gain : 5.9dBi (directivity) ♦ Front to back ratio: 22dB ♦ Cross polarization level: --	♦ UHF-RFID reader	
[65]	♦ Compact and broadband quasi Yagi antenna ♦ Enhanced performance at ISM band ♦ Dual-band ♦ Antenna size:300mm x 228.6 mm (0.428λ x0.325λ)	♦ Operating frequency: 433 and 868MHz ♦ Impedance bandwidth: 70% ♦ Gain: 5.5 and 5dBi ♦ Front to back ratio: 12 & 14dB ♦ Cross polarization level: --	♦ UHF-ISM band	
[66]	♦ Printed Yagi antenna ♦ Two elements array ♦ Antenna size:0.34λ x 0.58λ	♦ Operating frequency: 2.51GHz ♦ Impedance bandwidth:28.7 % ♦ Gain: 4.5 to 6.8dBi ♦ Front to back ratio: -- ♦ Cross polarization level: ---	♦ WLAN	
[67]	♦ Compact planar quasi Yagi antenna ♦ Notch band characteristics ♦ Antenna size:$0.51\lambda_g$ x 0.53 λ_g	♦ Operating frequency: GHz ♦ Impedance bandwidth: 122.6% ♦ Gain : ♦ Front to back ratio: ♦ Cross polarization level:	♦ WLAN ♦ Dedicated short-range for UWB	
[68]	♦ Printed Yagi Antenna ♦ Additional driven element ♦ Collinear configuration ♦ Antenna size:	♦ Operating frequency: 2.4GHz ♦ Impedance bandwidth: 6.25% ♦ Gain: 11dBi ♦ Front to back ratio: 20dB ♦ Cross polarization level:	♦ WLAN	
[69]	♦ Quasi Yagi antenna for dual-band operation ♦ Semi bow-tie driven element ♦ Antenna size:$0.35\lambda_0$ x $0.27\lambda_0$	♦ Operating frequency: 0.88GHz ♦ Impedance bandwidth: 14.7% ♦ Gain : 1.9 to 2.2dBi ♦ Front to back ratio: -- ♦ Cross polarization level: --	♦ Wireless power transmission	--

Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[70]	♦ Printed quasi Yagi antenna ♦ For location tracking, especially indoor ♦ Antenna size: 32.7mm x 33mm	♦ Operating frequency: 7.21GHz ♦ Impedance bandwidth: 60.47% ♦ Gain : 6.46dBi (peak) ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ Indoor location tracking	
[71]	♦ Wideband quasi- Yagi antenna ♦ Dual polarized characteristics ♦ Broad beam patterns ♦ Antenna volume: π mm x50 mm x 45mm	♦ Operating frequency: 2.32GHz ♦ Impedance bandwidth: 60% ♦ Gain: 7.7 ±0.8dBi ♦ Front to back ratio: -- ♦ Port to port isolation: 25dB	♦ Indoor access-points	
[72]	♦ Planar broadband quasi Yagi antenna ♦ Modified bow tie drove element ♦ Antenna size:1.24λ_{gc} x 0.94λ_{gc}	♦ Operating frequency: 2.425GHz ♦ Impedance bandwidth:80.4 % ♦ Gain: 4dBi ♦ Front to back ratio: 10dB ♦ Cross polarization level:	♦ 3G/4G	
[73]	♦ Quasi-Yagi loop and dipole antennas ♦ Silicon substrate ♦ Antenna size: 5002µm x 3502µm	♦ Operating frequency: 94GHz ♦ Impedance bandwidth: 25.53% ♦ Gain : 7.5dBi ♦ Front to back ratio: 15.74dB ♦ Cross polarization level:-14.8dB	♦ 94GHz imaging applications	--
[74]	♦ Ink printed Yagi antennas ♦ Wideband dipole array ♦ Flexible antenna	♦ Operating frequency: 26.5GHz ♦ Impedance bandwidth: 26.41% ♦ Gain : 4.2dBi (peak) ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ 5G applications ♦ Medical sensing	
[75]	♦ 60GHz printed Yagi antenna ♦ Two stacked planar arrays ♦ Antenna size:1.0687cm x 0.8015cm	♦ Operating frequency: 60GHz ♦ Impedance bandwidth:8.33 % ♦ Gain : 10dB ♦ Front to back ratio: 29dB (double layer) and 23dB for a single layer ♦ Cross polarization level:--	♦ MMIC ♦ Short-range wireless ♦ imaging	
[76]	♦ Wideband Yagi antenna ♦ Tightly-coupled directive element ♦ Antenna size:1.68λ_0 x0.72λ_0	♦ Operating frequency: 3.45GHz ♦ Impedance bandwidth: 49.27% ♦ Gain : 8.7dBi(peak) (Avg. 7dBi) ♦ Front to back ratio: dB ♦ Cross polarization level:--	♦ Broadband RF	
[77]	♦ Yagi antenna with close-spaced elements. ♦ Multiple folding in the driver ♦ Two elements antenna ♦ 50 µm PET film	♦ Operating frequency: 1GHz ♦ Impedance bandwidth: NA ♦ Gain: 9.56dB ♦ Front to back ratio: 7.59dB ♦ Cross polarization level:--	♦ RF-ID	

Ref.	Specifications and features of antenna geometry	Reported results	Applications	Specimen prototype
[78]	♦ Compact quasi-Yagi antenna ♦ Stable gain ♦ Enhanced bandwidth ♦ Antenna size:1.21λ_0 x1.55 λ_0	♦ Operating frequency: 9.6GHz ♦ Impedance bandwidth:11.43 % &13.1% ♦ Gain: 7.3 ±0.75 dB ♦ Front to back ratio: 12.5dB ♦ Cross polarization level:--	♦ --	
[79]	♦ Printed quasi-Yagi antenna ♦ Double dipole ♦ Stub loaded ♦ Antenna size:0.3 λ_0 x 0.3 λ_0	♦ Operating frequency: 6.4GHz ♦ Impedance bandwidth: 81.3% ♦ Gain: 2.7 to 6dBi ♦ Front to back ratio: 15dB ♦ Cross polarization level:--	♦ Multiband ♦ Broadband	
[80]	♦ Beam switchable Yagi antenna ♦ Suitable for mobile handsets ♦ Scan area: 180^0	♦ Operating frequency: 28GHz ♦ Impedance bandwidth: 42% ♦ Gain: 8dBi ♦ Front to back ratio: -- ♦ Cross polarization level:--	♦ 28GHz mobile devices ♦ Mobile handsets	

4. Summary and Conclusion

Quasi Yagi antennas suitable for the state of the art applications have been extensively discussed and presented. The following points may be noted with respect to the quasi Yagi antennas presented (Table 2) by several researchers:

- Researchers have made several efforts and investigated the design of quasi Yagi antennas for performance improvement by changing the shape of the driven elements (a simple monopole/dipole, patch, bow-tie/semi bow-tie, loop, log-periodic dipole etc.) [8, 9, 25, 19, 70] to improve the performance of quasi Yagi antenna designs suggested by them.
- A few researchers have focussed on simplifying the design of complex BALUN structures [8, 9, 25]. In some works, BALUN is replaced with coplanar waveguide (CPW) feed, a simple microstrip line with varying width or microstrip lines on different planes.
- Some works have been reported on addressing the MIMO applications [13, 27, 37-39, 81], pattern reconfiguration [2, 35] and combining the features of filter [29, 48-49] and radiation parameters.
- Among the reported results the maximum values of antenna parameters obtained are:
  - Impedance bandwidth: 122.6% [64]
  - Peak gain: 13.4dBi [43]
  - Front to back ratio: 22dB [34, 60]

  -Cross polarization level: -28dB [49, 50]
  -Maximum switchable beams: 07 (-60^0 to $+60^0$ in steps of 20^0) [2]
  -Maximum scan area: 180^0 [77]
- Dual-band antennas are presented in [34, 38, 47, 52, 62, 66]
- The dual-polarized antenna is presented in [68]
- Yagi antennas with monopole driven elements and the microstrip line/tapered microstrip line have a better performance than the geometries with dipole driven elements and other feed structures [8, 9, 25].
- Most researchers have made an effort on designing compact quasi Yagi antennas. However, no benchmark is found for defining the compactness of the quasi Yagi antennas.
- Among the compact antennas presented in [8, 9, 27, 45, 49, 50, 51, 56, 62, 64, 75], the most compact one in terms of antenna size has an overall area of $0.058\lambda^2$, which is 60% less in size compared to conventional printed Yagi antennas.
- A few antennas available are 3D printed/double/multi-layer Yagi antennas [40, 41] designed specifically to enhance the antenna's gain. A typical gain of these antennas is above 13dBi. However, these are highly undesirable for mobile wireless appliances due to their size constraints.
- It may be noted that researchers have designed quasi Yagi antennas which cover a wide range of state of the art wireless applications, including 5G technologies. Further, these works cover gain improvement, pattern diversity, frequency diversity, scanned beam antennas, dual-band, multi-band, and MIMO applications.

This extensive review study may conclude that these results are useful for the researchers who want to carry out further research work on Yagi antennas, especially for addressing the simplification of feed structure and improving/enhancing the performance parameters.

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