

# A miniaturized broadband quasi-Yagi antenna for X- to Ku-band applications

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**Abstract:** A miniaturized, broadband quasi-Yagi antenna utilizing a modified ultra-wideband microstrip-to-coplanar stripline (MS-to-CPS) balun is proposed. Excellent broadband phase and amplitude balance is possible due to the ultra-wideband MS-to-CPS balun based on field and impedance matching concept. The implemented antenna provides very wide bandwidth from 7 to 15.1 GHz (73.3%). The gain of the antenna is from 3.7 to 5.5 dBi, the front-to-back ratio is more than 10 dB, and the nominal radiation efficiency is about 94%.

**Keywords:** broadband antennas, microstrip antennas, baluns **Classification:** Microwave and millimeter wave devices, circuits, and systems

### References

LETTER

- W. Deal, N. Kaneda, J. Sor, Y. Qian, and T. Itoh, "A new quasi-Yagi antenna for planar active antenna arrays," *IEEE Trans. Microw. Theory Tech.*, vol. 48, no. 6, pp. 910–918, June 2000.
- [2] D. S. Woo, Y. G. Kim, K. W. Kim, and Y. K. Cho, "Design of quasi-Yagi antennas using an ultra-wideband balun," *Microwave Opt. Tech. Lett.*, vol. 50, pp. 2068–2071, Aug. 2008.
- [3] H. K. Kan, R. B. Waterhouse, A. M. Abbosh, and M. E. Bialkowski, "Simple broadband planar CPW-fed quasi-Yagi antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 6, pp. 18–20, 2007.
- [4] S. X. Ta, B. C. Kim, H. S. Choo, and I. M. Park, "Wideband quasi-yagi antenna fed by microstrip-to-slotline transition," *Microwave Opt. Tech. Lett.*, vol. 54, pp. 150–153, Jan. 2012.
- [5] K. M. K. H. Leong, Y. Qian, and T. Itoh, "Surface wave enhanced broadband planar antenna for wireless applications," *IEEE Microwave Wireless Compon. Lett.*, vol. 11, pp. 62–64, Feb. 2001.
- [6] Y. Qian and T. Itoh, "A broadband uniplanar microstrip-to-CPS transition," 1997 Asia Pacific Microwave Conf. Dig., pp. 609–612, Dec. 1997.
- [7] Y. G. Kim, D. S. Woo, K. W. Kim, and Y. K. Cho, "A new ultra-wideband microstrip-to-CPS transition," *IEEE MTT-S Int. Microw. Symp. Dig.*, pp. 1563–1566, June 2007.
- [8] B. Jokanovic, V. Trifunovic, and B. Reljic, "Balance measurements in double-Y baluns," *IEE Proc.-Microw. Antennas Propag.*, vol. 149, no. 6, pp. 257–260, 2002.
- [9] D. S. Woo, Y. G. Kim, Y. K. Cho, and K. W. Kim, "Ultra-wideband Fermi





antenna using microstrip-to-CPS balun," *IEICE Trans. Commun.*, vol. EB93-B, no. 8, pp. 2219–2222, Aug. 2010.

## **1** Introduction

The planar quasi-Yagi antennas [1] have widely been used in microwave/ mm-wave wireless systems because of their broad bandwidth, good gain, low cost, simple fabrication, and ease of integration with microwave integrated circuits (MICs). Several types of design for the planar quasi-Yagi antennas have been reported for various applications such as phased arrays, power combining, and active arrays [1, 2, 3, 4, 5, 6, 7]. With these antennas, the designs of the antenna radiating parts were similar, but the main differences lied at the antenna feeding networks. Various antenna feeding structures used for the quasi-Yagi antennas are MS-to-CPS balun (or transition) in [1, 2], coplanar waveguide (CPW)-to- CPS balun in [3], MS-to-slotine balun in [4], and the broadside coupled MS-to-CPS balun in [5].

In many designs of most commonly used MS-to-CPS balun structures for the quasi-Yagi antenna suggested by [6], 180 degree phase difference on the CPS lines was guaranteed only for narrow bandwidth near the center frequency; i.e., the odd-mode conversion with the phase delayed leg was expected to work only for narrow frequency bandwidth. Also, most of the broadband quasi-Yagi antenna designs were mainly based on return loss performances. But, broad impedance bandwidth may not be a sufficient criterion for good radiation characteristics for whole frequency band. Moreover, balun amplitude and phase imbalances on the CPS feed lines were not investigated in previous designs of broadband quasi-Yagi antennas [1, 2, 3, 4, 5, 6]. A systematic design approach of broadband quasi-Yagi antennas utilizing ultra-wideband MS-to-CPS balun [7] was introduced by the author's group [2]. Due to a metal strip used for a reflector was located at the bottom layer of the antenna, the front-to-back (F/B) ratio were sometimes degraded. The antenna size was also relatively larger than other configurations of the quasi-Yagi antennas.

In this paper, a miniaturized, broadband quasi-Yagi antenna using the modified MS-to-CPS balun with improved performance is presented. The shaped bottom ground reduces the antenna size and backside radiation. Also, the effects of amplitude and phase imbalance of the MS-to-CPS balun over the operating frequency band are discussed.

#### 2 Balun and antenna design

Figure 1 shows the configuration of the proposed quasi-Yagi antenna using the ultra-wideband MS-to-CPS balun. The antenna consists of the antenna feeding structure and the quasi-Yagi radiating elements. The antenna feed structure is composed of a microstrip line and the ultra-wideband MS-to-CPS balun. The radiating parts of the antenna consist of one dipole antenna (driver) and a conductor strip (parasitic director). The bottom ground conductor layer is shaped to serve as a reflector for the antenna. For design of the balun [7], the field distribution of the microstrip line is gradually transformed to that of the CPS through the ground-shaped







Fig. 1. The configuration of the proposed quasi-Yagi antenna, (a) Schematics, (b) fabricated antenna. Antenna design parameters (in unit of mil):  $L_1=245$ ,  $L_2=310$ ,  $W_1=70$ ,  $W_2=60$ ,  $S_d=35$ ,  $S_r=225$ ,  $S_g=5$ ,  $L_{cps}=50$ ,  $W_{cps}=30$  and  $L_{bal}=260$ .

structure while providing the ground continuity by using several via holes to maintain the same ground potential for broad bandwidth. In order to optimally match the impedances between the microstrip line and the CPS, Klopfenstein taper has been used to minimize the reflection coefficient. The balun has proven to provide broadband amplitude and phase balances between two CPS strips.

The proposed antenna was designed by the following procedure. Firstly, an ultra-wideband MS-to-CPS balun was designed using the guidelines presented in [7] as shown in Fig. 1. The substrate used in this design was the Rogers RO4003<sup>®</sup> ( $\varepsilon_r$ =3.38, tan $\delta$ =0.0027) substrate with 20-mil thickness. The characteristic impedance of the CPS was chosen as about  $107 \,\Omega$  with 5 mil gap  $(S_g)$  between CPS strips and 30 mil strip width  $(W_{cDS})$ . Secondly, the quasi-Yagi radiating elements (driver and parasitic director) were optimized to achieve a wide impedance bandwidth and good radiation performance over the broad frequency bandwidth from X- to Ku-band. The driver length (L<sub>2</sub>) was chosen as about  $\lambda_0/4$  at 9 GHz to provide good performance at low-band frequencies. The director length  $(L_1)$  and spacing  $(S_d)$  were optimized for good performance at high-band frequencies. The spacing  $(S_r)$  between the dipole and the bottom ground conductor was about  $\lambda_0/4$  at 12 GHz to reduce backward spill-over. After optimization and implementation, the size of the antenna was approximately  $19 \,\mathrm{mm}$   $\times$  $20 \,\mathrm{mm} \,(0.63\lambda_0 \times 0.67\lambda_0)$ , where  $\lambda_0$  is the free space wavelength at the center frequency. The area of the proposed antenna takes only 53% of our previous design [2]. If the antenna is to be designed with a high-permittivity substrate, the antenna size can be further reduced.

#### 3 Experimental results and discussions

Firstly, to evaluate performance of the balun, a back-to-back configuration of the balun was designed and implemented with the CPS length of 210 mil and the balun length  $(L_{bal})$  of 260 mil. 3-D EM simulations were performed with the ANSYS<sup>®</sup> HFSS<sup>TM</sup>. It is can be seen from Fig. 2(a) that the measured insertion loss is less than 1 dB per balun from 7 to 20 GHz. The







Fig. 2. Performances of the MS-to-CPS balun (a) insertion loss (IL) and return loss (RL), (b) simulated amplitude and phase imbalances.

simulated and measured results of the balun indicate that the impedance bandwidth with more than 10 dB return loss is from 7 to over 20 GHz. As can be seen, simulated results agree closely with measured results. To maintain close to 180 degree phase difference between the CPS strips, a balun must be properly matched and properly excite the odd-mode on the CPS strips. Poor excitation of the odd mode on the CPS line can cause degradation of the radiation patterns. EM simulation studies have been performed to evaluate phase and amplitude imbalances at the CPS port. Similarly to the test method suggested by [8], the balanced CPS line was symmetrically split into two unbalanced MS output ports. For 6 to 16 GHz range, the amplitude difference between the two CPS strips (S21 and S31) was less than 1 dB as shown in Fig. 2(b). Also, with the proposed balun, the phase deviation from 180° between the two CPS strips was maintained within  $7^{\circ}$  (from  $178^{\circ}$  to  $185^{\circ}$ ) over whole operating frequencies. The maximum allowable phase imbalance may be dependent on specific applications, but, in general,  $\pm 5^{\circ}$  deviation from  $180^{\circ}$  may be considered as a well-designed balun [8]. Therefore, the proposed MS-to-CPS balun is considered to be quite suitable for broadband balanced antennas (e.g., Fermi antenna) [9].

The designed and fabricated quasi-Yagi antenna is shown in Fig. 1(b). Figure 3(a) shows comparisons of the measured and simulated return losses of the antenna elements: i.e., the 2-element dipole array (A), the dipole array and reflector without the balun (B), and the whole antenna (C). The measurement was carried out by using an Anritsu universal test fixture 38801 K, which allowed the maximum usable frequency up to 40 GHz. As can be seen, the simulated return loss agrees closely with the measured result. The antenna operates from 7 to 15.1 GHz (73.3%) covering the X- to Ku-band. The addition of the reflector and balun to the two-element dipole array did not change the bandwidth of the dipole array, thus simplifying the antenna design process. Figure 3(b) shows the simulated and measured antenna gain and radiation efficiency. The antenna gain varies from 3.7 to 5.5 dBi. Some discrepancies noticed between the simulated and measured gain may have been caused by fabrication and measurement tolerances. The simulated radiation efficiency of the antenna is nominally 94% for the operating frequencies. Figures 4(a)-(d) show the measured radiation patterns at 8, 10, 12, and 14 GHz, respectively. As can be seen, the measured radiation patterns are very uniform over the whole operating







Fig. 3. Performances of the fabricated antenna (a) return loss, (b) gain and efficiency.





(c) (d) Fig. 4. Measured radiation patterns, (a) 8 GHz, (b) 10 GHz, (c) 12 GHz, and (d) 14 GHz. (CO-POL: co-polarization, X-POL: cross-polarization)

Table	I.	Performance	summary	of	the	quasi-Yagi
		antennas.				

Parameters	Unit	Ref. [1]	Ref. [2]	This work
Frequency	GHz	7.2 - 12	10.6 - 18.3	7 - 15.1
range	%	48	53.3	73.3
Gain	dBi	3.4 - 5.1	4.5 - 5.5	3.7 - 5.5
HPBW	deg(°)	110	78 - 85	70 - 87
F/B ratio	dB	> 12	8-15	10 - 25
X-pol. level	dB	< -12	< -12	< -10
Efficiency	%	93	94	94
Size	mm	$13 \times 20$	20 × 36	$19 \times 20$
Substrate material		Duroid6010 ( $\epsilon_r = 10.2$ ) t = 0.762 mm	RO4003 ( $\epsilon_r = 3.38$ ) t = 0.508 mm	





frequencies. The half-power bandwidth (HPBW) of E-plane is typically about  $80^{\circ}$  and F/B ratio ranges from 10 to 25 dB. Measured cross-polarization levels are better than  $-10 \, \text{dB}$ . The performances of the proposed quasi-Yagi antenna are summarized and compared with the reported antennas in Table I. As can be seen, the proposed antenna exhibits much wider bandwidth, smaller size, and better radiation performances as compared with the previous designs.

## 4 Conclusion

In this paper, a compact, broadband quasi-Yagi antenna utilizing ultrawideband MS-to-CPS balun has been introduced. The shaped bottom ground plane serves as a reflector and helps to reduce the antenna size by 53% of the previous design. The MS-to-CPS balun provides excellent phase and amplitude balances for the whole operating bandwidth. The measured radiation patterns show very uniform performances for the whole operating frequency band. The proposed antenna can be a cost-effective solution for various compact, broadband phased arrays and imaging systems for microwave/mm-wave frequencies.

# Acknowledgments

This research was supported by the MKE (The Ministry of Knowledge Economy), Korea, under the CITRC (Convergence Information Technology Research Center) support program (NIPA-2012-H0401-12-1006) supervised by the NIPA (National IT Industry Promotion Agency.)

