A Uniplanar Quasi-Yagi Antenna with Wide Bandwidth and Low Mutual Coupling Characteristics

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Abstract - *We report for the first time a planar quasi-Yagi antenna printed on a single layer of high dielectric constant substrate (Duroid,* $e_r=10.2$*) which measures 48 % bandwidth (VSWR<2). The antenna radiates an end-fire beam, with a front-to-back ratio >15 dB and cross polarization level below –12 dB across the entire frequency band. A very low mutual coupling level of below –22 dB has been measured for a two-element array with* $l_0/2$ *separation.*

I. Introduction

Planar antennas with wideband characteristics have been the pursuit of antenna designers for many years. Microstrip patch antennas are inherently narrowband, although broadband designs can be realized by employing multilayer structures with aperture coupling [1], or by introducing parasitic slots inside the patch [2]. Slot antennas with either microstrip or CPW feeding offer wider bandwidth, but require additional design considerations such as using cavities or reflectors to overcome the problem of bi-directional radiation [3]. Meanwhile, end-fire antennas such as the Vivaldi and linearly tapered slot antenna (LTSA) are traveling-wave type structures that can achieve broader bandwidth [4], although they usually have larger electrical size than resonant-type patches or slots. Tapered slot antennas also require either microstrip-to-slot or CPW-to-slot transitions as part of the feeding network, which not only increases the design complexity but also imposes a limit on the frequency response.

We have recently proposed and demonstrated a novel uniplanar quasi-Yagi antenna that has both the compactness of resonant-type antennas and broadband characteristics of traveling-wave radiators. Unlike the traditional Yagi dipole design, we employed the truncated microstrip ground plane as the reflecting element, thus eliminating the need for a reflector dipole [5]. This results in a very compact design ($< \lambda_0/2$) which is totally compatible with any microstrip-based MMIC circuitry. An X-band prototype with 17 % bandwidth, 6.5 dB gain, 18 dB front-to-back ratio and –15 dB cross polarization level has been achieved [6].

In this paper we demonstrate that by further optimization the quasi-Yagi antenna can achieve extremely broad bandwidth (48 % measured), while keeping an end-fire radiation pattern with acceptable front-to-back ratio (>15dB) and cross polarization level (<-12dB) across the entire band. Furthermore, the mutual coupling between neighboring elements of a quasi-Yagi antenna array is found to be very low, with a measured level of <–22 dB for a 2-element structure with $\lambda_0/2$ separation. Such compact array with low mutual coupling characteristics should find wide applications in modern communications and radar systems as well as millimeter-wave imaging arrays.

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II. Design and Measurement of Single Element

Fig. 1 shows the schematic of the uniplanar quasi-Yagi antenna, which has been modified slightly from a previous design in order to achieve maximum bandwidth [6]. The antenna consists of a printed dipole director, and a driver dipole fed by a broadband microstrip-to-coplanar strips (CPS) transition [7]. The unique feature of this antenna is the use of the truncated microstrip ground plane as the reflecting element. This results in a very compact and simple structure that can be easily integrated with any microstrip-based circuitry. The entire antenna, including the microstrip-to-CPS transition, is less than $0.5\lambda_0$ in size. In addition, it is built on high dielectric constant substrate (Duroid with ε_r=10.2), so that it offers the potential of monolithic integration with Si, GaAs or InP-based MMICs for higher frequency applications.

Fig. 2 is the picture of an X-band prototype that has been optimized by using an in-house FDTD code. The antenna uses 0.635 mm thick Duroid with $\varepsilon_r = 10.2$. Detailed dimensions are (unit: mm): $W_1 = W_3 = W_4 = W_5 = W_{dri} = W_{dir} = 0.6$, $W_2 = 1.2$, $W_6 = S_5 = S_6 = 0.3$, $L_1 = 3.3$, $L_2 = L_5 = 1.5$, $L_3 = 4.8$, $L_4 = 1.8$, $S_{ref} = 3.9$, $S_{dir} = 3.0$, $S_{dir} = 1.5$, $L_{dri} = 8.7$ and $L_{dir} = 3.3$. Fig. 3 plots both FDTD simulation and measurement results for the input return loss. The simulated and measured bandwidths (VSWR<2) are 43 and 48 %, respectively, which covers the entire X-band. The antenna is at least two orders smaller in volume than a standard horn antenna for the same frequency coverage. To the authors' best knowledge, no planar-type antenna printed on a single layer of high-permittivity dielectric substrate has ever achieved such wide bandwidth with such a compact design.

Fig. 4 shows the calculated radiation patterns (both co- and cross-polarization) of the quasi-Yagi antenna at 10 GHz, indicating a well-defined end-fire pattern with front-to-back ratio of 17.5 dB and maximum cross-polarization level of –16.3 dB. These results are in close agreement with those measured for a previous design in [6]. Further simulations reveal the radiation pattern is quite stable as the frequency changes, with the front-to-back ratio >15 dB and cross polarization level < –12 dB across the entire frequency band between 8 and 12 GHz. This is contrary to many other broadband planar antenna designs where an increased bandwidth is usually realized at the expense of degradation in either back-side radiation or cross polarization. It is believed that the truncation of the microstrip ground plane in our design, as shown in Fig. 1, not only contributes to a good front-to-back ratio, but also eliminates the possible excitation of TM_0 type surface wave which tends to contaminate the radiation patterns. We are currently pursuing a more detailed investigation of this effect.

We have also found that the quasi-Yagi antenna can be scaled linearly to any frequency band of interest while retaining the wideband characteristics. In fact, a C-band prototype we have simulated and fabricated on 1.27 mm thick Duroid (ε_r=10.2) measured 50 % frequency bandwidth (4.17 to 6.94 GHz). FDTD simulation for a millimeter-wave version indicates that a single quasi-Yagi antenna works from 41.6 to 70.1 GHz (51 % bandwidth), which covers part of Q- and most of the V-band.

III. Mutual Coupling Characteristics

As an end-fire radiator, the quasi-Yagi antenna can be easily configured into a 2D array by simply stacking multiple cards of sub-arrays, which will be useful for adaptive arrays for communications, power combining or phased array radars, and millimeter-wave imaging. One important parameter in this context is the mutual coupling between elements within an array environment, which may not only complicate the array design but also become the cause of the notorious scan-blindness problem in most existing planar antenna arrays.

Despite its very compact design, the quasi-Yagi antenna shows very low coupling effect. Fig. 5 (a) shows a 2-element array with 15 mm spacing, which corresponds to 0.5 λ_0 at 10 GHz. The substrate is truncated at both sides, with a total width of 30 mm. Therefore, the measured S21 reflects primarily the mutual coupling between two elements at the edge of a large array. As can be seen in Fig. 5 (b), the coupling level is quite low across the whole bandwidth from 8 to 12 GHz, even in the presence of this edge effect, with a maximum measured S21 of –18.5 dB at 12 GHz. Meanwhile, to emulate the situation of two elements within a large array, we attached two small pieces of absorbers (6 mm wide, 25 mm long and 1 mm thick) to the side edges of the array. The measured S21 in this case, as shown in Fig. 5 (b), reveals an even lower coupling level, with a maximum value of –22.4 dB at the upper end of the operating frequency range of the antenna.

IV. Conclusion

We have demonstrated a very simple, compact and easy-to-fabricate planar antenna which achieves extremely wide frequency bandwidth and good radiation characteristics in terms of beam pattern, front-to-back ratio, cross polarization as well as mutual coupling. We believe that this antenna should find wide applications in wireless communication systems, power combining and phased arrays, as well as millimeter-wave imaging arrays.

Acknowledgments

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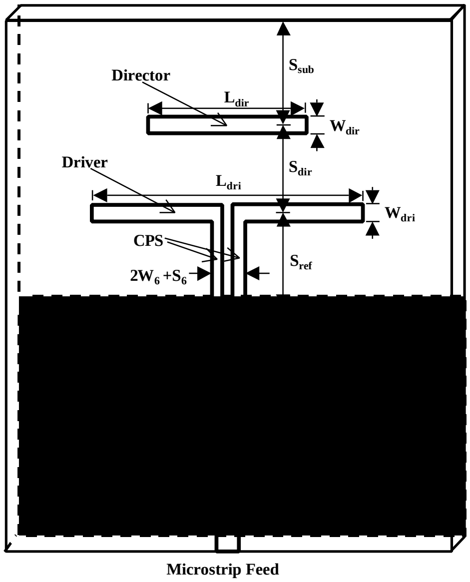


Fig. 1 Schematic of the uniplanar quasi-Yagi antenna.

Fig. 2 Picture of an X-band prototype quasi-Yagi antenna.

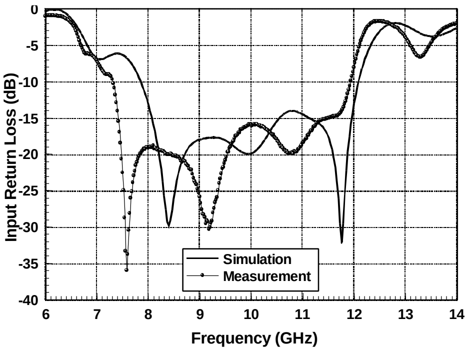


Fig. 3 FDTD simulation and measured input return loss of the X-band prototype antenna.

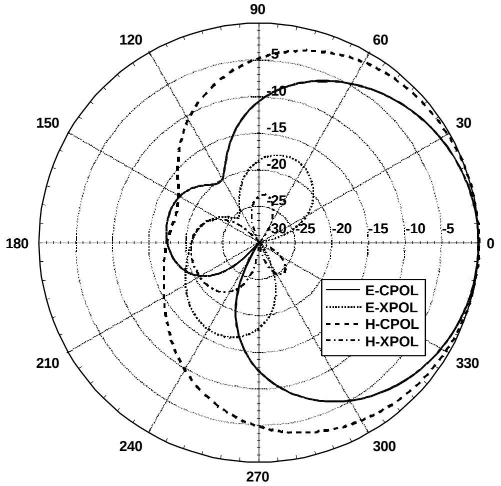
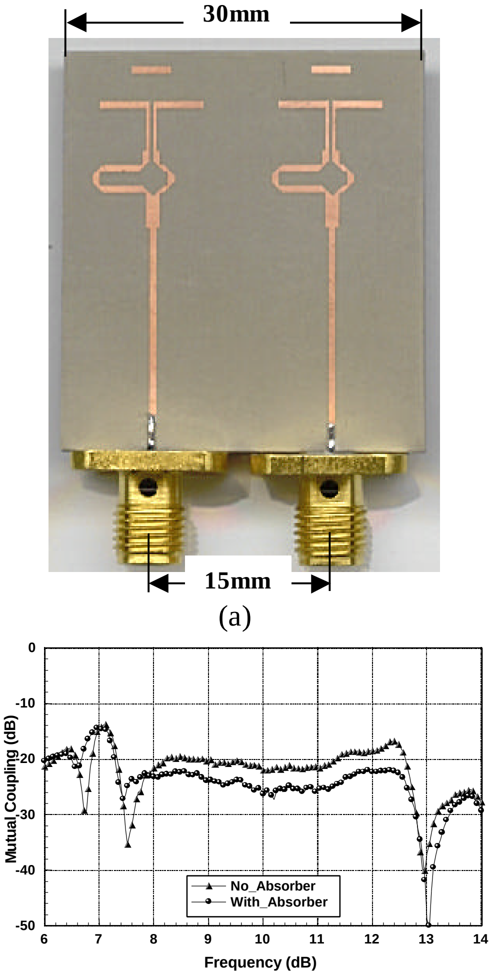


Fig. 4 Calculated radiation patterns of the quasi-Yagi antenna at 10 GHz.



(a)

(b)

Fig. 5 (a) Picture and (b) Measured mutual coupling (S21) of a two-element array.