A Compact 60-GHz Tapered Slot Antenna Printed on LCP Substrate for WPAN Applications

Lev Pazin and Yehuda Leviatan, *Fellow, IEEE*

***Abstract*—We describe a compact endfire 60-GHz tapered slot antenna (TSA), which is printed on a low-permittivity liquid crystal polymer (LCP) substrate. The antenna features a novel wideband collinear microstrip-to-slot transition, which is of smaller size compared to other transitions. This antenna can be integrated with a RF module for use in future wireless personal area network (WPAN) applications. Such an antenna can be used both as an individual radiator as well as an element of antenna array. The antenna also features a fork-shaped metallic carrier, which gives it good rigidity. In addition, the antenna features a metallic reflector, which increases its directive gain. Numerical simulations show that the operating frequency band of the antenna is from 53.3 to 69.6 GHz (greater than 25% bandwidth) and that the directive gain of the antenna within its operating frequency range 57–66 GHz is between 6.8 and 9.9 dB.**

***Index Terms*—Liquid crystal polymer (LCP), microstrip-to-slot transition, RF module, tapered slot antenna (TSA), wireless personal area network (WPAN).**

I. INTRODUCTION

bandwidth (5.6 GHz around 62 GHz) has also been recently proposed [7].

In this letter, a compact broadband endfire 60-GHz TSA printed on thin LCP substrate is proposed and simulated by use of the commercial CST Microwave Studio software. The antenna features a concise collinear-stub microstrip-to-slot transition between the microstrip feed line and the tapered slot. This transition provides a relatively wide frequency bandwidth. The transition is compact and has low insertion loss. In addition, the antenna features a metallic fork-shaped carrier, which gives the antenna good rigidity, and a metallic reflector, which increases its directive gain. The reflector also serves to reduce possible effects of other parts of the RF module on the antenna. The operating frequency range of the antenna covers the frequency ranges of 57–64, 59–62, 62–63, and 65–66 GHz allocated for high-speed data rate wireless communications in various countries [8], [9]. Such an antenna also offers wide-angle radiation in both the horizontal and elevation planes and can therefore be used as a laptop RF module antenna for wireless personal area network (WPAN) applications, where

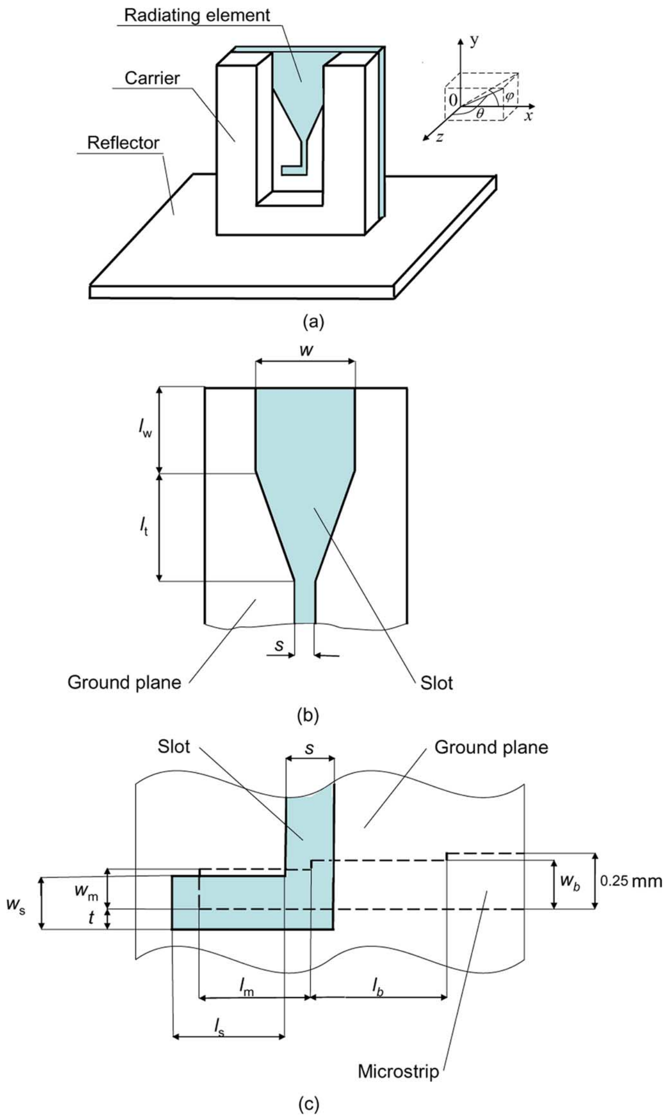

Fig. 1. Geometry of the proposed antenna: (a) isometric view; (b) radiating element; (c) microstrip-to-slot transition.

authors' knowledge is novel and compact and facilitates a bandwidth of operation wider than that required for WPAN applications.

In addition, the antenna is assumed to feature a metallic fork-shaped carrier, which gives the antenna good rigidity and serves as a base for mounting the metallic reflector as well as a means for connecting the antenna to the RF module (not shown in Fig. 1). As mentioned earlier, not only can the reflector improve the antenna directive gain, but it also can reduce possible effects of other parts of the RF module on the antenna.

III. Antenna Design

The design of the proposed antenna was carried out in three stages by use of the commercial CST Microwave Studio software. In the first stage, the antenna was considered without the carrier and reflector. The initial topology and dimensions of the slot were chosen like those of the compact linear-tapered slot antenna (LTSA) described in [11]. Specifically, we considered a feeding slot of width $s = 0.2$ mm and a linearly tapered slot of length $l_t = 4$ mm and aperture of width $w = 2.5$ mm. The initial topology and dimensions of the microstrip-to-slot transition were chosen in accordance with [12], where the theory of slotline transitions is described. Specifically, the microstrip and slot lines were set to cross each other at a right angle while the microstrip extended about one-quarter of a microstrip wavelength beyond the slot, and, similarly, the slot extended about one-quarter of a the slotline wavelength beyond the microstrip. To assess the wideband nature this preliminary antenna, we studied the antenna $|S_{11}|$ as a function of frequency in the 57–66 GHz operating frequency range. The study clearly revealed that the matching of the antenna to the 50-Ω impedance of the microstrip feed line in this frequency range was far from being satisfactory. To render the matching more wideband, the topology of Fig. 1 was adopted, and the dimensions l_t, l_w, and w, as well as dimensions of the transition stubs l_b, w_b, l_m, and w_m, were modified.

A further improvement of the antenna input matching was achieved after bending the slot-stub section by 90°, resulting in a new microstrip-to-slot transition topology, where the microstrip and slot stub section are laid collinearly, partially overlapping each other, as shown in Fig. 1. In the second stage, the antenna with the dimensions found during the first stage was considered with a fork-shaped metallic carrier 9.2 mm long, 4.5 mm wide, and 1 mm high, which is connected to the antenna ground plane and surrounds the slot-transition system. The dimensions of both stubs were slightly modified to maintain the matching close to that achieved earlier. A negligible modification of some of the antenna dimensions was needed in the third stage, when a square reflector of 10×10 mm^2 in size was connected to the carrier. The resulting dimensions of the slot and transition were found to be $l_t = 3.4$ mm, $l_w = 1.9$ mm, $w = 2.35$ mm, $l = 1.5$ mm, $s = 0.16$ mm, $l_s = 0.67$ mm, $w_s = 0.23$ mm, $l_b = 0.8$ mm, $w_b = 0.2$ mm, $l_m = 0.6$ mm, $w_m = 0.15$ mm, and $t = 0.04$ mm. It should be pointed out that the area occupied by the proposed collinear microstrip-to-slot transition is actually very small. In fact, it is twice less than the area occupied by the transition used in [7].

IV. Simulation and Measurement Results

The matching and radiation characteristics of the antenna were simulated using CST Microwave Studio. From the plot of the simulation results, shown in Fig. 2, it can be seen that the operating frequency band of the antenna, where $|S_{11}| \leq -10$ dB, is from 53.3 up to 69.8 GHz (greater than 25% bandwidth). It is particularly noteworthy that the antenna is exhibiting an even better impedance matching ($|S_{11}| \leq -15$ dB) in the 57–66 GHz frequency range allocated for WPAN applications.

The simulated radiation patterns of the antenna in the xy (E) and in the yz (H) planes are shown in Fig. 3 for the dominant component (E_φ) of the radiated electric field. As can be deduced from the graphs, the antenna 3-dB beamwidth in the E-plane is varying in the 57–66 GHz frequency range between 35° and 89°, while in the H-plane it is varying between 58° and 72°. Also, the front-to-back ratio of the radiation is ranging between 17 and 22 dB. Other simulation results we obtained indicate that the antenna's directive gain in this frequency range

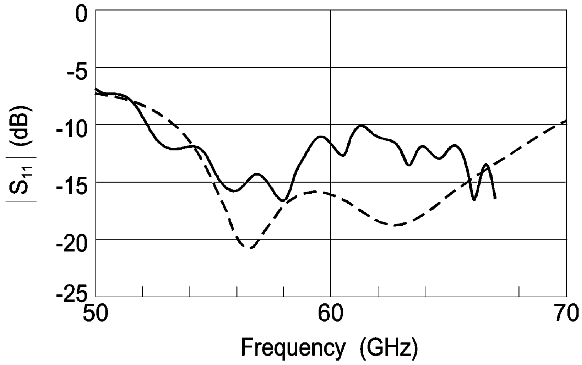

Fig. 2. Matching characteristics of the proposed antenna: measured (solid) and simulated (dashed).

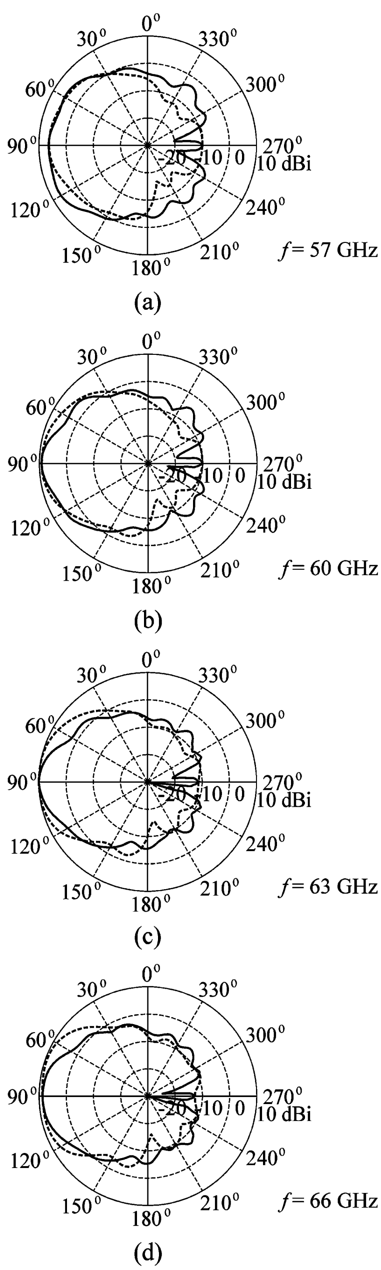

Fig. 3. Simulated radiated field (E_φ component) of the proposed antenna in xy plane (solid line) and yz plane (dashed line) at (a) 57, (b) 60, (c) 63, and (d) 66 GHz.

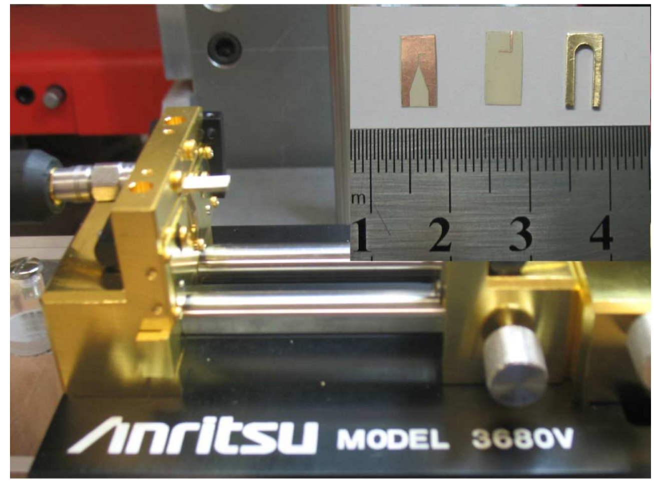

Fig. 4. Photograph of the measurement setup showing the proposed antenna connected to UTF. An enlarged photograph of the radiating element (from both sides) and the carrier are shown in the insert.

is varying between 6.8 and 9.9 dB. Also obtained from the simulation results is the antenna's radiation efficiency (the ratio between the radiated power and the sum of this radiated power plus the surface mode power) throughout this frequency range is nearly 96%, while its total efficiency, which is the product of its impedance-mismatch loss $\left(1-|S_{11}|^2\right)$ and radiation efficiency, is nearly 94%.

The model of the simulated antenna, excluding the reflector, was fabricated, and its matching characteristics were measured. A photograph of the measurement setup comprising an Anritsu 3680 V Universal Test Fixture (UTF), accommodating the antenna under test, and an Agilent Technologies E8361A Vector Network Analyzer (VNA) is shown in Fig. 4. The antenna was held in place between the spring-loaded jaws on the back side of the UTF's fixed connector block, with the antenna's microstrip feed line pressed against the backwardly protruding tip of the center conductor of the connector. In this way, the wall of the fixed block also served as the reflector for the antenna. The front side of the fixed connector block was connected through its V-type RF connector to the VNA via coaxial cable. Clearly, the measurement setup was fully calibrated before the measurements. The calibration was effected by a line–reflect–match (LRM) method. The measured results of S_{11} are plotted, for comparison purposes, alongside the simulation results in Fig. 2. The measured results are in good agreement with the simulated results, showing that the operation band of the actual antenna is even slightly wider. The level of S_{11} is slightly greater, but nevertheless under -10 dB throughout. To evaluate the total efficiency of the fabricated antenna, we consider the actual values of the antenna's S_{11} and assume that its radiation efficiency throughout the 57–66 GHz frequency band differs only very little from that obtained via simulations. The total efficiency thus evaluated was found to be greater than 85% throughout the required frequency band.

V. Conclusion

A compact endfire 60-GHz tapered slot antenna, which is printed on a low-permittivity LCP substrate has been proposed.

The antenna features a novel wideband collinear microstrip-to-slot transition, which is of smaller size compared to other transitions. The antenna also features a fork-shaped metallic carrier, which gives it good rigidity, and a metallic reflector, which increases its directive gain. The antenna can be a simpler to manufacture and less pricey substitute for 60-GHz tapered slot antennas printed on multilayer LTCC substrate [10]. It can be used both as an individual radiator as well as an element of antenna array and readily integrated with a RF module for use in future WPAN applications.

REFERENCES

[1] M. M. Tentzeris, J. Laskar, J. Papapolymerou, S. Pinel, V. Palazzari, R. Li, G. DeJean, N. Papageorgiou, D. Thompson, R. Bairavasubramanian, S. Sarkar, and J.-H. Lee, “3–D-integrated RF and millimeter-wave functions and modules using liquid crystal polymer (LCP) system-on-package technology,” *IEEE Trans. Adv. Packag.*, vol. 27, no. 2, pp. 332–340, May 2004.

[2] D. C. Thompson, O. Tantot, H. Jallageas, G. E. Ponchak, M. M. Tentzeris, and J. Papapolymerou, “Characterization of liquid crystal polymer LCP material and transmission lines on LCP substrates from 30 to 110 GHz,” *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 4, pp. 1343–1352, Apr. 2004.

[3] S. Nikolaou, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, “Conformal double exponentially tapered slot antennas (DETSA) on LCP for UWB application,” *IEEE Trans. Antennas Propag.*, vol. 54, no. 6, pp. 1663–1669, Jun. 2006.

[4] X.-R. Yan, S.-S. Zhong, and X. Zhang, “Compact printed monopole antenna on liquid crystal polymer (LCP) for EWB applications,” in *Proc. Int. Microw. Millim.-Wave Conf.*, Nanjing, China, 2008, vol. 3, pp. 1080–1082.

[5] J. S. Kot, N. Nikolic, and O. Sevimli, “An integrated wideband circularly-polarized 60 GHz array antenna with low axial-ratio,” in *Proc. 2nd Int. Wireless Broadband Ultra-Wideband Commun. Conf.*, Sydney, Australia, Aug. 2007.

[6] A. L. Amadjikpe, A. Vera, D. Choudhury, and J. Papapolymerou, “Study of a 60 GHz rectangular patch antenna on a flexible LCP substrate for mobile applications,” in *IEEE Antennas Propag. Soc. Int. Symp. Dig.*, San Diego, CA, Jul. 2008, pp. 1–4.

[7] L. Amadjikpe, D. Choudhury, G. E. Ponchak, and J. Papapolymerou, “A compact conformal end-fire antenna for 60 GHz applications,” in *IEEE Antennas Propag. Soc. Int. Symp. Dig.*, Jun. 2009, pp. 1–4.

[8] “Use of the 57–64 GHz frequency band for point-to-point fixed wireless systems,” ECC Recommendation, Jan., 2009.

[9] J. Laskar, S. Pinel, C.-H. Lee, S. Sarkar, B. Perumana, J. Papapolymerou, and E. Tentzeris, “Circuit and module challenges for 60 GHz Gb/s radio,” in *Proc. 2005 IEEE/ACES Int. Wireless Commun. Appl. Comput. Electromagn. Conf.*, Honolulu, HI, 2005, pp. 447–450.

[10] P. Smulders, “Exploiting the 60 GHz band for local wireless multimedia access: Prospects and future directions,” *IEEE Commun. Mag.*, vol. 40, no. 1, pp. 140–147, Jan. 2002.

[11] I. K. Kim, N. Kidera, S. Pinel, J. Papapolymerou, J. Laskar, J.-G. Yook, and M. M. Tentzeris, “Linear tapered cavity-backed slot antenna for millimeter-wave LTCC modules,” *IEEE Antennas Wireless Propag. Lett.*, vol. 5, pp. 175–178, 2006.

[12] J. B. Knorr, “Slot-line transitions,” *IEEE Trans. Microw. Theory Tech.*, vol. MTT-22, no. 5, pp. 548–554, May 1974.