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SUBSTRATE INTEGRATED PROBE-FEDPATCHANTENNAFOR WIDEBAND WIRELESS DEVICES

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ABSTRACT

This paper presents linearly polarized (LP) patch antenna for wideband wireless devices. Innovative electrical characteristics of the antennas including wide bandwidth, low cross polarization, low backradiation, and polarization insensitivity contribute to improvethe signal quality of wireless connectivity. It is a realization ofantenna foundation by employing multilayer microwave laminatesto form a substrate integrated meandering probe-fedpatch antenna. First, a design and investigation of the proposedpatch antenna for LP operation is carried out. This paper is considered as a part of RF modules that could be integrated with other constituents like sensors, Microcontroller units, and electronic parts to form a wireless product by means of conventional packaging process.

Index Terms: Antenna in package, low cross patch antenna,polarization, substrate integrated meandering probe, wideband antenna.

I. INTRODUCTION

The standard of IEEE 802.11 ac is the fifth generationin Wi-Fi wireless communication systems. It is attractive for the fast, high-quality, and nearly instantaneous data streamingto notebooks, tablets, and mobile phones. The Wi-Fiwireless communication systems are composed of manycomponents . As one of the key components,antennas are essential to be low profile, ease of fabrication,and integrated with RF circuits. Patch antennas are good candidatesfor integrated RF circuits due to their low profile andconformal structure. However, the integration of an antennainto a package is still perplexing and it is difficult to obtain thecharacteristics such as wide bandwidth, low cross-polarizationlevel, and so on .A lot of techniques have been described to achieve widebandpatch antennas , such as *L*-probe feed, parasitic patch, folded patch, modified ground plane, and so on.

However, those techniques agonize from high cross-polarization(cross-pol) radiation. This problem is often found in thewideband patch antennas , which not only leads to adistortion in the co-polarization (co-pol) radiation pattern butalso reduces the polarization purity of the antennas. In recentyears, differential feeds and a meandering probe have been proposed to overpower the cross-pol radiation for thepatch antennas. However, the method of differential feeds requires an additional 180° broadband power divider and themeandering probe is hard to be invented and integratedin package.The forementioned antennas yield linearly polarized (LP)radiation, which may suffer from the polarization disparity in certain cases. Thus, circularly polarized (CP) antennas arepreferred. However, a lot of CP antenna designs have narrow operating bandwidths. To solve this problem,some techniques have been suggested. Although the aperturecoupling and*L*-probe feed techniques are suitablefor improving the impedance bandwidth, both of them cannotenhance the axial ratio (AR) bandwidth significantly. The AR bandwidth can be improved greatly by employing dual feed excitations, but an extra circuit is required .The AR bandwidth can be improved considerably by adding stacked patch . Nevertheless, this can increase the thickness of the antenna. Without increasing the thickness ofthe antenna greatly, the AR bandwidth of single-feed patchantenna can be improved by 3-D meandering probe feed .However, the feed lines are realized in air, which is also notfitting for the antenna in package (AiP) applications.

This paper presents multilayer antennas fed by the substrateintegrated meandering probe for wideband wireless devices.The classical printed-circuit-board (PCB) fabrication processis employed to realize the proposed multilayer antennas, whichis suitable for AiPapplications , with the advantages of low profile and lower cost than Low Temperature Co-firedCeramic (LTCC).

Improved cross-pol radiation and co-polar radiation patterns are found in both LP and CP substrate integrated meandering probe fed patch antennas. In addition,wide impedance and AR bandwidths are obtained, together with good radiation performance.

For demo, we implement two substrate integrated meandering probe fedpatch antennas operating at 5G Wi-Fi frequency band.

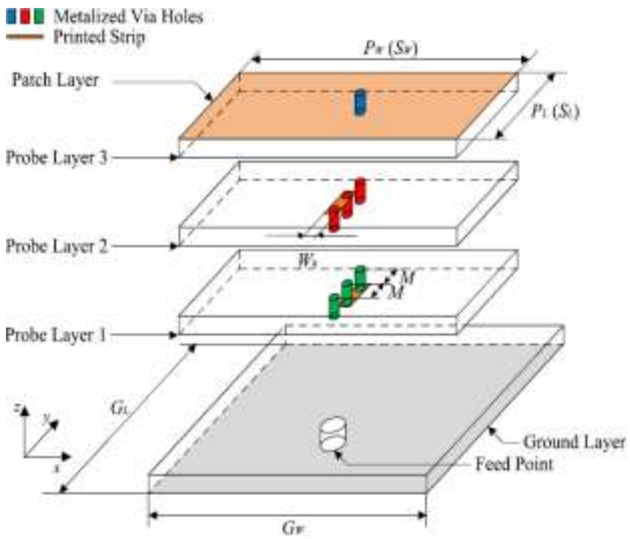

Figure 1:- Geometry of the substrate integrated meandering probe fed wideband patch antenna 3D view

withnoble radiation performance. For demonstration, we implement two substrate integrated meandering probe fed patch antennas operating at 5G Wi-Fi frequency band.

II. WIDEBAND SUBSTRATE INTEGRATED PATCHANTENNA FOR LP OPERATION

2.1. Antenna Description

A meandering probe is one of bandwidth broadening techniques for patch antennas by introducing an further capacitance to lessen the probe inductance.

Although this technique is effective to obtain a wide impedance bandwidth for the patch antenna, the air-loaded meandering structure is not proper for AiP applications. In this paper, the meandering probe can be precisely fabricated and integrated with the help of a multilayer PCB process. In this section, a design guide is given. A study and analysis of LP substrate integrated meandering probe patch antenna is conferred as follows.

Fig. 1 shows the geometry of substrate integrated meandering probe patch antenna. The antenna is constructed by four pieces of PCB substrates. It contains of a rectangular patch, a substrate integrated meandering probe portion, and a ground plane. The substrates are RT/duroid5870 with a dielectric constant of 2.33, and every thickness of them is 1.57 mm.

The substrate integrated meandering probe is formed by printed strips and the plate over holes on the probe layers, as shown in Fig. 1.

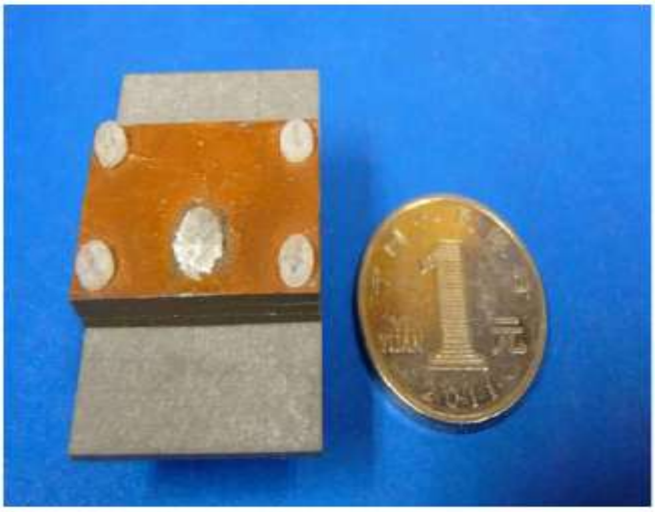

Fig. 2. Prototype of substrate integrated meandering probe fed LP patch antenna.

The center frequency of this antenna is designed at 2.5 GHz. The proposed antenna has a rectangular patch with length PL = 16 mm and width PW = 26 mm, which is situated at the top layer of the antenna. The substrate integrated meandering probe is made by a folded strip with two horizontal arms and three vertical portions. As shown in Fig.1.

The horizontal arm of the meandering strip, which is printed on the probe layers 1 and 3, has a width of Wh= 1.2 mm and a length of M = 3.5 mm. Metallic via holes with a diameter of 1 mm are built into the probe layers 1, 2, and 3 for realizing the M-probe structure. Besides, there are pads on the probe layers 1, 2, and 3 for realizing the via holes with a size of 1.2 mm × 1.2 mm. A small dug hole on the ground layer PCB is for the feeding connection from the Sub Miniature version A to the meandering strip.

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2.2. Simulation and Measurement

2.2.1 Impedance Bandwidth, Radiation Pattern, and Gain:-A prototyped LP substrate integrated meandering probe patch antenna was fabricated and measured, Fig shows the simulated and measured reflection coefficient. The antenna operates from 2.5 to 3.5 GHz with an impedance bandwidth of 33.8% (for the reflection coefficient ≤−10 dB) and 28.35% (for the reflection coefficient ≤−15 dB) from 3.51 to 4.5 GHz. A good agreement between the measured and simulated results is observed. From the obtained results, the antenna produces a wide impedance characteristic mainly due to the employment of the meandering probe. The horizontal portion on layer 3 contributes an additional capacitance to suppress the probe inductances from the vertical via of the probe that enlarges the impedance bandwidth of the antenna.

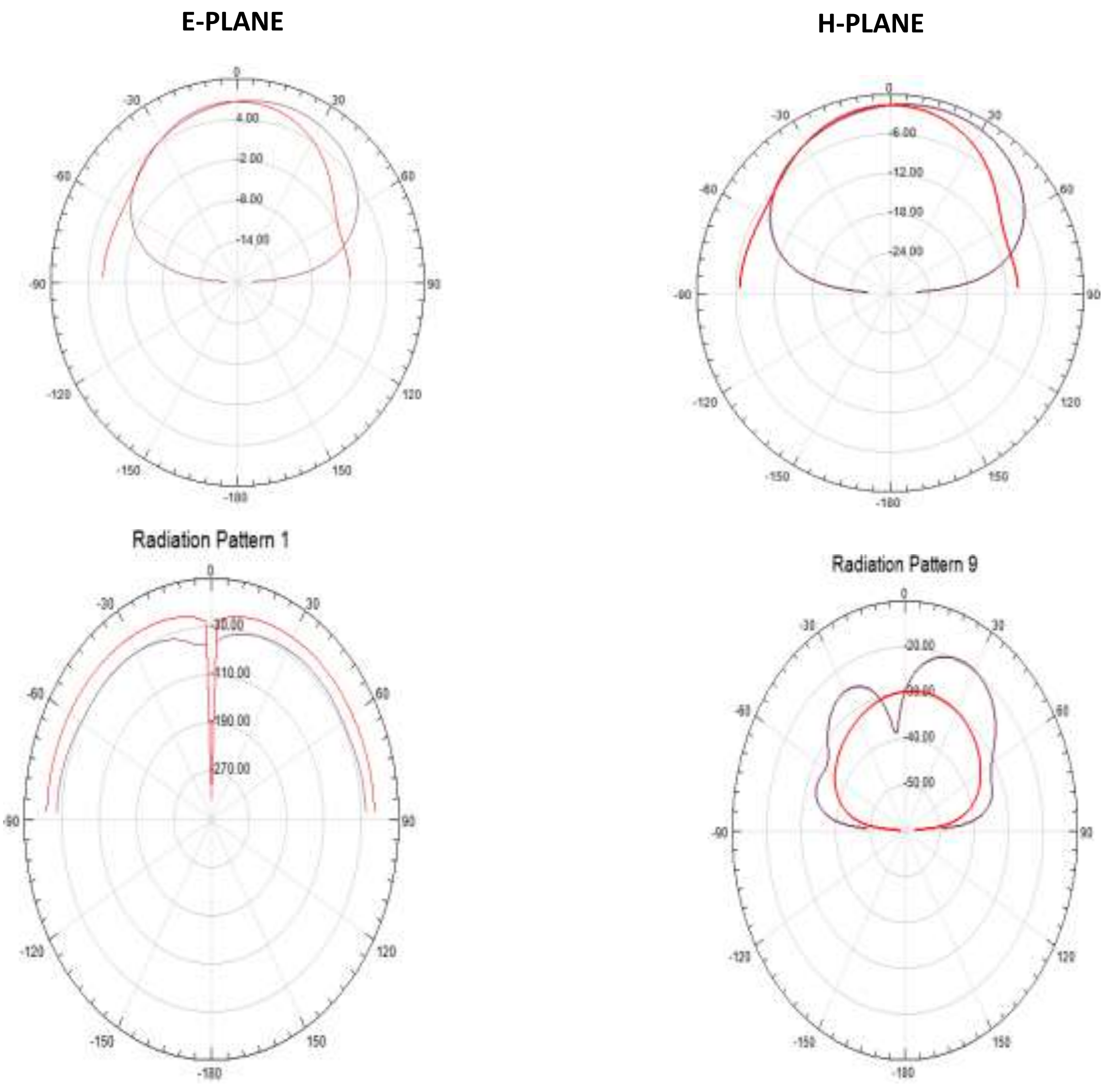

Fig. 3. Simulated and measured radiation pattern for the proposed antenna shown at (a) 2.5, (b) 4.5 GHz.

The radiation patterns of the proposed antenna in both *E* and *H* planes (*yz*and *xz*planes) were measured and shown in Fig. 3. It is found that the patch antenna has symmetric radiation patterns across the operating bandwidth.

The obtained results show that the cross-polarization level has a minimum value at a center frequency of 4.5 GHz, which are −45 and −32 dB in the H-plane by simulation and measurement, respectively. In addition, the restrained maximum cross-polarization level is between −20 and −32 dB within the operating bandwidth. It determines that the proposed patch antenna does not only achieve with a wide impedance bandwidth, but also produces stable gain and low cross-polarization radiation over the operating bandwidth.

2.2.2 Current Distribution: Instead of wide impedance, one of design purposes for this proposed antenna is low crosspol radiation, which is due to the out of phase current on the feeding probes. In this proposed design, the total length of the meandering probe is equal to half guided wavelength at the center frequency (4.5 GHz). When the minimum of the current density ensues at the center of the central vertical portions of the meandering probe, the currents on the outer portions are opposite in direction. The current distributions on the two horizontal portions of the meandering probe are also opposite in direction. When the minimum of the current density happens at the two ends of the meandering probealthough the currents on the outer vertical portions of the meanderingprobe are in phase, the densities are too little to generate the cross-polarization radiation. Also, the currents on the two horizontal portions are in phase for exhilarating the patch antenna. Therefore, the unwanted radiation eager from the vertical portions of the meandering probe can be suppressed and the co-polarization radiation can be excited by the horizontal portion.

2.3. Parametric Study

The aim of this parametric study is to devote a design guideline for choosing the optimal parameters in *M*, *PW*, and *PL* such that the antenna can obtain wide impedance bandwidth, high gain, and low cross polarization. First of all, it is well known that the length of patch, *PL* , is the key parameter for indicating the resonant frequency of the antenna. A patch antenna intended to operate at a center resonance frequency *fr*attached on a substrate having dielectric constant *εr*would have length *PL* of the patch as found from the following equation neglecting the fringing

effect:

$$P_L = \frac{c}{2f_r\sqrt{\varepsilon_r}}$$

where*c* is the free-space speed of light. The calculated value of *PL* is 17.8 mm . The bandwidth and gain of patch antenna relate to the patch width *PW*. The ratio of *PW*/*PL* should be within the range of 1 < *PW*/*PL* <2 that canobtain a wideband impedance characteristic for the antenna.

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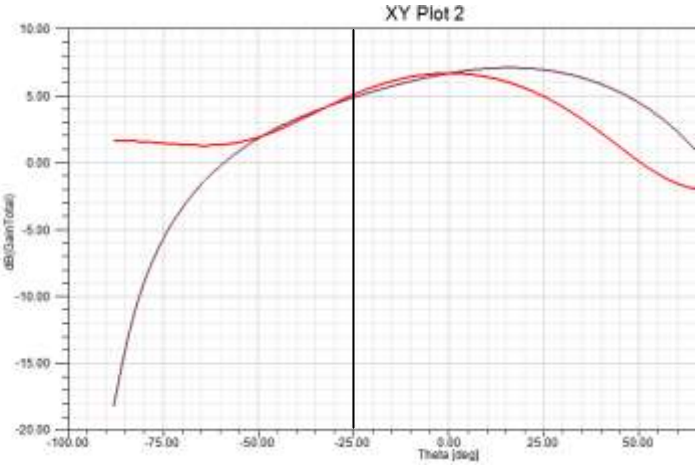

Fig. 4. Simulated gain at 2.5 GHz

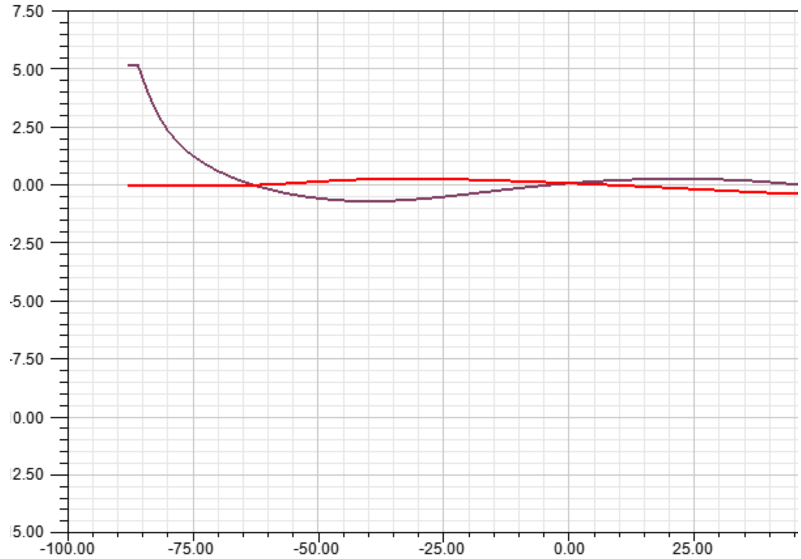

Fig. 5.Simulated cross-polarization level for different *M*

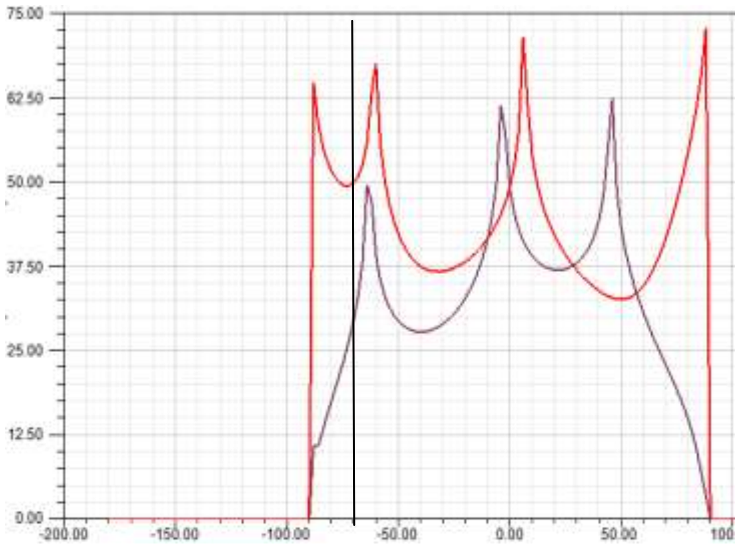

Fig. 6. Reflection coefficient for frequencies

This relationship is found by the intensive study. In the parametric study, the values of *PL* and *PW* are chosen from 14 to 19 mm and from 22 to 32 mm, respectively, which results from the above theory. From the obtained result, the value of *PL* should be chosen around 16–17 mm, which is lower than 17.8 mm due to the fringing field effect. Meanwhile, the gain of the proposed antenna at 4.5 GHz increases when *PW* is increased. However, the impedance bandwidth decreases with the increase of *PW*. As a result, the joint point at the two curves of gain and bandwidth replies shows a suitable value for *PW*, which is the optimal value to obtain the wide impedance and the reasonable antenna gain. Besides the antenna gain and the impedance bandwidth, the low cross-polarization level is one of the attractive characteristics of this design. The value of *M* has a great effect on the cross-polarization level. It is observed that the minimum value of cross-polarization level shifts to lower frequencies with the increase of *M*. It is due to the fact that the total length of the 2-D *M*-probe should be optimized to half guided wavelength at the center frequency (4.5 GHz).

III. CONCLUSION

The value of *M* relates to the impedance bandwidth. The obtained result shows that the impedance bandwidth would decease when *M* is reduced. The first resonance of the antenna slightly shifts to higher frequency when *M* is reduced.

These planned antennas have the features of low profile, low cost, low cross-polarization, stable radiation pattern, and wide bandwidth. The inherited multilayered structures are easy to be realized by PCB technology. Moreover, this paper is considered as a part of RF modules that could be integrated with other components like sensors, Microcontroller units, and electronic parts to form a wireless product by means of conventional packaging.LP designs of substrate integrated meandering probe fed patch antenna for wideband wireless devices has been presented. The LP patch antenna has an impedance bandwidth of 33.8% and an average gain of 6.9 dBi.

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