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Patch Antenna Based on Quartz and Pyrex Materials Operating at 60 GHz

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Abstract In this paper we present the design and characterization of a broadband patch antenna capable of covering the entire IEEE 802.11ad wireless gigabit (WiGig) frequency band (57-66 GHz). The coplanar waveguide (CPW)-fed loop slot couples the energy to the patch antenna, resulting in a broad bandwidth. The patch metallization is deposited on top of pyrex substrate. The main role of the pyrex material is to provide a mechanical support for the patch metallization, with the air cavities underneath, thus resulting in an antenna substrate with a very low loss. That leads to improved antenna performances. The simulated and measured impedance characteristics agree well, showing ~15% bandwidth. Also, the simulated radiation pattern results demonstrate the integrity of radiation pattern with good gain values (average ~8.5 dB) over the entire WiGig band.

Keywords: Patch Antenna, Coplanar waveguide, Quartz, Pyrex.

هوائي الرقعة مركب على الكوارتز و زجاج البيركس يعمل على تردد 60 جيجا هيرتز

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الملخص في هذه الورقة نقدم تصميم وتوصيف هوائي الرقعة واسع النطاق قادر على تغطية كامل IEEE 802.11ad (WiGig) نطاق التردد .(57- GHz66) تغذية الهوائي عن طريق موجه الموجات الذي على شكل حلقة (CPW)) يؤدي إلى نطاق ترددي واسع. يركب الهوائي على شريحة زجاج البيركس، والدور الرئيسي لمادة البيريكس هو توفير الدعم الميكانيكي لتثبيت الهوائي، ومع وجود تجاويف الهواء المحفورة في شريحة البيركس تحت الهوائي تؤدي إلى خفض الفاقد في الإشارة، وهذا يؤدي إلى تحسين أداء الهوائي. نتائج المحاكاه تشير إلى ان نمط الإشعاع له كسب جيدة (~ 8،5) dBعلى كامل نطاق .WiGig

الكلمات المفتاحية: هوائي الرقعة، موجه الموجات، كوارتز، زجاج البيركس، عرض النطاق.

Introduction

This technology is struggling to support the rapidly increasing demand for high data rates due to the increasing popularity of smartphones, tablets, netbooks, and cloud computing. Additionally, the future wireless systems are envisaged to enable wireless connectivity for everybody. WiGig wireless technology (57-66 GHz) enabling wireless data, voice and video application at multi-gigabit speeds has recently been attracting much interest in academia and industry [1]. Antennas operating at mm-wave frequencies have thus far mainly been fabricated using low temperature co-fired ceramic (LTCC) [2-4], polymer substrates [5] and SU-8substrate [6]. Although LTCC can create mechanically robust and hermetically sealed packages with high yield, it might create unwanted surface waves due to the high dielectric constant of substrate. Recently, planar antennas have also been realized on benzocyclobutene (BCB) polymers at mm waves [5]. BCB (ε_r = 2.65, tan δ = 0.0008, due to its properties, is a good choice for improved antenna performance. However, it is quite difficult to achieve the desired thickness with BCB need for a obtaining a reasonable operational band-width (BW) to a planar antenna within the IEEE 802.11ad band (57-66 GHz). Also, the very short shelf-life time of BCB under room temperature is another disadvantage [3d micro].

ANTENNA DESIGN: The antenna as depicted in figures 1 and 2, is a coplanar wave guide (CPW) fed broad-band patch antenna micro-fabricated on an RF compatible quartz substrate (ε_r = 3:9, tan δ = 0:0002 at 60 GHz). The feed metallization, which consists of a 50Ω conductor backed CPW, along with the loop is formed on a 525μm thick quartz substrate. The coplanar wave guide structure in figure 3 consists of a center strip with two parallel ground planes placed equidistant from it on either side. All three conductors in the coplanar wave guide are located on the same side of the substrate surface. The dimensions of the center strip, the gap, the thickness and permittivity of the dielectric substrate determined the effective dielectric constant, characteristic impedance and the attenuation of the line. The characteristic impedance, Z_0, may be calculated as [7]

$$\varepsilon_{eff} = \frac{1 + \varepsilon r \dfrac{K(k')}{K(k)} \dfrac{K(k_3)}{K(k'_3)}}{1 + \dfrac{K(k')}{K(k)} \dfrac{K(k_3)}{K(k'_3)}} \quad (1)$$

$$Z_o = \frac{60\pi}{\sqrt{\varepsilon_{eff}}} \frac{1}{\frac{K(k)}{K(k')} + \frac{K(k_3)}{K(k'_3)}} \qquad (2)$$

Where;
$k = W/W+2S$
$k_3 = \tanh(\pi W/2h)/\tanh(\pi(W+2S)/2h)$
$k' = \sqrt{1.0 - k^2}$
$k'_3 = \sqrt{1.0 - (k_3)^2}$
And K(k) is the complete elliptic integral of the first kind.

The gap in the coplanar wave guide is usually very small and supports electric fields primarily concentrated in the dielectric. With little fringing field in the air space, the coplanar wave guide exhibits low dispersion [8].

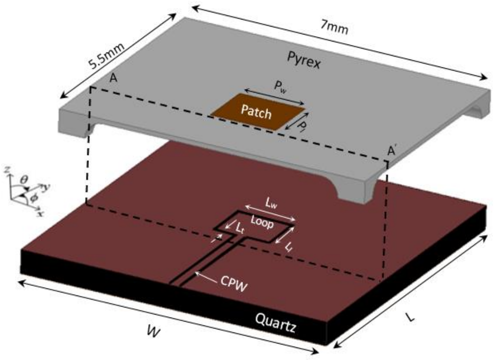

Fig. 1: Schematic depicting 3-D drawing of the antenna (For the sake of illustration, the pyrex layers is suspended on top of the CPW metallization).

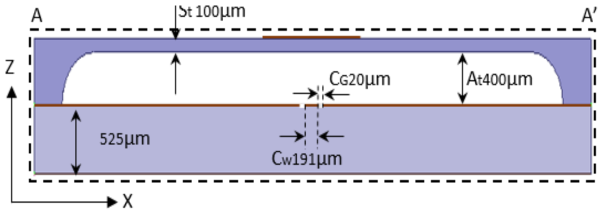

Fig. 2: Schematic showing cross-sectional drawing of the single-element two-layers antenna.

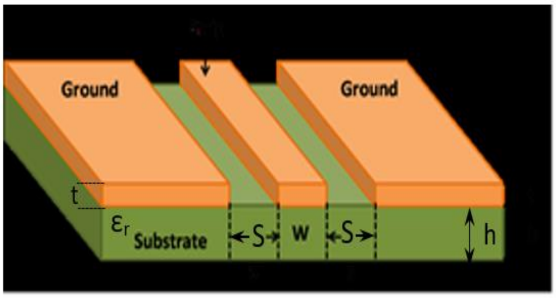

Fig. 3: Coplanar wave guide design. The width of the central conductor (W), the gap from the ground planes (S), the substrate thickness (h), the conductor thickness (t).

The pyrex substrate (ε_r = 4.9, tanδ = 0.01 at 60 GHz) is located on top of the quartz layer. The patch antenna metallization is finally formed on this substrate. Pyrex material which is thinned down to 100µm by using standard chemical wet-etch process is incorporated to decrease the dielectric loss which would in turn enhance the performance of the antenna. The height of the air pocket (At), formed under the thinned pyrex has an effect on the impedance BW and realized gain of the antenna [9–12]. To enhance the BW of patch antenna a conductor backed CPW-fed rectangular loop slot (with dimensions Ll, Lw and Lt) are showing in figure 4 couples the energy to the patch antenna.

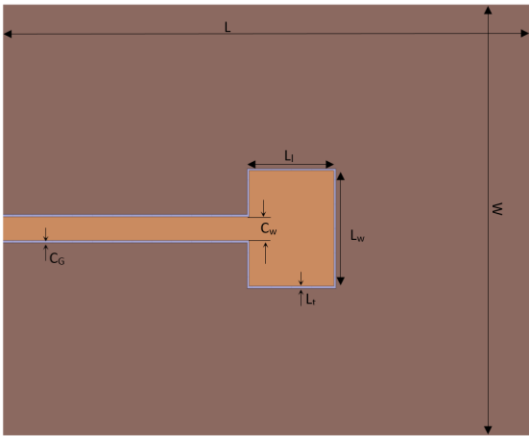

Fig.4: Top view of CPW layer (Loop is centralized w.r.t. CPW layer).

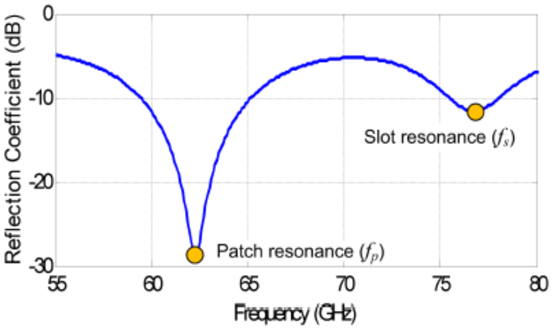

Fig.5: Initial dual-band response of CB CPW-fed slot-loop coupled patch antenna with slot and patch resonances separated prior to design optimization.

The resonant length of the loop is calculated as [6]:

$$Ll + (Lw)/2 \approx (\lambda_g)/2 \qquad (3)$$

Where, λ_g is the guide wavelength in quartz substrate at the resonant frequency (f_s).

The substrate thickness of conductor backed CPW fed loop slot plays an important role in broadening the radiation BW of the antenna. One of the main contributions of this paper is not only to improve the antenna performances in the WiGig band but also to make the antenna design compatible with micro-fabrication processes, resulting in efficient and economic fabrication. The patch antenna dimensions are calculated accordingly by using the following [13]:

$$Pl = C/(2 f_p \sqrt{\varepsilon_r}) \qquad (4a)$$

$$Pl < Pw < 2Pl \qquad (4b)$$

Where Pl and Pw represent the patch length and width (see figure1), C is the speed of light in vacuum and f_p is the patch design frequency, and ε_r is the relative permittivity of the material. The initial dual band response of the loop slot coupled patch antenna is shown in figure 5, where the resonances at f_p = 62.5 GHz and f_s = 77 GHz correspond to patch and loop slots, respectively, according to Eqs. (3), (4a), and (4b). The optimized design parameters of the patch element, CPW-fed loop, and the pyrex substrate which obtained from full-wave simulation by using the Ansoft company's HFSS software are provided in Table 1.

Table 1: The critical design parameters of the WiGig antenna (all dimensions are in mm).

W	7	Pw	1.5	Ll	1	CG	0.02
L	7	Pl	1.3	Lw	1.2	Cw	0.191
Lt	0.02	St	0.1	At	0.4		

This design methodology which minimizes the dielectric loss of pyrex through air pocket formed results in better performances. Secondly, the patch metallization on top of the pyrex substrate focuses the EM energy to result in a narrower beam width which is otherwise broader for a standard CPW-fed loop.

Simulation Results and Characterizations

The performance of the micro-fabricated loop-coupled patch antenna with CPW feed has been measured with an Agilent 8510C vector network analyzer (VNA) together with a GSG probe station from 57 to 67 GHz.

The simulated and measured reflection coefficients, with well agreement between them, for a frequency range from 57 to 67 GHz are plotted in the figure 6, The reflection coefficient shows that the antenna has a 2:1 VSWR BW of greater than 9 GHz (~ 15% of fractional BW), which covers the entire frequency range of the IEEE 802.11ad (57 - 66 GHz).

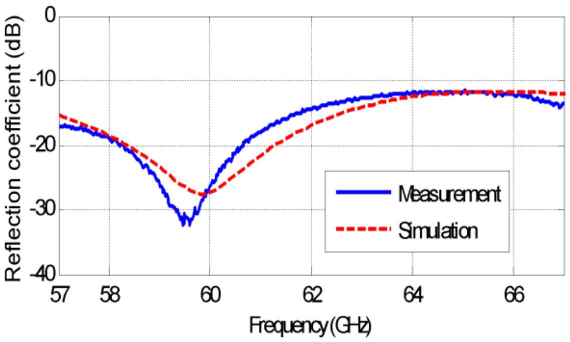

Fig. 6: Simulated and measured magnitudes of S11 parameter (reflection coefficient) for a frequency range from 57 to 67 GHz obtained for the micro-fabricated broadband patch antenna.

The simulated radiation patterns of the linearly polarized antenna in y-z plane at 60 GHz is shown in figure 7.

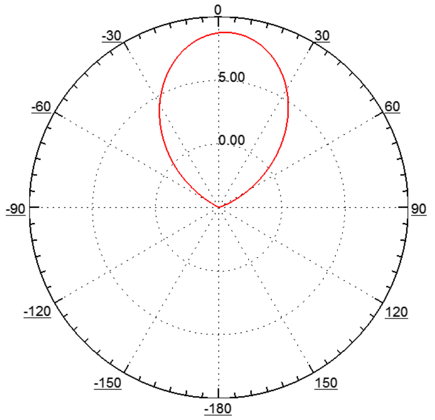

Fig. 7: Simulated radiation patterns of the linearly polarized antenna in y-z plane at 60 GHz.

The realized maximum gain of the antenna stays relatively constant and is in the range ~ 8.4 − 8.7 dB over the entire BW as shown in figure 8.

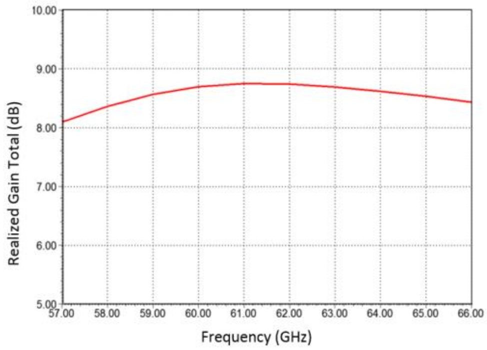

Fig. 8: Simulated realized gain (dB) in the broadside direction of the antenna with respect to frequency.

Conclusion: The design and characterization of a CPW-fed broadband patch antenna compatible with IEEE 802.11ad standard (WiGig).

The simulated and measured impedance characteristics agree well, showing ~ 15% bandwidth. Also, the simulated radiation pattern results demonstrate the integrity of radiation pattern with good gain values (~ 8.5 dB) in the broadside direction over the entire WiGig band (57-66 GHz) indicate a design with low dielectric loss. The pyrex microfabrication processes develop for this antenna structure provides an important advantage for custom-made reconfigurable antennas that might also be greatly useful in WiGig applications.

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