Ultra-Wideband, Glass Package-Integrated Power Dividers for 5G and mm-Wave Applications

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***Abstract*—This paper presents an ultra-wideband, glass package-integrated, equal-split power divider with footprint smaller than the unit free-space wavelength corresponding to the operating frequency of 28 GHz 5G band. The utilization of precision low-loss redistribution layers (RDL) on ultra-thin glass substrates with stable electrical properties at mm-wave frequencies enable the ultra-wideband power dividing networks to have a small footprint in x-y-z dimensions along with excellent performance. This approach aggregates the benefits of ceramic, low-loss polymers and silicon: electrical performance of the ceramic, processability of polymers and the dimensional stability of silicon, simulated in glass substrate to realize fine features for the power dividers. The power divider exhibits low added insertion loss, minimal phase shift between its output ports and has a height less than 150-μm.**

***Keywords*—5G and mm-wave; small-cell; power divider; T-junction; Yagi-Uda; semi-additive process**

I. Introduction

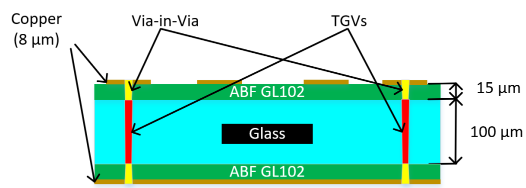
In recent times, a lot of effort has been directed towards next generation wireless communication systems to devise reliable components and modules to power a range of applications. 5G wireless systems will use a combination of sub-7 GHz and mm-wave frequencies to provide ultra-high data rates of at least 100 Mb/s to end-users in a dense urban environment. This is only possible by coexistence of multi-band multi-standard (MBMS) communication systems which require massive multiple-input multiple-output (MIMO) antennas [1]. The trends have been moving towards antennas-in-package (AiP) in which integrating the power dividing network with the antenna array becomes a critical task. The power divider can be integrated either in the same metal layer as the antenna array or in the layer buried underneath it [2], [3].

In this paper, a two-way equal-split power divider and a 2×1 Yagi-Uda antenna array is demonstrated. The design and fabrication of the power divider is presented in section-II, followed by section-III which focuses on the results and discussion. Finally, the paper is concluded in section-IV.

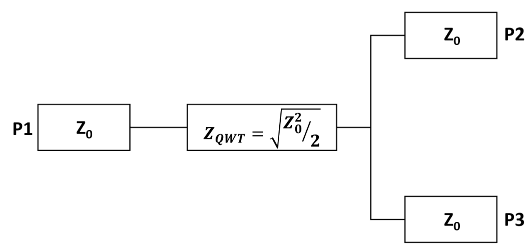
II. Design and Fabrication

A. Material Stackup and Design

In this section, the material stackup and design procedure is discussed. The material stackup consists of an ultra-thin 100-μm glass core, laminated with 15-μm thin epoxy film from Ajinomoto (ABF GL102). The glass substrate has a Dk of 5.6 and Df of 0.005 characterized at 10 GHz. Similarly, ABF GL102 has a Dk of 3.3 and Df of 0.0044 at 5.8 GHz and has stable electrical properties upto 50 GHz [4]. The material stackup is shown in Fig. 1a.



(a)



(b)

Fig. 1. (a) Material stackup, and (b) schematic diagram of the power divider

The transmission line modeling of the two-way equal-split power divider is based on a microstrip T-junction as shown in Fig. 1b. Another common choice is Wilkinson power divider as it provides isolation between output ports [5]. However, it requires a lumped resistor which can be disadvantageous in small packages. The matching between one input and two output ports is performed using a quarter wave transformer for the T-junction. The transformer sees the characteristic impedance (50 Ω) on the input side and half of it on the output side. Once the design is finished using a single-section transformer, it fulfills the bandwidth requirements and covers the entire 28 GHz band: from 24.5 to 29.5 GHz (fractional bandwidth (FBW)=18.51%). The frequency dependent and independent behavior of the substrate stackup is calculated to determine the characteristic impedance and electrical lengths of the power divider transmission lines [6], [7]. The layout of the designed power divider with and without Yagi-Uda antennas is shown in Fig 2.

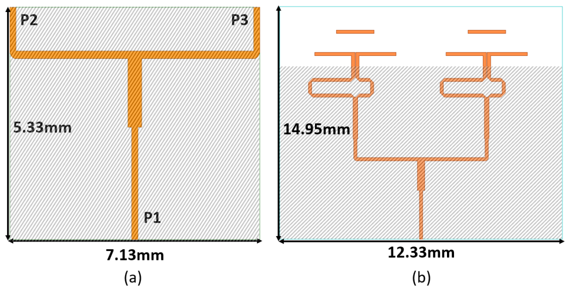


Fig. 2. Layout of the microstrip power divider (ground plane is shown in grey) (a) without antennas, and (b) with Yagi-Uda antennas

B. Fabrication

Semi-additive patterning (SAP) process is utilized to pattern the copper structures on ultra-thin glass substrate. The process begins with a glass panel with vias, which is chemically treated to laminate dielectric films on it. Next, through panel vias are drilled in it to connect top and bottom metal layers in the stackup, followed by deposition of a very thin copper seed-layer. The panel is lithographically patterned after photoresist lamination, followed by electrolytic plating. In the final steps, the photoresist is stripped away and seed layer is differentially etched to obtain desired circuit pattern. After the fabrication process, the measured copper thickness is 8±0.5 μm, which makes the total height of the package to be 147-μm.

III. Results and Discussion

The s-parameters of the proposed power divider with and without Yagi-Uda antennas are shown in Fig. 3. As evident from the figure, the bandwidth of the power divider spans much larger than the required 18.51% FBW of the 28 GHz 5G band. When the power divider is combined with the Yagi-Uda antennas for 28 GHz 5G band, the antennas limit the -10 dB bandwidth to the desired band of operation. The combined response shows an excellent match in the passband, indicating a low (<2) VSWR as well as low added insertion loss (greater than 3.01 dB) of less than 0.45 dB. The realized gain of a single planar Yagi-Uda antenna is 4 dBi at the center frequency of 28 GHz band. When it is equiped as a 2×1 array using the designed power divider, the realized gain increases to 7 dBi. Both 2D and 3D radiation patterns of the antenna array are shown in Fig. 4.

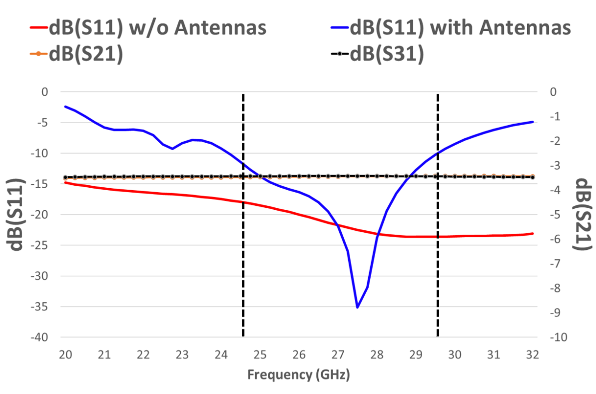


Fig. 3. S-parameters of the power divider and corresponding antenna array

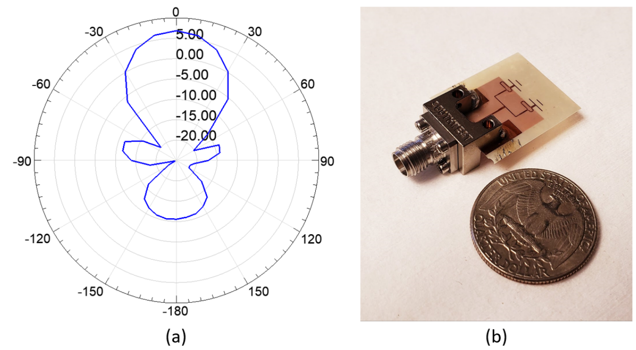


Fig. 4. 2×1 antenna array (a) 2D radiation pattern, and (b) fabricated coupon

Dimensional analysis reveals that the power divider has the physical dimensions of 7.13×5.33×0.147 mm^3 and the corresponding electrical dimensions are 0.67×0.51×0.014 $(\lambda_0)^3$.

IV. Conclusion

This paper presents the detailed design, fabrication and analysis of an ultra-wideband, glass package-integrated, equal-split power divider with footprint smaller than the unit free-space wavelength corresponding to the operating frequency of 28 GHz 5G band. The power divider is fabricated using SAP process to meet the dimensional accuracy requirement for such structures on ultra-thin glass. The demonstrated network can be used in the top metal layers of RF front-end packages where size in all dimensions is a critical requirement. It exhibits low added insertion loss and minimal phase shift between output ports, making it ideal for strict-footprint specifications.

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