International Journal of Microwave and Wireless Technologies

cambridge.org/mrf

3D-printed wideband Vivaldi antenna for millimeter wave applications

Zunnurain Ahmad and Lee Harle

Michigan State University, East Lansing, Michigan, USA

Research Paper

Cite this article: Ahmad Z, Harle L (2023). 3D-printed wideband Vivaldi antenna for millimeter wave applications. *International Journal of Microwave and Wireless Technologies* **15**, 1212–1215. https://doi.org/10.1017/S1759078722001234

Received: 22 April 2022
Revised: 27 September 2022
Accepted: 2 October 2022

Key words:
3D printed; chip interconnect; millimeter wave antennas; wideband

Author for correspondence:
Zunnurain Ahmad,
E-mail: zunnurain@outlook.de

Abstract

Main aim behind this study is to utilize 3D printing technique for designing and fabrication of a flexible wideband Vivaldi antenna for the upcoming 5 G systems. Frequency bands starting from 24 up to 65 GHz are receiving particular attention as they have potential for both high data rate communications and high-resolution radar applications. A Vivaldi antenna is used for its very wideband properties and planar design. The radiating structure covers a bandwidth of 25–65 GHz for a match better than −10 dB and demonstrates reasonably high gain and efficiency performance. The simulated radiation efficiency of the antenna remains above 90% for the entire bandwidth. Hence, the main advantage of this approach is that wideband or switched transceivers for future 5 G communications can be integrated using this concept without the need of complex matching networks.

Introduction

As demand for high-speed communications is constantly growing there are several proposals to build modules in the mm-wave spectrum. Frequency bands starting from 24 up to 65 GHz are receiving particular attention as they have potential for both high data rate communications and high-resolution radar applications. In near future transceivers covering a broad frequency band or switchable systems that can cover the mm-wave bands will be enabled [1]. In order for these transceivers to function there is a requirement for wideband antennas that can cover this wide bandwidth and at the same time have a reasonable gain and efficiency performance. The other solution would be to have multiple antennas catering to each individual frequency band, however this will require extra area in the module.

There have been studies going on to have a single antenna with an extremely wide bandwidth that can cover a wide frequency spectrum [2, 3]. These require multiple via connections with multilayer printed circuit boards and are for broad side applications. In this work, an end fire antenna on a flexible substrate is proposed. Typically, end fire antennas for mm-wave applications are based on dipole and folded slot antennas [4–6]. However, they have narrow bandwidth. 3D antennas can solve the bandwidth requirements as investigated in [7–9] but the drawback is they can occupy more space and are relatively rigid in nature.

To address the above-mentioned issues a wideband Vivaldi antenna is investigated in this work. These kinds of antennas are very broadband in nature and can cover extremely wide bandwidths.

Antenna concept

As a first step, a conventional Vivaldi antenna was simulated with a differential port. Flexible Ultralam 3850 and Polymide thin film were used as a substrate for this antenna. The antenna performance is optimized for a wide frequency band and gain performance. The antenna is designed to cover the frequency band of 25–65 GHz; therefore, it can cover the frequency range for the frequency bands allocated for 5G. Corrugations on the arms are added to increase the directivity of the antenna. As a next step a coplanar waveguide (CPW) to coplanar stripline transition was designed in order to probe the antenna with a ground-signal-ground (GSG) probe [10]. Alternatively, a ground-signal probe can be used to feed the antenna. Antenna has a total length of 15 mm and a flare opening of 11.5 mm. Figure 1 shows the dimension of the antenna along with the electric field plot on the surface of the antenna.

As mentioned earlier the main motivation of designing this antenna is to have a wideband performance for the upcoming 5 G systems. However, integrating the antenna with a wideband transceiver is also a big challenge as the typical chip integration approaches such as bond wire and solder bump are typically working for low frequencies and show a narrow band performance when compensation networks are introduced.

To solve this integration issue, a ramp transition was introduced from a dummy chip. These kinds of transitions have the potential to provide a wide bandwidth over the other

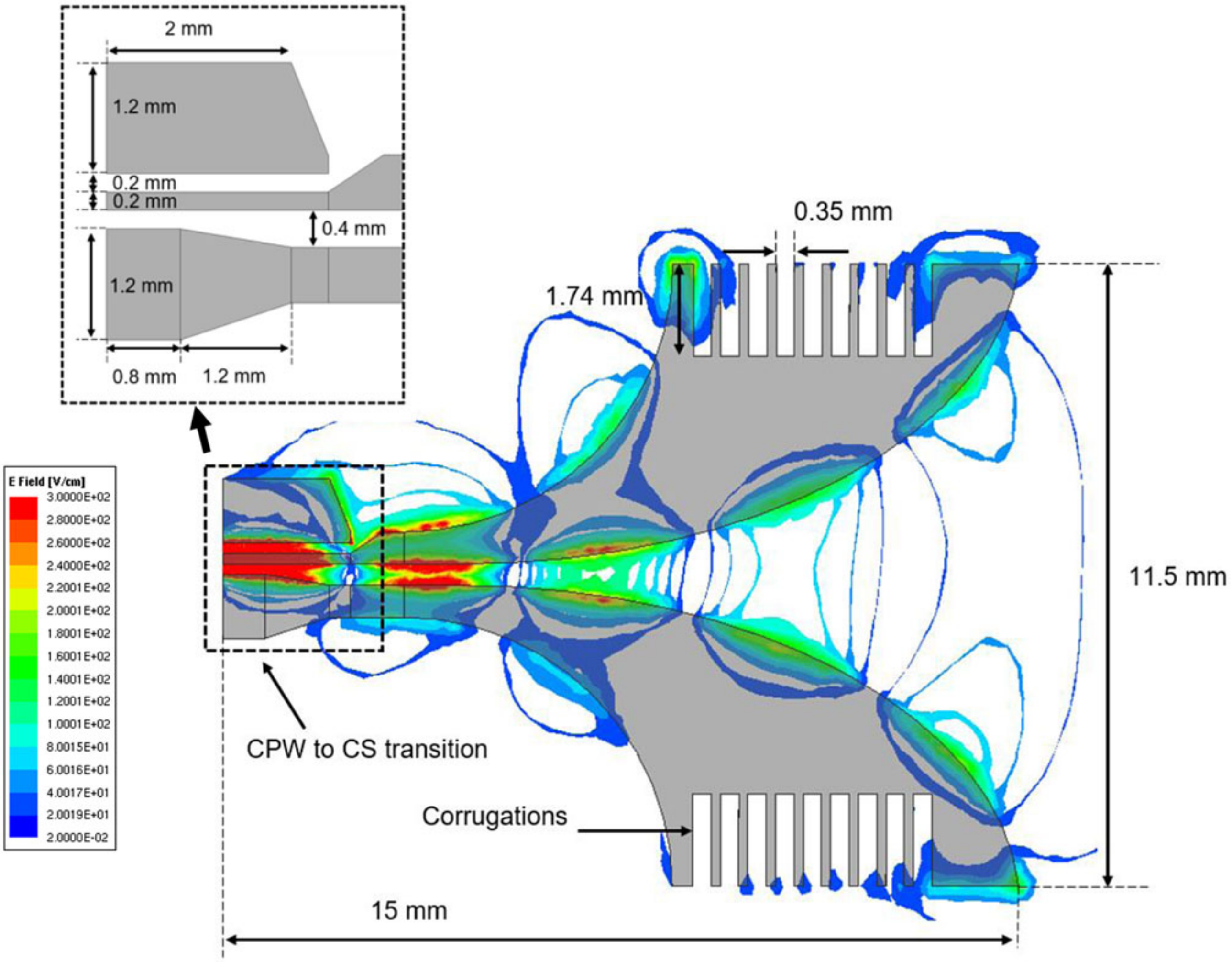


Fig. 1. Top view of the printed Vivaldi antenna with E-field distribution across the structures and dimensions.

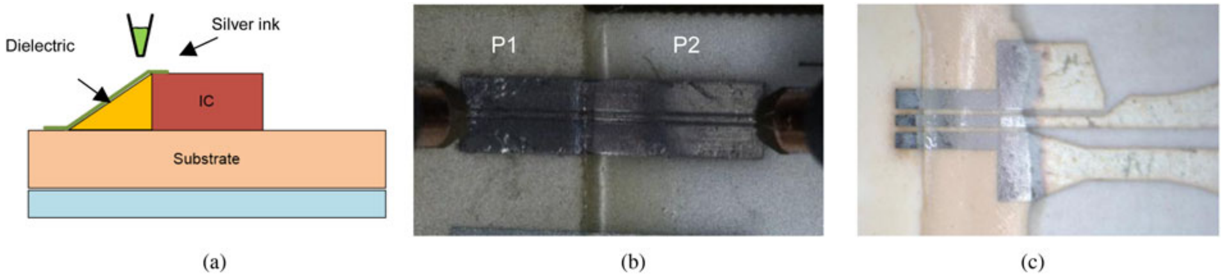


Fig. 2. Coplanar waveguide (CPW) transition over the ramp structure. (a) Ramp transition concept. (b) Ramp fabricated with printed silver coplanar waveguide (CPW) lines. (c) Antenna integrated with the ramp transition.

conventional solutions [11]. Figure 2(a) shows the transition concept where a chip can be placed on a substrate and a ramp can be made with a dielectric material starting from the edge of the chip to the substrate. Once the ramp is made, an aerosol jet printer can be used to print the conductive lines connecting the chip to the laminate. Figure 2(b) shows the ramp interconnect measured with a GSG probe. A laminate is used instead of chip for demonstration purposes. The measured reflection and insertion loss of this structure are shown in Fig. 3. The measurements show that this ramp interconnect can cover the mm-wave band up to 65 GHz without any matching networks. As this transition covers the mm-wave range the antenna can be integrated with such a transition. Figure 2(c) shows the antenna integrated with a ramp interconnect. A Polytec TC 430-T thermal adhesive was

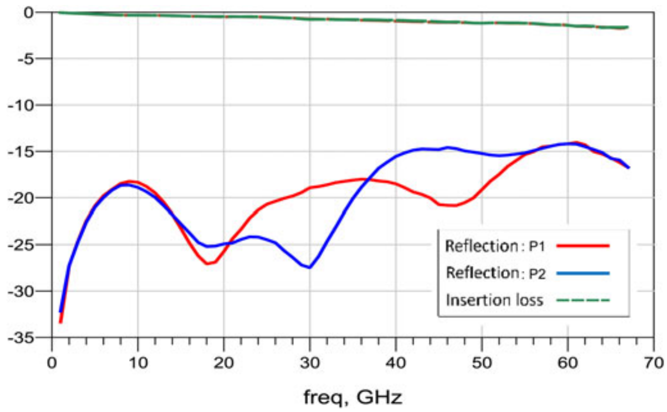


Fig. 3. Measured reflection and insertion loss of the ramp structure (see Fig. 2 (b)).

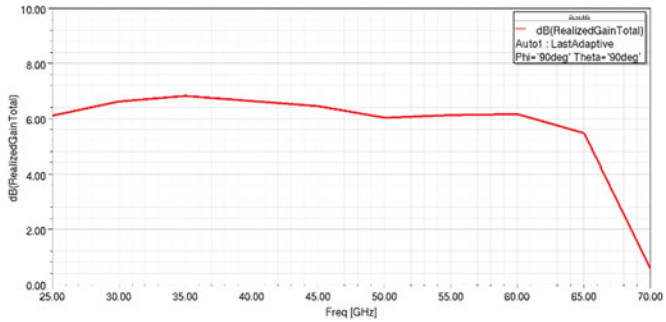
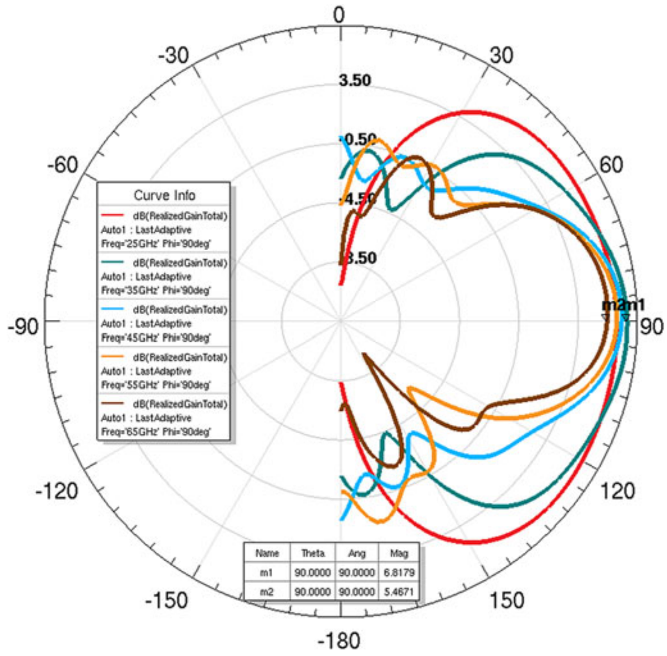


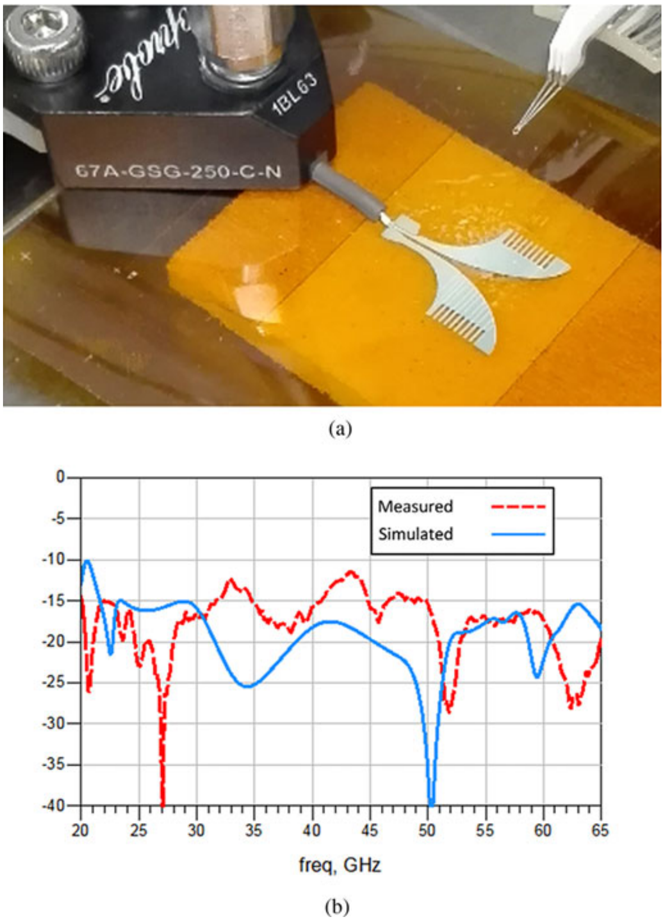
Fig. 4. Simulated gain performance of the antenna.



Name	Theta	Ang	Mag
m1	90.0000	90.0000	6.8179
m2	90.0000	90.0000	5.4671

Fig. 5. Simulated radiation pattern of the antenna at 25, 35, 45, 55, and 65 GHz.

used as a ramp structure which was deposited by syringe. Once the adhesive is thermally cured, silver nano particle ink CPW lines are printed and sintered. Sixty percent of bulk conductivity of silver is obtained for the printed lines.



(a)

(b)

Fig. 6. Measurement of the antenna. (a) Ground-signal-ground (GSG) measurement setup. (b) Simulated versus measured reflection of the antenna.

Antenna characteristics

The antenna when integrated with a ramp transition shows a wide bandwidth performance. The simulated gain performance of the antenna is shown in Fig. 4. The gain of the antenna remains above 5 dBi for the frequency range of 25–65 GHz. The radiation pattern of the antenna is shown in Fig. 5 for 25–65 GHz with 10 GHz increment. The reflection of the antenna is measured with a GSG probe which is calibrated up to the probe tips with a Short, Open Load, Thru calibration kit. The setup is shown in Fig. 6. Measured and simulated *S*-parameters of the antenna are also shown in Fig. 6. The reflection remains under −10 dB for the frequency band of 25–65 GHz.

Conclusion

The design of a wideband Vivaldi antenna is presented in this work with a wideband interconnect concept. This provides a solution for a radiator to cover the millimeter-wave spectrum from 25 to 65 GHz. The main advantage of this approach is that wideband or switched transceivers for future 5 G communications can be integrated using this concept without the need of complex matching networks.

References

1. **Nawaz AA, Albrecht JD and Çağrı Ulusoy A** (2020) A 28-/60-GHz band-switchable bidirectional amplifier for reconfigurable mm-wave transceivers. *IEEE Transactions on Microwave Theory and Techniques* **68**, 3197–3205.

2. **Novak MH, Miranda FA and Volakis JL** (2018) Ultra-wideband phased array for millimeter-wave ISM and 5 G bands, realized in PCB. *IEEE Transactions on Antennas and Propagation* **66**, 6930–6938.
3. **Moghaddam SM, Yang J and Zaman AU** (2020) Fully-planar ultrawideband tightly-coupled array (FPU-TCA) with integrated feed for wide-scanning millimeter-wave applications. *Antennas and Propagation IEEE Transactions on* **68**, 6591–6601.
4. **Park J, Seong H, Whang YN and Hong W** (2020) Energy-Efficient 5 G phased arrays incorporating vertically polarized endfire planar folded slot antenna for mmWave mobile terminals. *IEEE Transactions on Antennas and Propagation* **68**, 230–241.
5. **Hong W, Baek K and Ko S** (2017) Millimeter-wave 5 G antennas for smartphones: overview and experimental demonstration. *IEEE Transactions on Antennas and Propagation* **65**, 6250–6261.
6. **Harle L, He Y and Papapolymerou J** (2017) 3D printed 77 GHz planar Yagi-Uda antenna. *IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 13–14. doi: 10.1109/APUSNCURSINRSM.2017.8072049
7. **Ahmad Z and Hesselbarth J** (2017) High-efficiency wideband surface-mount elevated 3-D patch antenna for millimeter waves. *IEEE Antennas and Wireless Propagation Letters* **16**, 573–576.
8. **Ahmad Z and Hesselbarth J** (2017) High-efficiency 3-D antenna for 60-GHz band. *IEEE Transactions on Antennas and Propagation* **65**, 6274–6281.
9. **Ahmad Z and Hesselbarth J** (2017) “Circuit-board edge-mount dual-polarized millimeter-wave antenna,” 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2017, pp. 1443–1444, doi: 10.1109/APUSNCURSINRSM.2017.8072764
10. **Anagnostou DE, Morton M, Papapolymerou J and Christodoulou CG** (2008) A 0–55-GHz coplanar waveguide to coplanar strip transition. *IEEE Transactions on Microwave Theory and Techniques* **56**, 1–6.
11. **Qayyum JA, Abt M, Roch A, Ulusoy AC and Papapolymerou J** (2017) “Ultra wideband 3D interconnects using aerosol jet printing up to 110 GHz,” 2017 12th European Microwave Integrated Circuits Conference (EuMIC), 2017, pp. 372–375, doi: 10.23919/EuMIC.2017.8230736

Zunnurain Ahmad (S’17) received his Ph.D. degree in electrical engineering from University of Stuttgart, Germany. His current research interests include high efficiency 3-D antennas for millimeter wave applications and interconnect.

Lee Harle (S’97–M’03) received her B.S. degree in physics from Indiana University, Bloomington, in 1996, and the M.S.E. and Ph.D. degrees in electrical engineering from The University of Michigan at Ann Arbor, in 1998 and 2003, respectively. Her thesis focused on micromachined cavity resonator filters in silicon.