WHITE PAPER

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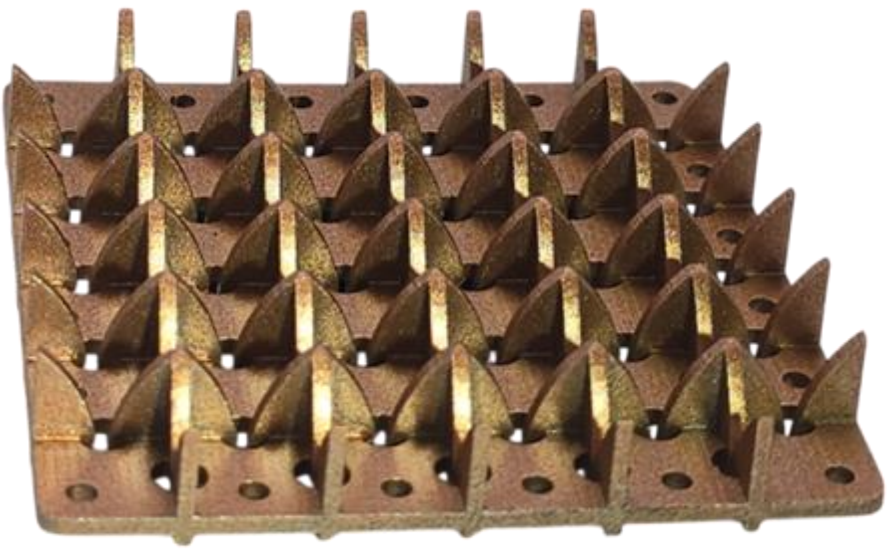
APPLICATION-READY MM-WAVE COMPONENTS USING PRECISION METALLISED AM



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INTRODUCTION

As millimetre-wave (mm-wave) technologies continue to evolve, the performance, integration, and manufacturing readiness of passive RF components become increasingly critical. Fields such as telecommunications, satellite communications, industrial sensing, and aerospace require high-frequency components that are compact, lightweight, and built to endure harsh environments while maintaining excellent electromagnetic performance. Components such as filters and antennas (including increasingly complex variants like corrugated or quad-ridged horn antennas as well as monolithic integrations of antennas and filters, OMTs, etc.) must meet extremely high standards for dimensional precision, conductivity, and reliability. Traditional manufacturing methods, however, face limitations in producing three-dimensionally complex, tightly integrated geometries with the ultra-low surface roughness, micron-level tolerances, and consistent high conductivity needed to meet these performance and integration demands.

Horizon Microtechnologies bridges this gap through the combination of high-precision additive manufacturing (precision AM) and its proprietary high-conductivity metallisation processes. This hybrid manufacturing approach enables the production of mm-wave components with complex internal geometries, extremely fine tolerances, and exceptionally low surface roughness. In fact, Horizon consistently achieves the lowest surface roughness values demonstrated to date for 3D-printed RF components, on par with, and in some cases exceeding, the finish quality of conventional machining methods. Combined with equally smooth, robust, highly conductive metallisation, this capability allows Horizon to deliver application-ready components that meet or exceed the stringent performance standards required for commercial deployment, not just laboratory demonstration.

This white paper outlines how Horizon's micro-AM platform is already delivering production-ready solutions for some of the most challenging components in the mm-wave domain. We will explore use cases across filters, horn antennas, corrugated and dual-polarised horn antennas, and dielectric-loaded structures. Waveguide components present different considerations and are treated in a separate document that can be requested from info@3dmicrofabrication.com. We will also detail Horizon's proven capabilities in delivering environmentally robust components — encompassing resistance to temperature shock, humidity, vibration, and outgassing — supported by a range of passivation options including wet chemical treatments, silver, and proprietary overcoatings.

In addition to manufacturing, Horizon provides specialist RF design-for-additive-manufacture expertise, ensuring that component geometries are not only optimised for electromagnetic performance but also tailored for seamless production with precision AM and metallisation. Such early-stage collaboration between a vertically integrated design and manufacturing company and the end user ensures that overall application requirements, and design and manufacturing aspects are taken into account from the start, shortening development cycles, avoiding manufacturability pitfalls, and maximising the performance of the final part.

A key advantage of Horizon's approach is the ability to produce polymer-based components that, once metallised, deliver the electrical performance of solid metal parts at a fraction of the weight. Compared to CNC-machined metal equivalents, weight savings of up to 85% are possible through the use of lightweight plastic rather than metal, which is a critical benefit for aerospace, satellite, and mobile platforms where mass reduction directly translates into cost savings or increased payload capacity. The combination of lightweight structures and mechanical robustness means customers no longer need to choose between performance and portability.

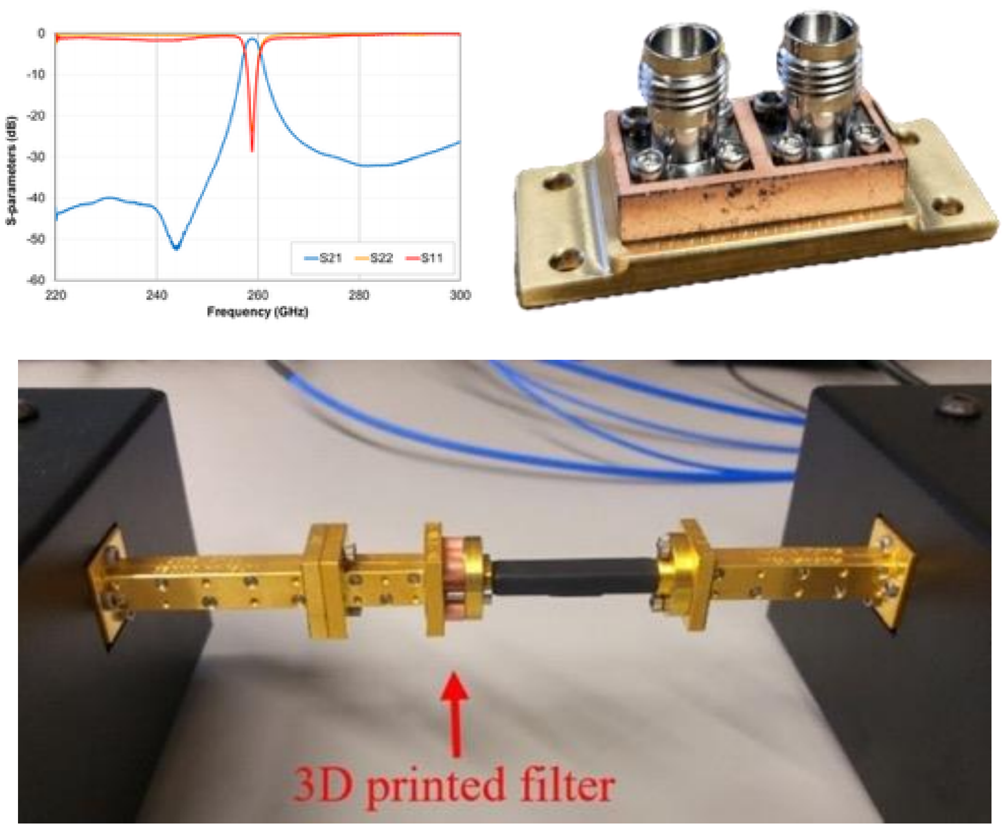
WR62 Coax-to-waveguide transition

APPLICATION FOCUS

MILIMETER WAVE FILTERS

Filters are essential to many mm-wave systems, serving as spectral gates that isolate desired frequency bands and suppress unwanted signals. Achieving sharp frequency roll-off and low insertion loss depends critically on high conductivity, geometric accuracy, and smooth internal surfaces. Horizon has produced filters for a broad range of frequencies between 4 GHz and 270 GHz. Here, dimensional tolerances in the low tens of microns or better are required and even slight deviations can result in significant performance degradation. The achieved Q-factors of as high as 800 at 260 GHz are a strong proof that the overall fabrication process is competitive with high-end alternatives and is able to deliver on the required combination of excellent surface finish as well as high conductivity and accuracy simultaneously. [1]

Using micro-AM, Horizon can manufacture filters with intricate resonator cavities and internal geometries that are difficult or impossible to achieve with conventional machining. This enables highly compact, lightweight designs with optimised RF performance, reduced insertion loss, and improved out-of-band rejection — directly benefiting customers with smaller form factors, lower mass for space and aerospace applications, and faster time to market.



Top Left: S-Parameters of the J-Band bandpass filter. Top Right: U-Band filter with connectors. Bottom: The same filter shown inside the measurement fixture. (Image: Copyright XLIM, France.)

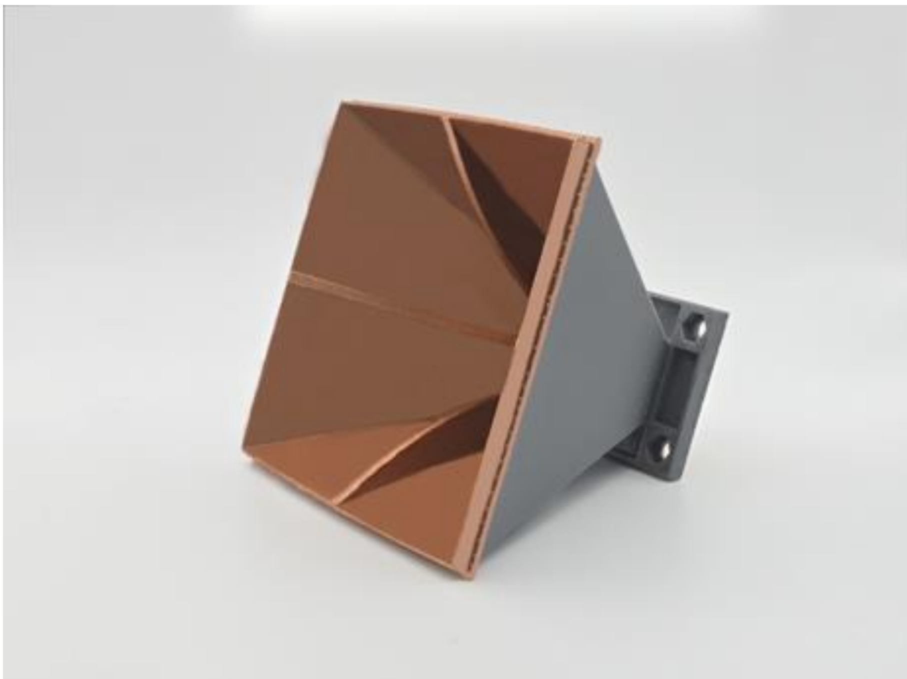
The micro-AM derived polymer components are coated using Horizon's proprietary metallisation process, delivering conductivity as effective as bulk copper or silver with coating thicknesses corresponding to at least five skin depths (typically 2–10 µm). The underlying printed parts already exhibit exceptionally low surface roughness well below 1 µm R_a, and the coating process preserves this smoothness — meaning the final coated surfaces are among the smoothest demonstrated to date for 3D-printed RF components, on par with or better than most conventional machining methods. The metallisation is conformal, fully covering undercuts and fine features, ensuring consistently high surface conductivity across even the most complex internal geometries.

Horizon's passivation options (wet chemical treatments, silver overcoats, and a custom-developed proprietary coating for RF applications) further ensure environmental stability and long-term reliability. These coatings prevent oxidation and surface degradation that could occur due to such factors as high humidity and temperature cycling without introducing RF losses.

STANDARD GAIN HORN ANTENNAS

Horn antennas are valued for delivering high gain while also offering relatively high bandwidth, which many other high-gain antennas struggle to achieve. Ridged horn antennas can extend this advantage even further, providing exceptionally wide bandwidth.

For applications requiring high gain but not justifying the need or budget for a fully bespoke development, standard gain horn antennas are an attractive choice. They are established, mature solutions, available off the shelf, and can be integrated into a system design with relative ease (provided the physical form factor — including the "pointiness" of the horn — is acceptable).

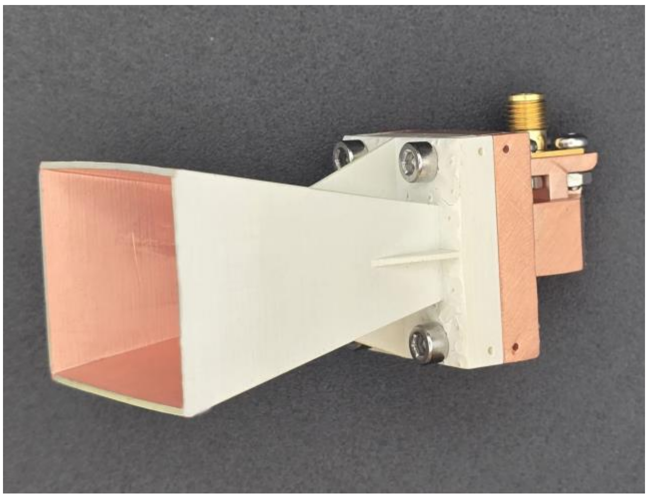


Quadridged, dual polarized broadband horn antenna for 2-18 GHz

Where additional performance requirements exist, such as high polarisation purity or extended bandwidth, horn-based concepts provide a robust and proven foundation. Starting from these baseline concepts not only reduces design risk but also shortens development cycles, allowing tailored solutions to be realised more quickly and with greater confidence in their performance. This approach enables adaptation to meet specialised needs without the need to reinvent the wheel. While still technically demanding, a bespoke horn antenna can typically be designed mostly independently of the rest of the system — an advantage not usually possible with strongly integrated antennas.

Performance at frequencies above 100 GHz demands antennas with a few micron-scale accuracy in waveguide cross-section, ridge spacing, and feed transitions. Manufacturing such parts with CNC or other subtractive methods is costly, slow, and constrained by the need for a tool to physically access the material being removed, as well as the requirement to avoid distorting delicate features through local mechanical forces or thermal stresses during machining. In contrast, Horizon's polymer micro-AM process achieves the required tolerances in a single additive build process without significant mechanical or thermal load on the part during most steps of the (post)-process, eliminating the alignment and assembly risks inherent in traditional methods while enabling geometries that are simply not practical with subtractive approaches.

Horizon's proprietary metallisation process produces a highly conductive coating with exceptional uniformity on the printed polymer parts. The printed surfaces are already smooth, and the coating preserves this quality, resulting in an application-relevant surface roughness of well below 1 µm R_a.



WR62-Horn with an SMA connector

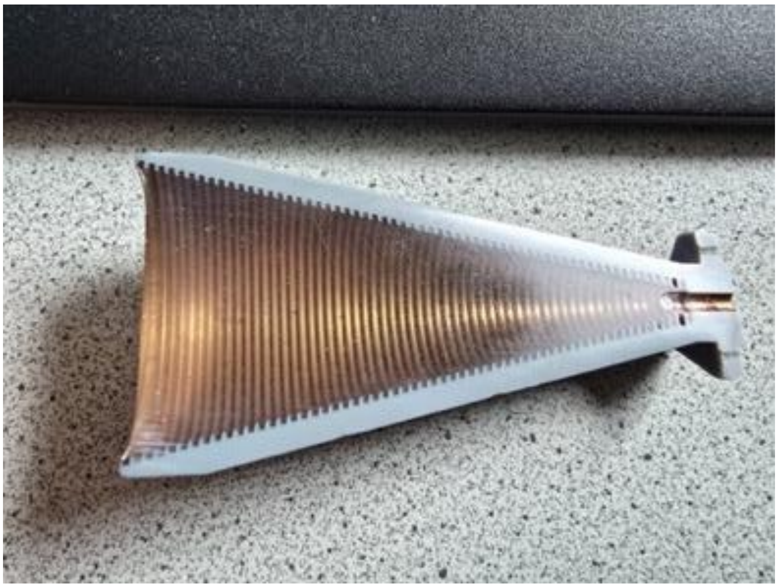
Horizon has manufactured horn antennas across a range of frequencies and design parameters, including D-band variants with gains up to 20 dBi, and tested them against traditionally manufactured counterparts. These evaluations have included S11 parameter measurements, radiation pattern analysis, and cross-polarisation determination. In the case of D-band horns (110–170 GHz), the 3D-printed and metallised antennas achieved return losses better than –24 dB across the entire band while cross-polarisation was minimal at -30 dB or less, and measured radiation patterns showed excellent agreement with simulated models, an indicator of high manufacturing accuracy. At the same time, unit-to-unit variability was negligible, reflecting the precision and repeatability of the process. In addition, the 3D-printed antennas were 85% lighter and occupied 15% less volume compared to CNC-machined versions, clear advantages for aerospace and mobile platforms where weight and space are at a premium. [2]

CORRUGATED HORNS

Corrugated horn antennas represent a further evolution in antenna performance, with the corrugations offering additional ways to control the beam profile. They are the preferred choice in applications where precise beam shape and low sidelobe levels are essential, such as radio astronomy, satellite payloads, and advanced radar systems.

The manufacturing of corrugated horns using traditional machining is prohibitively difficult, if not impossible, especially at frequencies above 100 GHz. Corrugation depths and spacings are often in the range of very few 100 µm, requiring micrometre-level accuracy and uniformity. Horizon overcomes this barrier by using micro-AM to print the full horn, including all internal features, and then metallising it.

One WR10-range corrugated horn antenna was produced in this way, featuring a textbook round-to-rectangular transition and a built-in mode transformer section. Post-embedding and sectioning revealed consistent metallisation across all internal surfaces, including within the corrugations.



Inside of corrugated horn made by 3D printing and metallization, revealing high quality metal deposition even inside the depth of the corrugations. The horn was filled with epoxy prior to cutting only to increase the quality of the cut.

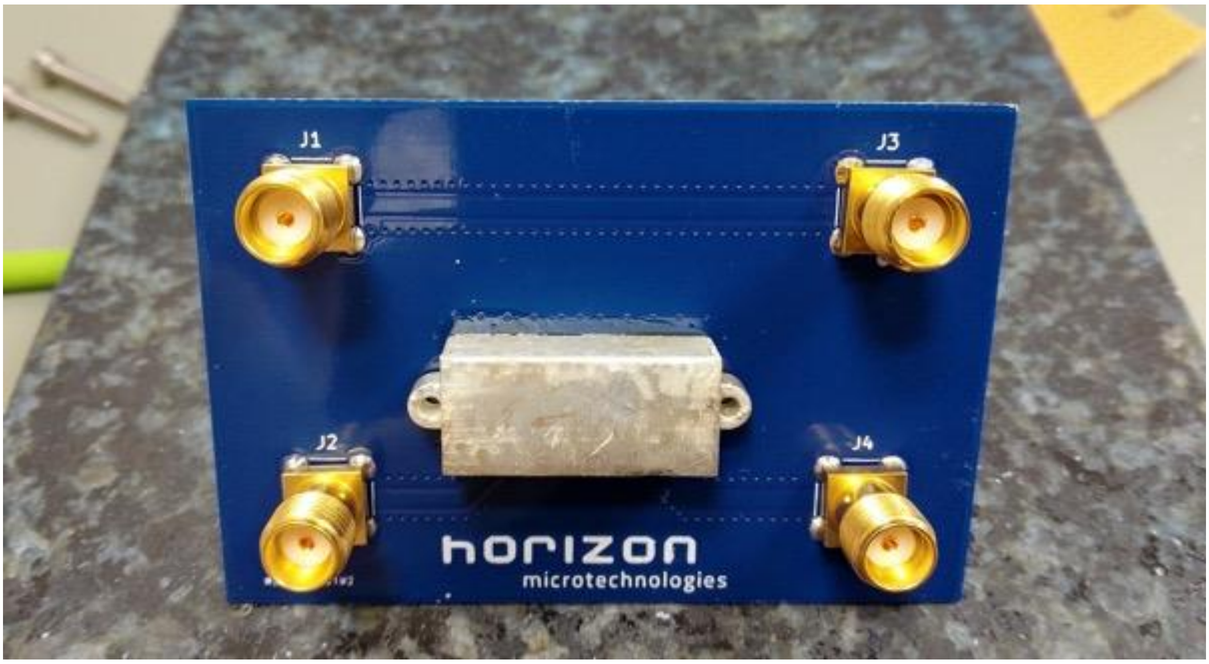
Customers can source such components from Horizon with lead times of under three weeks, significantly shorter than the 8+ weeks typically required for electroformed corrugated horns.

AM DESIGN FLEXIBILITY – BENEFITS FOR INTEGRATION, ASSEMBLY AND PART CONSOLIDATION

While the preceding sections have illustrated Horizon's capabilities through specific application examples such as filters and horn antennas, the underlying value of our platform extends beyond any single device type. To fully appreciate the potential of precision AM combined with advanced metallisation, it is important to step back from individual use cases and additionally consider broader manufacturing principles and technology enablers. The following sections highlight the cross-cutting strengths which underpin all of Horizon's application-ready solutions.

Horizon's AM-based approach enables novel connector and antenna design options that combine RF performance with features beneficial for structural integration or a reduction of assembly steps. For example, an antenna or connector can be easily produced with a custom flange or a monolithically attached housing or fixture. Such simple geometric modifications add little to no complexity to the overall production process.

However, these modifications can be very useful as they allow for the easy and precise mounting of PCBs or by doubling as a shielding housing when metallised. This results in a reduced part count and assembly steps. Horizon has also developed generalized concepts for forming connections between two 3D printed parts as well as between 3D printed and conventionally made parts, including solderable metallised parts and alternatives to screws and nuts for multipart-assemblies. This illustrates how its technology supports established downstream assembly processes and lends itself as a drop-in-replacement. Collectively, these examples underline the breadth of application possibilities that arise when additive design freedom is combined with robust metallisation and application engineering.



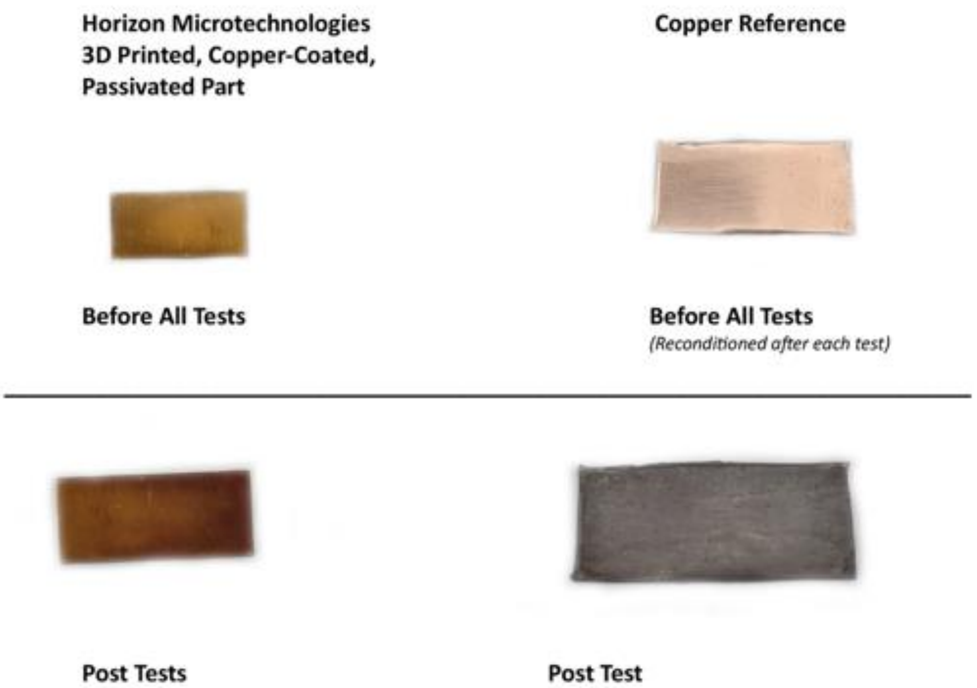
3D printed, silver coated polymer 5 GHz bandpass filter soldered to a PCB

RELIABILITY AND ENVIRONMENTAL ROBUSTNESS

Performance means little without reliability, particularly in sectors such as aerospace, defence, and satellite communications where components face extreme environmental and operational conditions and where repair or replacement is often impossible. Horizon's platform is engineered for both electromagnetic performance and real-world application readiness:

- **Temperature shock and hot/humid conditions:** Metallised components remain stable and maintain electrical performance , without delamination, after temperature shock from -40 °C to +120 °C as well as prolonged exposure to hot temperatures and high humidity (85°C, 85% relative humidity) without moisture ingress or apparent oxidation.*
- **Outgassing control:** Materials and processes result in components passing outgassing standards as set out by the European standard for thermal vacuum outgassing screening for space materials, ECSS-Q-ST-70-02C.*
- **Mechanical robustness:** Parts withstand standard vibration and shock profiles and show no loss of adhesion between the part itself and the coating.
- **Radiation hardness:** Coating adhesion and conductivity is maintained through 100 kRad of radiation exposure. *

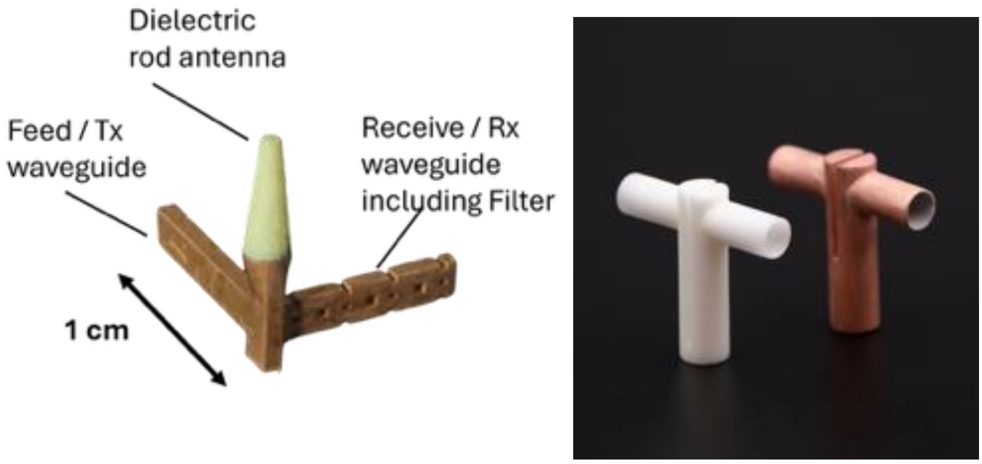
Each of these attributes is treated as a baseline requirement rather than an added bonus. Horizon's design-for-manufacture process ensures that components deliver not only on simulated performance but also in deployment under harsh conditions.



Side by side comparison of environmental stress test coupons. Left column: 3D printed, metallized polymer part before and after 125°C bake and 85%RH/85°C hot-humid exposure, Right: copper sheet before and after the same exposures

CERAMIC PRECISION AM FOR MINIATURISATION

For certain waveguide applications, especially where miniaturisation is critical, ceramic materials offer distinct advantages. Ceramics with high permittivity and low dielectric loss (such as alumina) allow for guided wave propagation in smaller cross-sectional areas than hollow waveguides. This enables significant downsizing of mm-wave components.



Left: Ceramic-loaded metallised waveguide plus antenna assembly consisting of a dielectric rod antenna, a waveguide filter and a feed waveguide. Right: Orthomode transducer realized as a monolithic alumina-filled waveguide with metallized surfaces. The alumina body (left, white) is printed and sintered with a tailored slit in it that, when metallized (as shown on the right), implements polarization splitting between the 2 ports/ arms facing to the side, respectively.

Horizon's ceramic precision AM and coating capabilities enable the production of dielectric-loaded structures with external metallisation. These parts retain high dimensional fidelity and surface quality, while allowing fully integrated functionality in a single component. An example is the component shown in the picture, designed to work at 50 GHz. Using 3D printed alumina as a dielectric core and applying high-conductivity external metallisation, Horizon fabricated a complete integrated module incorporating a waveguide section for feeding a high power signal, connecting to a junction that is in turn connected to a rod antenna for transmitting and receiving a signal as well as a filter that separates the received and transmitted frequency signals. This part is three times smaller in each dimension than an equivalent air-filled hollow waveguide system could be.

Such miniaturisation benefits not only component packaging but also system-level design by enabling higher density layouts.

POSITIONING: A MATURE SOLUTION FOR MM-WAVE INNOVATORS

Horizon's micro-AM and metallisation platform is not simply an alternative to CNC machining or metal 3D printing, it is a uniquely positioned solution designed to meet the demands of next-generation mm-wave component manufacturing. While other methods struggle with surface roughness, feature resolution, assembly complexity, or cost scalability, Horizon's technology overcomes these challenges through a single, integrated, and coordinated process chain — developed to work seamlessly across all steps and available from a single source.

Conventional waveguide and antenna assemblies often rely on split-block construction, where milled halves are screwed together, creating seams that complicate assembly and introduce potential signal leakage and alignment issues. By contrast, Horizon's process enables the manufacture of monolithic or simplified multi-part structures, reducing assembly effort, weight, and potential RF losses. This not only streamlines production but also opens pathways to designs impractical with traditional machining or electroforming.

The platform delivers precision geometries ranging from features as small as 100 µm to components measuring several hundred millimetres, allowing the production of both intricate details and large structures within the same build. Its proprietary metallisation process achieves electrical conductivity exceeding 30 MS/m, comparable to bulk copper or silver, ensuring excellent high-frequency performance. Surface roughness values can be as low as 0.06 µm R_a on optimized internal surfaces — levels unmatched in the 3D printing field and on par with high-end machining, but without the associated cost and complexity.

Horizon also enables complete monolithic construction for parts where alignment-free assembly is critical, or split-block designs where modularity or internal access is required. Environmental robustness is built in from the start, with proven resistance to temperature shock, vibration, humidity, and corrosion through options such as custom passivation. The result is a comprehensive performance and integration profile that allows customers to focus on innovation and rapid deployment rather than compromise or engineering workarounds.

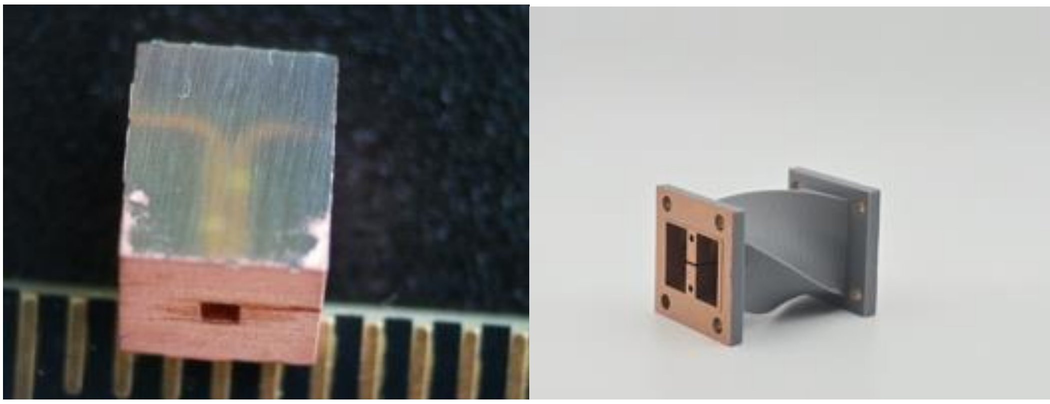
APPLICATIONS AND INDUSTRIES

While this white paper has emphasised filters and horn antennas, Horizon's platform supports a much broader range of mm-wave components. Orthomode transducers (OMTs) can be produced with precise internal geometries that ensure high isolation and low loss, even in complex, multi-port configurations. Feed networks for phased array antennas benefit from Horizon's ability to fabricate intricate, fully metallised internal pathways that minimise loss and phase error. Mode converters and transitions — often difficult to manufacture using conventional techniques — can be realised with exacting tolerances in a single build, eliminating the need for multi-part assembly. Diplexers and hybrid couplers can be manufactured with optimised internal features that directly translate into improved bandwidth, isolation, and power handling.

Industries actively using or evaluating Horizon-enabled components span a diverse set of advanced technology sectors. In aerospace, particularly for LEO/MEO satellite payloads, weight savings and precision performance are critical to mission success and lend themselves to Horizon's solutions. In industrial automation and robotics, Horizon enables compact, high-performance sensing and communication frontends. Scientific instrumentation and materials analysis applications will gain from Horizon's ability to deliver components with extreme precision and tailored electromagnetic behaviour, opening new possibilities for research and measurement systems.

MANUFACTURING CONSIDERATIONS FOR HOLLOW WAVEGUIDE-BASED DEVICES

While this white paper has emphasised filters and antennas, many of the same considerations extend directly to waveguide-based devices. However, waveguides represent a particularly challenging class of components due to their length, potential branching, and the need for extremely smooth internal surfaces across extended geometries. As such waveguides are dealt with in a separate document that can be requested from info@3dmicrofabrication.com. It is important to point out that the same benefits that underpin Horizon's antenna and filter solutions — high conductivity, ultra-low roughness, lightweighting, and design freedom — are equally relevant to waveguides.



Waveguide examples, made by 3D printing a polymer body and metallizing the inside surfaces. Left: WR3 orthomode transducer, right: double ridged waveguide twist

References and Footnotes:

[1]: A. Perigaud, N. Delhote, D. Passerieux, C. Wolff, A. Frölich, "3D printed 260 GHz drawer-like bandpass filter using groove gap waveguide concept", Paper EUMC-33-3, *2025 55th European Microwave Conference (EuMC).*

[2]: A. C. Atak, A. Frölich, A. Quint, T. Zwick and C. Wolff, "A D–band horn antenna made by a proprietary metallization process of photopolymer 3D–prints," *54th European Microwave Conference (EuMC)*, 2024, pp. 220-223, doi: 10.23919/EuMC61614.2024.10732276

*** Contact Horizon Microtechnologies for details on reliability testing. Data continuously updated.**

CONCLUSION

The demand for mm-wave components is growing rapidly, driven by expanding use in communications, sensing, and scientific research. But this demand is not just for proof-of-concept. The market requires hardware that is production-ready, reliable, lightweight, compact, and electrically excellent.

Horizon Microtechnologies meets this demand with a platform combining plastic and ceramic precision AM with extremely conductive metallisation. The solution supports complex geometries, environmental resilience, integrated functionality, and short lead times. Through validated case studies and rigorous testing, Horizon has demonstrated performance equivalence or superiority to traditionally manufactured components, all while enabling new design possibilities and faster development cycles.

For companies working at the cutting edge of mm-wave innovation, Horizon offers not just parts, but partnership. A reliable source of precision-manufactured, application-ready components designed to meet today's requirements and tomorrow's possibilities.

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