

3D Waveguide Metallized Plastic Antennas Aim to Revolutionize Automotive Radar

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Today, the 3D waveguide antenna metallized plastic technology, first introduced by HUBER+SUHNER more than a decade ago, plays an integral role in several industries, particularly in automotive radar for advanced driving systems. This article provides insight into the technology and products and how the products meet the technical demands of the automotive industry. The article recounts on the technology journey from antennas for mmWave backhaul through fixed wireless communications to automotive radar, establishing HUBER+SUHNER as a 3D metallized plastic antenna supplier.

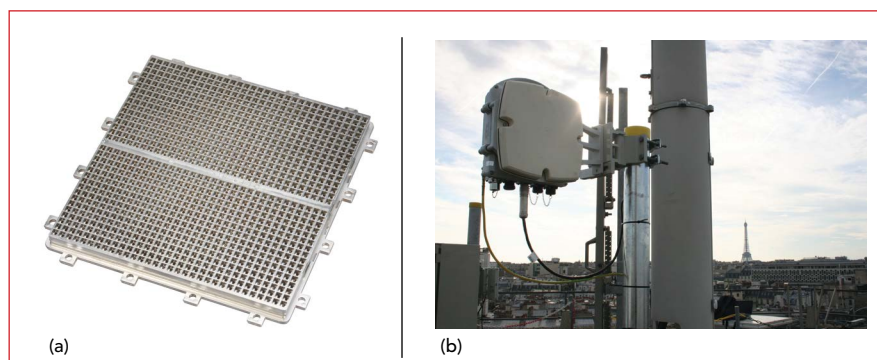
In the search for highly efficient and compact radiators that can be produced at an attractive manufacturing cost, engineers at HUBER+SUHNER have worked on metallized plastic technology since the early 2000s. Through multiple innovation steps, lightweight 3D waveguide antennas

with compact form factors have been successfully designed, manufactured and validated.

Thanks to improved efficiency, pattern stability and large bandwidth, these products are becoming increasingly sought after in the automotive world. This work reviews the journey HUBER+SUHNER has taken to become the supplier of 3D radar waveguide antennas.^{1,2}

THE ORIGIN: MMWAVE BACKHAUL

The first 3D waveguide metallized plastic antennas (see **Figure 1**) were designed by HUBER+SUHNER and have been manufactured there since 2006.^{3,4} These products provide high gain and small form factor for mmWave backhaul at V- and E-Bands (57 to

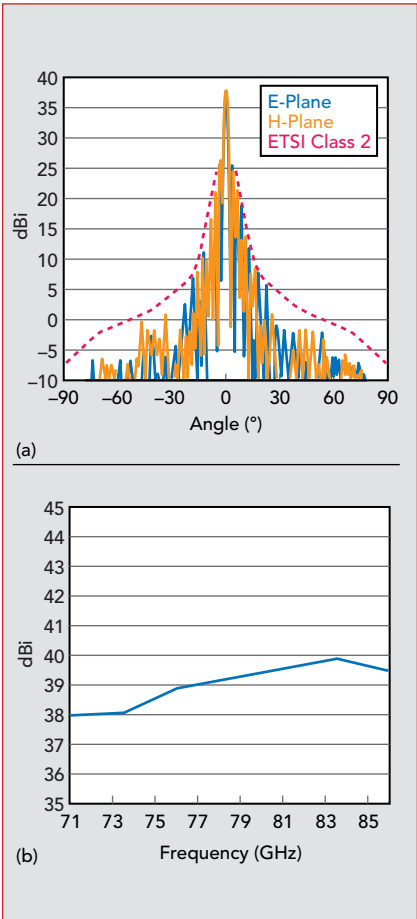


▲ Fig. 1 HUBER+SUHNER mmWave backhaul antennas: 38 dBi (a) and 43 dBi (b).

66 GHz and 71 to 86 GHz, respectively) while remaining compliant with international regulations.⁵

For this purpose, several designs incorporating 1024 to 4096 radiators are fed with the same amplitude and phase and are combined into a single input. This approach results in a radiation pattern with a very focused pencil beam (directivity ranging from 38 to 43 dBi, respectively), controlled sidelobe levels and stable gain over frequency (see **Figure 2**).

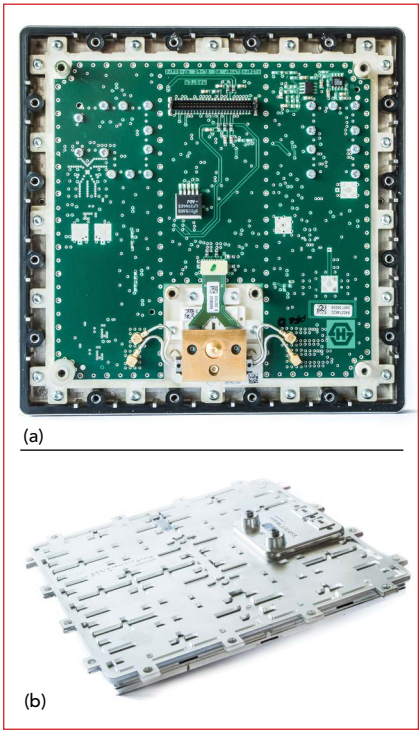
Filters and duplexers with high Q factors were also built with the same technology. This led to further advantages, including compact mechanical housing and fixation concepts which enabled the realization of a fully integrated point-to-point mmWave radio backhaul system, the 'SL60' (see **Figure 3a**).³ A more recent version of the V-Band antenna and the duplexer combination is shown in **Figure 3b**.



▲ **Fig. 2** HUBER+SUHNER mmWave backhaul antennas measured radiation pattern at 73.5 GHz (a) and boresight gain over frequency (b).

SOLVING THE URBAN BANDWIDTH CHALLENGE

The next phase of the metallized plastic antenna evolution occurred with the shift from point-to-point links to multipoint-to-multipoint wireless distribution network applications within the Terragraph⁶ program. This project seeks to provide more people with access to fast internet, deploying gigabit connectivity quicker and more efficiently in markets where fiber trenching is expensive. The solution developed by HUBER+SUHNER, given its broadband characteristic covering the frequency spectrum from 57 to 66 GHz, formed the backbone of the first technology demonstrators for sustained, reliable connectivity (see **Figure 4**).



▲ **Fig. 3** SL60 RF front-end (a) and integrated V-Band antenna-duplexer (b).



▲ **Fig. 4** Terragraph RF front-end board. Two antennas were used for transmitting (Tx) and receiving (Rx), respectively.

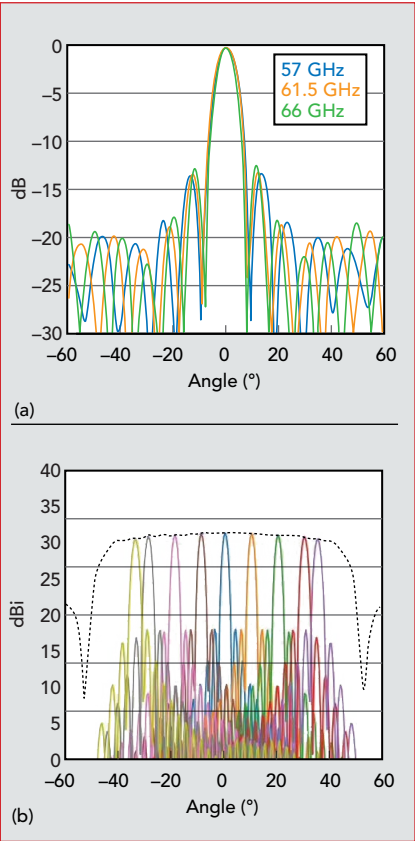
THE MULTI-CHANNEL EVOLUTION

The multipoint-to-multipoint wireless distribution network called for HUBER+SUHNER metallized plastic antennas to evolve from single to multi-channel; a 36-input antenna with vertical polarization was designed and manufactured.

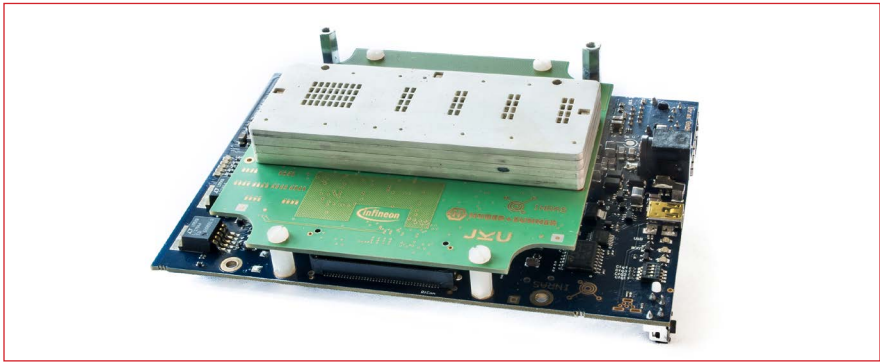
The combined use of all channels makes it possible to steer the main radiation beam to point the communication link to where it is most needed. **Figure 5** shows how full coverage over ± 35 degrees in the horizontal plane is achieved while maintaining a realized gain above 29 dBi.

Designing and manufacturing a multi-channel antenna dramatically impacted its testing as well. As early as 2016, HUBER+SUHNER engineers designed a semi-automated system to test all channels and ensure the quality of the delivered products.

Finally, the simultaneous use of several channels called for higher integration between the antenna and the active electronics. A dedi-



▲ **Fig. 5** 36-channel antenna module normalized elevation pattern vs. frequency (a) and azimuth beam steering at 61.5 GHz (b).



▲ Fig. 6 Demorad radar developed with Infineon.

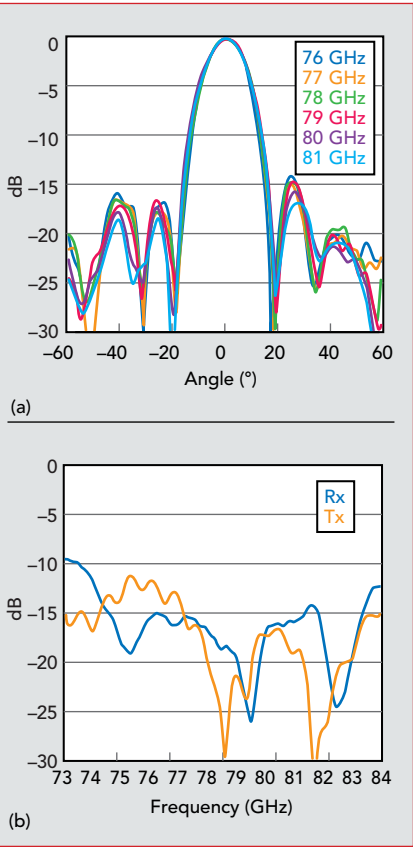
cated, and proprietary, RF interface solution was developed to directly mount the antenna onto the printed circuit board (PCB) with no waveguide flanges required to increase overall product compactness and achieve higher performance.⁷

77 GHZ AUTOMOTIVE MIMO RADAR: A SWEET SPOT

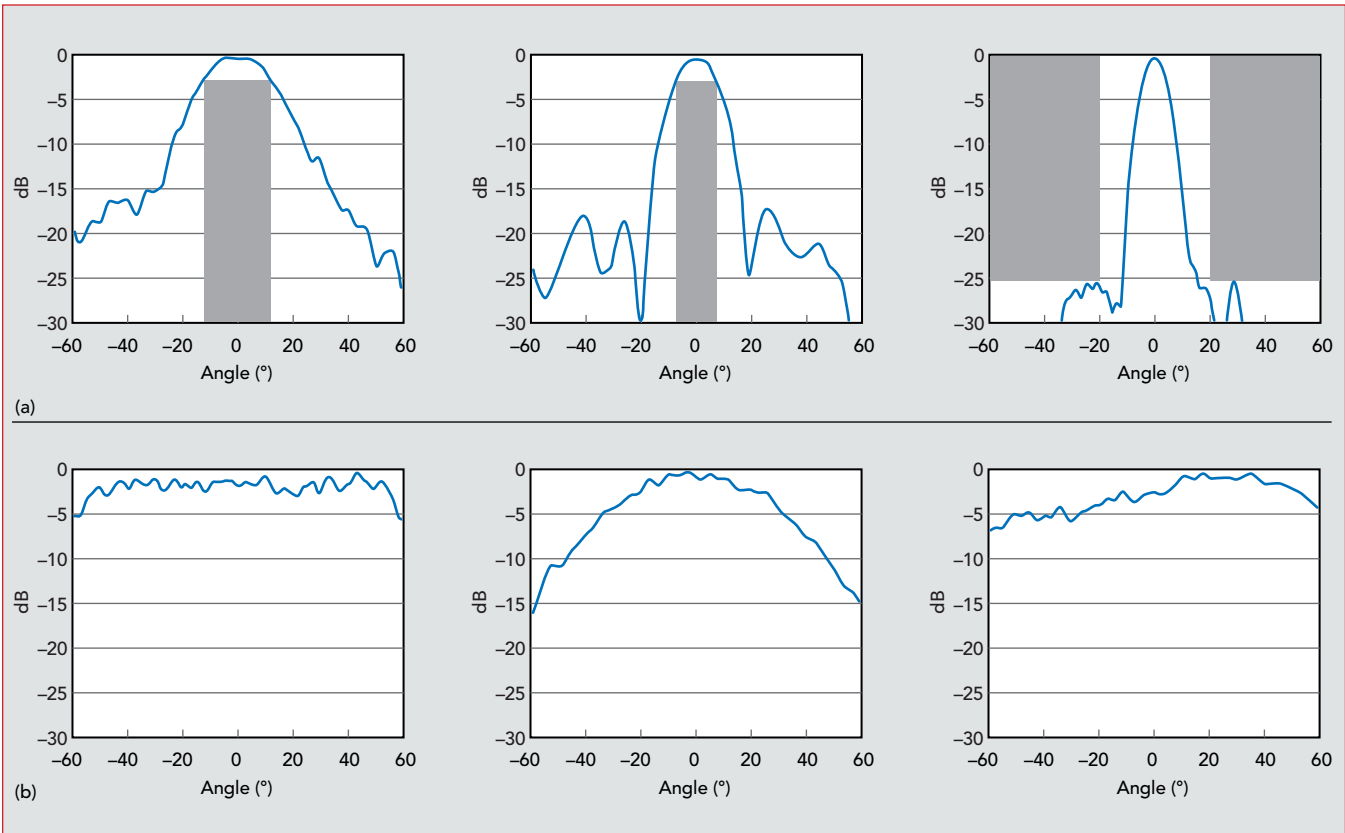
After the implementation of HUBER+SUHNER metallized plastic antennas into the communication market, the use of this technology was introduced for automotive radar applications in 2016,⁸ with its

first demonstration in 2018.⁹ Since then, several antenna solutions and sensors have been designed, manufactured and validated, focusing on both product development and their integration into the ecosystem.

As most original equipment manufacturers (OEMs) and Tier-1 suppliers require dedicated and customized antenna designs protected under confidentiality, this article describes antennas and systems that are the result of internal HUBER+SUHNER development for different radar applications (long-, mid- and short-range, corner and side-looking radars).



▲ Fig. 7 Measured Demorad normalized antenna pattern from 76 to 81 GHz (a) and $|S_{11}|$ of the Rx and Tx antenna elements (b).



▲ Fig. 8 Measured automotive radar antenna patterns: elevation (a) and azimuth (b) planes.

THE 3D ANTENNA AND ITS ECOSYSTEM

The antenna developed for the first system demonstrator—‘Demorad’ (see **Figure 6**)—comprised four 3D-printed layers, standard microstrip-to-hollow waveguide launchers on a low loss RF PCB substrate and an almost uniformly corporate-fed antenna array. Lambda over two and lambda over four spacings were selected for receive (Rx) and transmit (Tx) elements, respectively, to establish a virtual linear array (8 Rx, 4 Tx).

Figure 7 shows some of the measured characteristics of the manufactured prototype. The technology demonstrates a broadband behavior (12 percent relative bandwidth), enabling use of the entire 76 to 81 GHz automotive radar frequency band. Such performance is matched by a stable radiation pattern over frequency with -15 dB sidelobe levels and a high efficiency of 90 percent (0.5 dB loss).

These characteristics outperform the state-of-the-art PCB-based antennas traditionally used within the industry.¹⁰ While this initial demonstration was developed in collaboration with Infineon, the technical solution finds application with all MMIC suppliers.

Today, the design and the technology have taken several steps forward. The first step is product miniaturization. ‘Demorad’ offered exceptional RF performance but, due to the use of four plastic layers, the product was bulky. With technological evolution, the number of layers is now reduced to two, with the overall thickness reduced to less than two lambdas.

The second step is the introduction of advanced feeding techniques with both amplitude and phase tapering for complex radiation pattern shaping. With just two plastic layers different performance characteristics are achieved, from broad azimuth pattern coverage through a tilted beam to narrow elevation patterns with extremely low sidelobe levels, as shown by the measured radiation characteristics in **Figure 8**. All the typical automotive radar requirements for long-, mid- and short-range radar

can now be fulfilled. As a further result of modern advancements, diverse polarizations such as horizontal, vertical, slant or circular can be easily obtained, allowing for polarimetric radar applications as well.

The third step comes in the form of integration with the rest of the sensor and the MMIC. The first demonstrator employed a low loss RF substrate to route and launch signals from the MMIC to the antenna; however, this requires the presence of high performance/high-cost RF substrate material that still generates noticeable losses within the substrate and fails to use the full potential of the low loss waveguide technology.

Thanks to the latest joint development with Texas Instruments,^{11,12} a highly integrated sensor has been realized (see **Figure 9a**). Direct coupling from the MMIC, through plated holes in the PCB, to the antenna dedicated RF interface enables efficient power transmission without the need for a low loss substrate. This provides an RF substrate independent solution and a dramatic benefit in terms of both performance (because there is no need for PCB launchers that easily add 2 to 3 dB loss to the link budget) and cost (by avoiding the need for a high performing RF material).

Figure 9b is another example of integration showing a HUBER+SUHNER 3D metallized plastic antenna as part of the next generation of digital imaging radars. Its low loss characteristics are crucial to providing an antenna array with a highly sparse location of elements over large apertures.

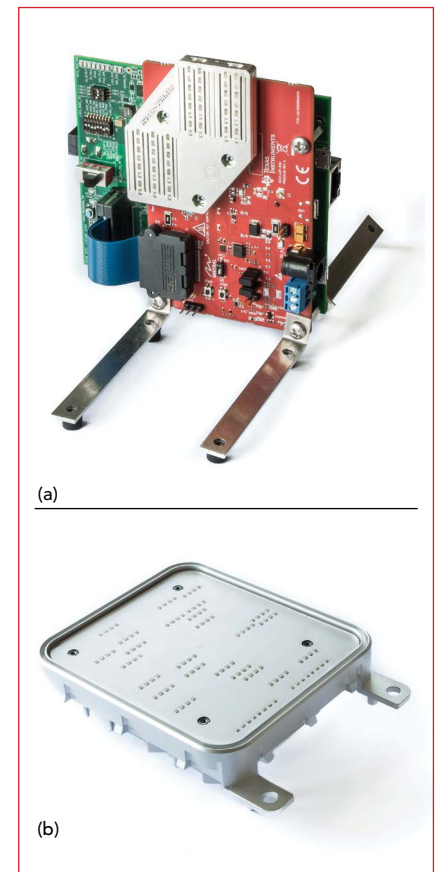
Finally, using a 3D antenna with a large area allows for novel design features to be added to mitigate—if not cancel—radiation pattern distortion introduced by the radome and/or the bumper placed in front of the radiator.¹³

The orange traces in **Figure 10** show the result of multiple reflections when simulating a simple case of antenna-bumper radiation interaction using a flat bumper model with dielectric constant of 3.0, 3.5 mm thickness and an antenna to bumper distance of 18 mm. By in-

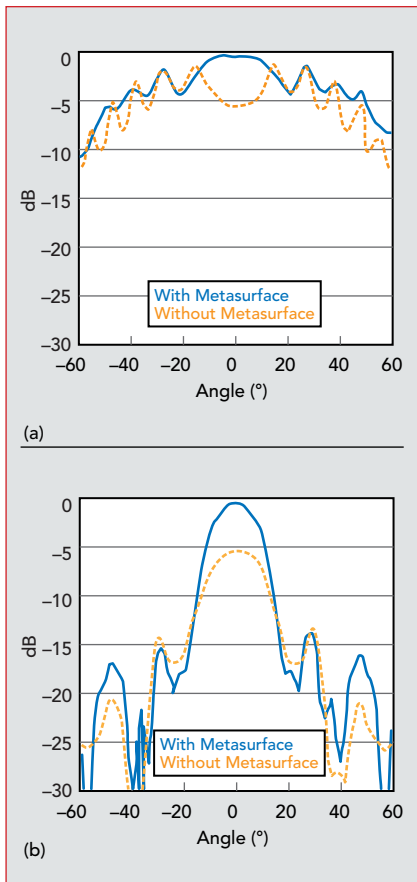
troducing periodic elements (i.e., a metasurface) on the antenna top layer, the desired main beam radiation performance is substantially recovered and pattern ripples are noticeably reduced (blue traces).^{14,15}

TECHNOLOGY: MEANT FOR MASS PRODUCTION...

Since its inception, HUBER+SUHNER metallized plastic technology has incorporated large volume, low-cost and well-established manufacturing technological steps, such as injection molding (IM), physical vapor deposition coating (PVD) and soldering (e.g., reflow soldering including solder paste application and inspection). Due to complete ownership of the three technologies and their joint optimization, HUBER+SUHNER could revise all its core manufacturing steps when moving from the communication segment to the automotive market with its stringent



▲ **Fig. 9** Mid-range demonstrator developed with Texas Instruments (a) and Uhnder digital imaging radar using HUBER+SUHNER 3D antennas (b).



▲ Fig. 10 Simulated effect of a metasurface to minimize antenna-bumper reflections: azimuth (a) and elevation (b) planes.

lifetime and reliability requirement (e.g., extended temperature and humidity ranges, increased number of cycles).

This level of expertise is matched by a proprietary design for manufacturability.^{16,17} To ensure the use of the manufacturing technologies mentioned above, the complex 3D RF geometries are separated into several different layers, paying close attention to both RF performance and the manufacturability.

For example, the waveguides, designed to support the TE₁₀ mode and created by joining different layers, are split across at the maximum of the E-field, corresponding at the null of surface current.¹⁸ This enables a high performance, robust, easy to implement and energy leakage-free assembly. This design approach, together with a proprietary coating, leads to losses as low as 8 to 10 dB per meter with no cross coupling between adjacent channels.

Finally, drawing on its experience, as previously described, HUBER+SUHNER developed a complete RF testing station that can verify all RF channels in a matter of seconds.

Figure 11 shows the process

flow of a typical manufacturing line for metallized plastic technologies that provides a modular approach to fit different customer needs.

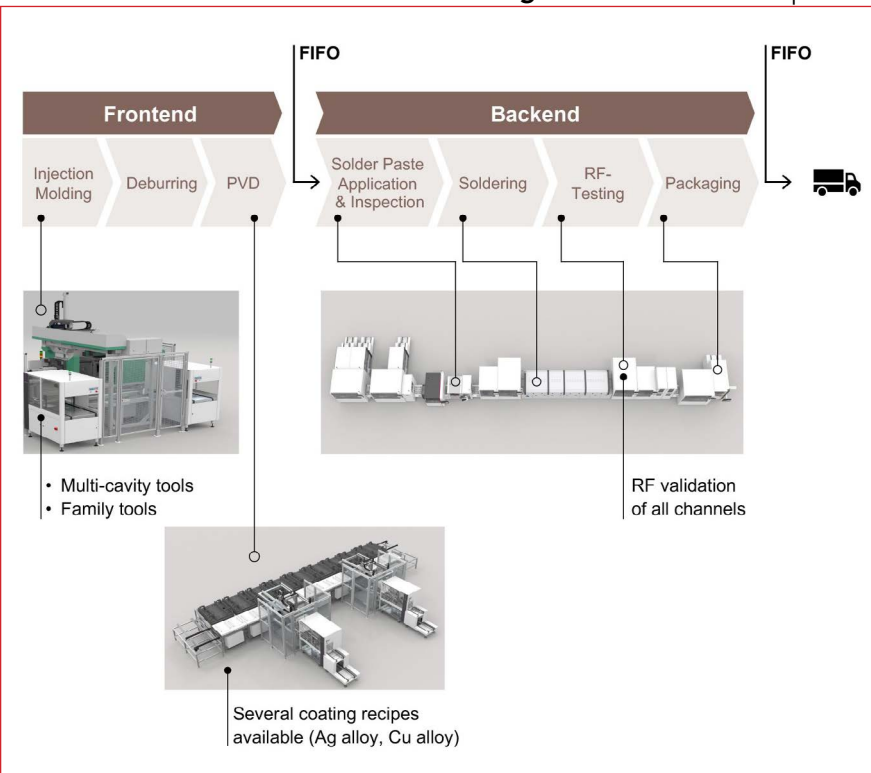
TECHNOLOGY: ...WHILE BEING AGILE

The availability and the use of mass production equipment may endanger the agility required in a product development program, especially when introducing the latest technologies into a new market. Indeed, validating complex and challenging product design iterations requires fast and simple manufacturing technologies.

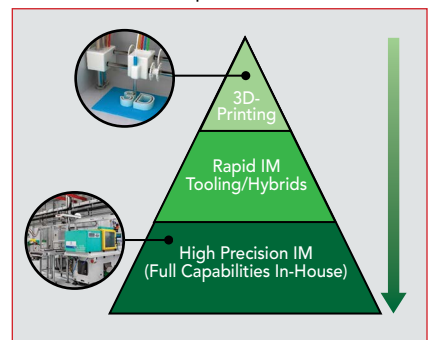
HUBER+SUHNER masters 3D printing technology and rapid IM (i.e., using aluminum tools) to produce individual plastic layers while maintaining an in-house dedicated prototype shop for coating and soldering. Such know-how and capability enables the production of individual samples for concept studies and validation purposes, along with small series production, to match product development requirements, timing and cost. The challenge, thus the art, lies in the implementation of a solution that is as close as possible to series production, even at the earlier stages of product development. HUBER+SUHNER controls the complete value chain from polymer granulates to final validated product (see Figure 12).

MASS PRODUCTION: TODAY AND BEYOND

The demand for automotive radar antennas shows no signs of slowing. Driver assistance functions are increasingly coming to the fore, whether it is an emergency brake assistant, adaptive cruise con-



▲ Fig. 11 Antenna production flow showing main manufacturing steps.



▲ Fig. 12 Available technologies to support product development.

trol or even autonomous driving. To meet this increasing demand, HUBER+SUHNER implemented high volume production technologies that incorporate a high degree of automation from the start.

In addition to the first highly automated production line for long-range radar antennas in Switzerland, a short-range radar production line was recently set up at the HUBER+SUHNER premises in Poland. As a next step, matching customer and market requirements, production lines could be implemented at HUBER+SUHNER locations in other key markets such as China and America. Doing so allows production close to customers' sites, minimizing the product-related CO₂ footprint.

CONCLUSION

HUBER+SUHNER metallized plastic technology is revolutionizing the automotive radar world for all radar applications (long-, mid- and short-range, corner and side-looking radars) as it enables the achievement of very low insertion loss, improved efficiency, pattern stability and impedance bandwidth. It offers overwhelmingly higher performance compared to PCB antennas, with competitive manufacturing costs. Particularly, very low routing losses (less than 8 to 10 dB per meter) enable the distribution of antenna arrays quite freely over a large aperture, enabling high angular resolution and increased virtual array possibilities.

Based on more than a decade of experience and applications into multiple markets, HUBER+SUHNER 3D antennas for radar applications are meeting the demands by major OEMs and Tier-1 suppliers for increased waveguide antenna performance.^{1,2} ■

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