Technical White Paper

Advancements in mmWave Technology: Launch on Package for Automotive Radars

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ABSTRACT

The landscape of automotive radar technology has undergone significant transformation, particularly in the realm of millimeter-wave (mmWave) semiconductor package technology and 3D waveguide antenna. From the initial use of microstrip patch antennas to the evolution towards 3D antennas, the quest for improved performance and efficiency has been relentless. TI's Launch on Package (LoP) technology enables direct signal transmission from the package radiating element to the 3D antenna through the waveguide within the PCB, thereby enabling efficient electromagnetic signal transfer. In the current era, the spotlight is on LoP technologies, accompanied by sophisticated 3D waveguide antennas for providing better range and object detection.

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1 Importance of mmWave and LoP in Automotive Radars

The utilization of mmWave frequencies, specifically around 77GHz, has become pivotal in enhancing the capabilities of automotive radar systems. This frequency range offers the best resolution and accuracy that are crucial for applications like collision avoidance, adaptive cruise control, blind-spot detection, and cross-traffic alerts. The ability to operate effectively in adverse weather conditions such as rain or fog further solidifies the importance of mmWave in modern automotive radar technology.

2 Evolution From Non-LoP With Microstrip Patch Antenna to LoP With 3D Antennas

The journey from standard packages with microstrip patch antennas to an advanced LoP package with 3D waveguide antennas was propelled by the need for increased performance and adaptability. Microstrip patch antennas, while effective, had limitations in beamforming and directionality. The transition to 3D antennas marked a significant leap, providing improved capabilities in steering the radar beam with enhanced precision, (see Figure 2-1).

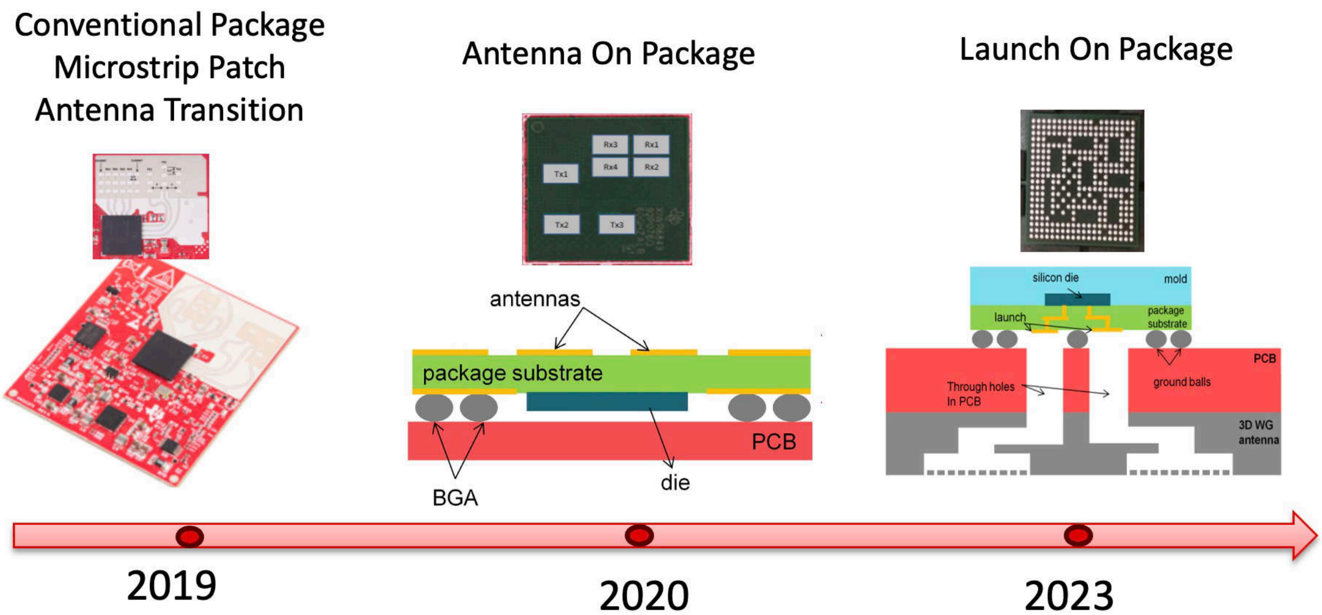

Figure 2-1. Innovations in mmWave Packages at Texas Instruments

Texas Instruments has been innovating mmWave radar package technologies for several years. Early generations of TI mmWave radar integrated circuits used to route the signal from the FCCSP package (non-LoP) through BGA balls, where the signals had to go through four radio frequency (RF) transitions from DIE to package substrate to BGA to PCB before being fed to either a microstrip patch antenna or a 3D waveguide antenna. In later generations where the size of the mmWave radar designs became a key consideration, like in applications such as radar door handles for obstacle detections, TI innovated antenna on package (AoP) technology where antenna elements are integrated within the package. Current generations of TI products include LoP technology where a new way of connecting RF signals to 3D antennas was invented. This connection takes only two RF transitions from DIE to package substrate to waveguide launch which can be directly fed to a 3D antenna through the PCB waveguide. These improvements provide less signal loss and better overall SNR.

Table 2-1. Performance Improvement non-LoP vs TI LoP Technology

Parameters	Standard Package (Non-LOP)		Launch On Package
	Microstrip Patch Antenna	3D Antenna	3D Antenna
RF Transitions	**4** (DIE > Package Substrate > (1)BGA > (1)PCB > Microstrip Patch Antenna)	**4** (DIE > Package Substrate > (1)BGA > (1)PCB > Waveguide Launch > 3D Antenna)	**2** (DIE > Package Substrate > Waveguide Launch > 3D Antenna)

Table 2-1. Performance Improvement non-LoP vs TI LoP Technology (continued)

Parameters	Standard Package (Non-LOP)		Launch On Package
	Microstrip Patch Antenna	3D Antenna	3D Antenna
SNR Performance	Baseline	Baseline	**Baseline + (about 1 + dB)**

(1) Additional RF transitions

3 Introduction to TI Launch on Package (LOP)

mmWave LoP is the latest innovation in radar package technology. These advancements focus on the seamless integration of mmWave radar integrated chips with 3D antennas, presenting a paradigm shift in design and functionality. TI LoP technology is a promising avenue for optimizing performance, reducing emissions and thermal concerns, maintaining signal integrity, and optimizing overall radar system performance.

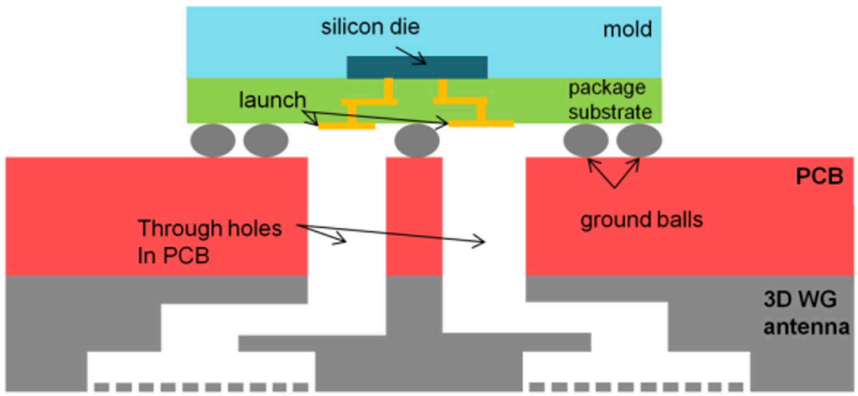

Figure 3-1. Texas Instruments Inc. Launch on Package

Figure 3-1 depicts TI's LoP package technology. Silicon die sits within the package mold compound and RF signals propagate from die bumps through the package substrate to the radiating element. The radiating element directly radiates into the 3D antenna via a waveguide through the PCB. TI LoP technology enables direct signal transfer from the package to the antenna, contrasting the traditional MMIC packages which first transition a signal to the PCB and then to the antenna. The launch is embedded into the package bottom layer and the BGA balls around the launch provide RF shielding of the signals as the signals are propagated into the 3D antenna through the PCB waveguide holes.

4 LOP Design and Operation at 77GHz

Designing mmWave integrated circuits and packages for operation at 77GHz comes with a set of challenges and considerations. The intricacies of this frequency demand meticulous attention to achieve the best performance. Design engineers must navigate factors such as signal propagation, impedance mismatch, interference, and antenna gain, to make sure the radar system operates at peak efficiency within the 77GHz spectrum.

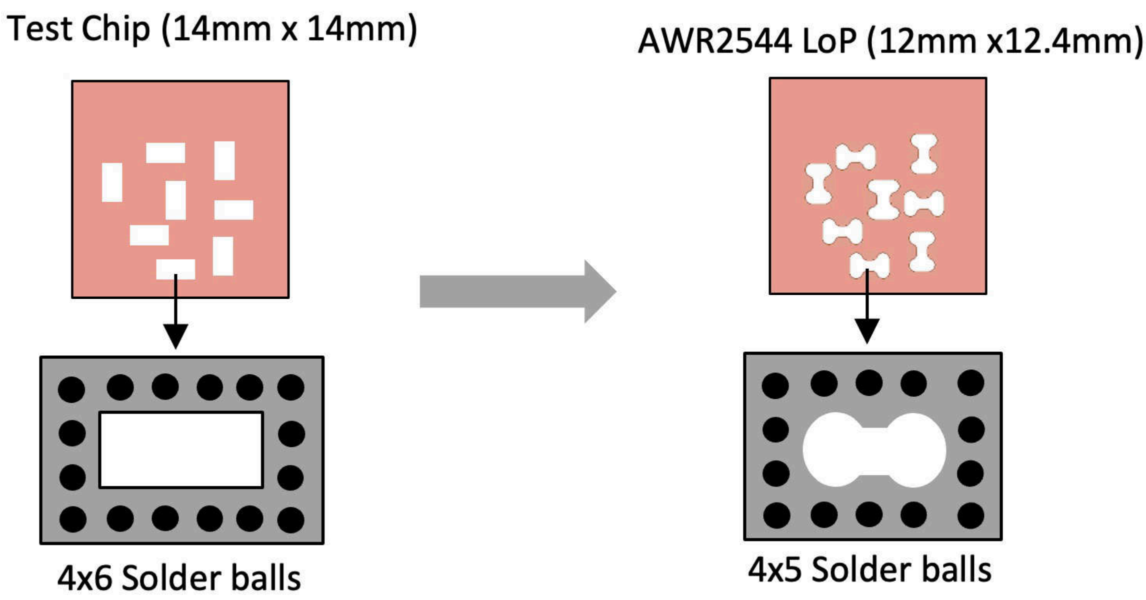

Figure 4-1. LoP Improvements 'Rectangular Waveguide Launch' to 'Double Ridge Waveguide Launch'

Figure 4-1 shows the improvements TI made on LoP technology. After proving the concept with rectangular waveguide launch, TI developed a double ridge wave guide launch that enables smaller size and better performance. The AWR2544 device is a single chip 76–81GHz mmWave sensor composed of a FMCW transceiver that uses the LoP package to launch into a double ridge waveguide structure on the PCB. The AWR2544 sensor is a low-power, self-monitored, and ultra-accurate radar device for satellite architecture, helping to enable centralization of automotive systems.

At frequencies where mmWave radar operates, it is important to maintain a low loss and high signal integrity from power amplifier output to the package substrate, and RF BGA transitions to antenna. Radar advanced driver-assistance system (ADAS) systems can fail if a right match is not established throughout the chain due to the short wavelengths at these frequencies.

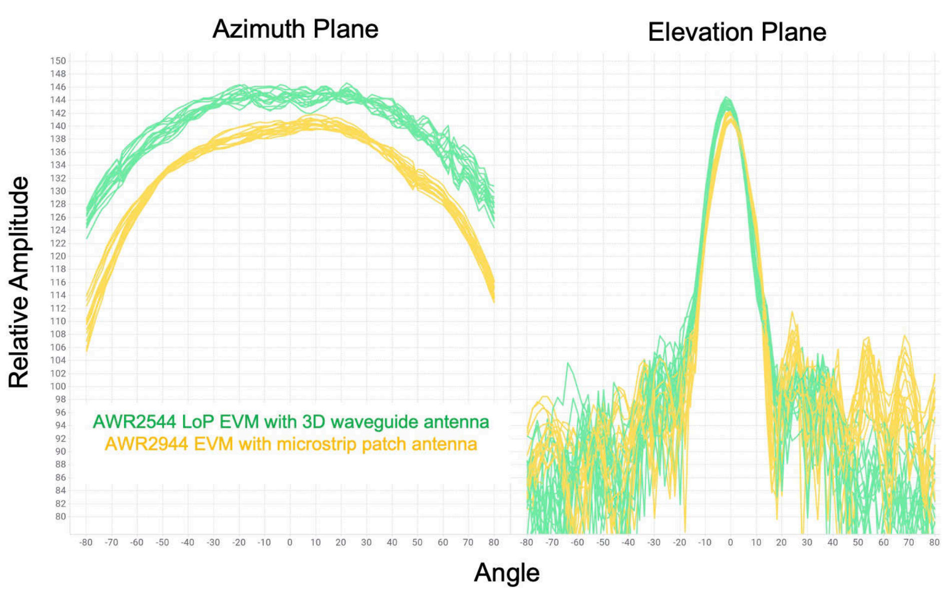

Figure 4-2. Performance Comparison of LoP Technology With 3D Antenna and non-LOP Technology With Microstrip Patch Antenna

Figure 4-2 shows AWR2544 LoP evaluation module (EVM) performance with a 3D waveguide antenna, compared with AWR2944 non-LoP package, which uses a microstrip patch on the AWR2944 EVM. The AWR2944 device is a single-chip, fully integrated 77–81GHz frequency-modulated continuous wave (FMCW) edge radar sensor offering high-performance detections for safety and comfort functions. The AWR2944 has a similar RF front end as the AWR2544. The one main difference between a non-LoP and LoP EVM approach is that a high-quality, low-loss expensive PCB material is needed for the micro-strip patch antenna (AWR2944EVM). However, for the LoP 3D antenna the PCB can be made from a relatively cheaper substrate (AWR2544EVM). Figure 4-3 shows AWR2544 LoP EVM setup with 3D antenna and DCA1000 capture design.

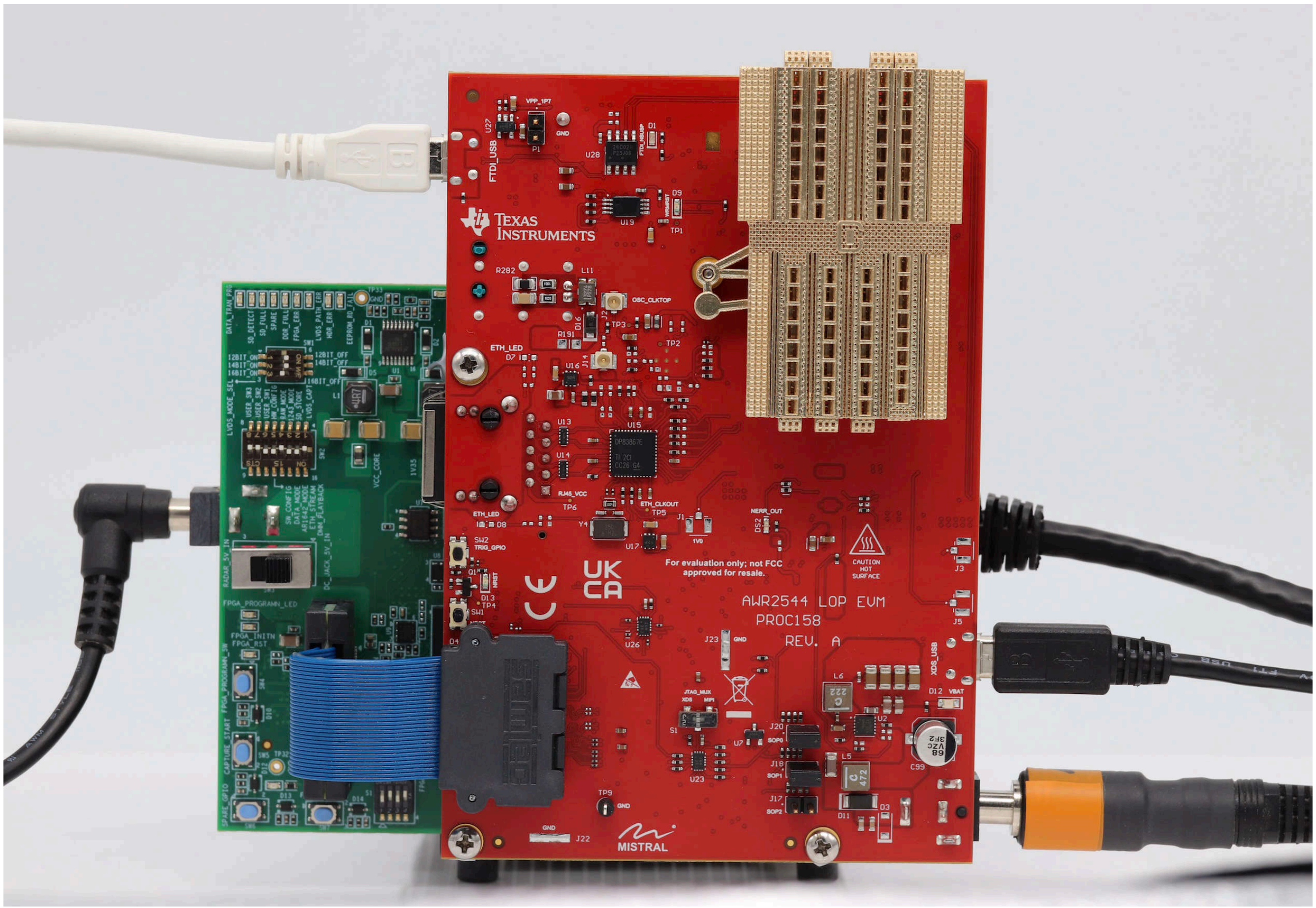

Figure 4-3. AWR2544 LOP EVM Setup With 3D Waveguide Antenna and DCA1000 Capture Board

5 Advantages of LoP for mmWave Radar Chips

The integration of LoP technology enables multiple benefits:

- **Performance Advantage**: TI LoP enables lower transition power loss as the MMIC-to-antenna transition is through a PCB waveguide. This enables an SNR advantage at the sensor level when compared to conventional package and resulting in a higher maximum range for same angular resolution and FOV. Additionally, more stable performance from 3D antennas across channels is achieved compared to microstrip patch antenna.
- **Thermal management:** TI LoP technology which has the launches on the bottom side of the package enables thermal management at the top side as a provision for top side heat sink.
- **Emissions Advantage:** TI LoP with the launches on the bottom side of the package enables lower EMI/C issues as 3D antenna is placed on one side of the PCB and mmWave integrated chip is on the other side of the PCB, thereby increasing isolation from the MMIC to the 3D antenna.
- **Cost and Size Advantage:** TI LoP technology enables a cost advantage at the sensor level due to PCB material and size. PCB cost savings are enabled by the ability to use inexpensive PCB material. Additional

PCB cost savings can be achieved as no micro vias are needed. The potential number of PCB ground layers can also be reduced, thereby reducing in total number of PCB layers.

- **Flexibility:** LoP with external 3D antenna enables better PCB reuse across multiple sensors designs as the waveguide antenna can be changed for multiple sensors that have different field of view. Radar sensors with fewer PCB variants can be designed, enabling higher volume during production, thereby reducing logistics and cost. Moreover, a wider selection of PCB suppliers is available in market due for non-premium RF substrates.

Thus, by minimizing signal loss and optimizing integration, TI LoP technology contribute significantly to the efficiency and reliability of mmWave radar chips. The compact design facilitated by TI LoP technology provides seamless incorporation into automotive radar systems.

6 Applications in Front and Corner Radars

The impact of mmWave LoP technology extends to both front and corner radar systems in vehicles. The precision enabled by TI LoP technology enhances the accuracy of object detection, which is integral in applications such as collision mitigation and blind-spot monitoring. The synergy between TI LoP and 3D waveguide antennas propels automotive radar systems into new frontiers of safety and autonomy.

7 Challenges and Future Developments

While TI LoP technology offers promising advancements, there are some design challenges. The launch must be designed to transfer maximum power from mmWave integrated circuit to the 3D antenna, minimizing return loss and signal leakage. Design the mechanical stability of the 3D antenna and LoP robustly to withstand adverse temperature changes and environmental stresses. High-precision manufacturing and assembly practices, which is needed for better alignment between the PCB and antenna to minimize leakage of electromagnetic signals at optimize cost, needs further improvement.

Movement towards L3 autonomous driving needs higher angular resolution (both azimuth and elevation) to resolve static environment (overhead structures, guard rails, road debris) and improve object classification. This demand increases the number of transmitter and receiver channels. Thereby, it is a challenge to design a LoP package with reduced size, isolation, and cost for a large number of integrated channels. Lastly, another challenge is that the height of the 3D antenna is more relative to microstrip patch antenna thereby increasing overall sensor size.

Ongoing efforts in research and development aim to overcome these challenges and usher in the next wave of innovations in mmWave semiconductor and antenna technology for automotive radars.

8 Conclusion

In conclusion, the integration of TI LoP technology with 3D waveguide antennas marks a significant milestone in the evolution of mmWave Radar sensors for automotive radar systems. The capabilities unlocked by these advancements at 77GHz pave the way for safer and more sophisticated autonomous driving systems. As challenges are addressed and technology continues to evolve, the future holds the promise of even more groundbreaking developments in the realm of automotive radar technology.