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The real third wave of semiconductor market growth and some packaging challenges

By Asif Chowdhury [UTAC Group]

At about 0.5%, the semiconductor industry is a small percentage of global GDP. However, semiconductor devices play a very large role in advancement and growth of almost all other market sectors and industries. Semiconductors are an integral part of our everyday lives. In the last 50 years, this niche market has grown from almost nothing to about a \$500B market ushering in new technologies and innovations that have not only significantly altered and improved almost all aspects of our lives, but also propelled the growth of many other markets. [Note: Forecasts in this article were made before the full potential market downside of the COVID-19 pandemic were known.]

Figure 1 shows 5-year compound annual growth rates (CAGRs) for the semiconductor market from 1995 through 2019. While the semiconductor industry has steadily grown since its inception, there were a couple of periods during which the industry saw waves of double-digit growth. The first wave was in the nineties driven by the significant growth in the personal computer (PC) and laptop markets. Figure 1 shows

5-year CAGRs north of 20% during this growth phase. Then the market went through a down cycle due to the Dot-com bust in 2000. The next growth spurt, or the second wave of growth, was driven by the advent and proliferation of mobile handsets and tablets from the early 2000s to about 2008, just before the last financial crash (2008). Since then, the market has rarely seen any double-digit growth year-over-year. In the last decade, there wasn't a single 5-year CAGR with double-digit growth.

As the industry has matured, year-over-year growth has naturally become moderate. Still, there has been continued discussion among the semiconductor market pundits as to what will drive the next double-digit growth spurt for the semiconductor market, if anything. There were a good few years during the last decade when it was widely believed that the Internet of Things (IoT) would be the next double-digit growth driver for the semiconductor market. However, despite all the hype around IoT, that expected growth didn't take place for various reasons. Perhaps one of the key reasons is because the price points for fundamental technologies remained relatively high

causing prices of many of the novel IoT end products to remain outside the reach of mass consumers.

The latest hype in the semiconductor world is 5G. There is another round of consensus building around the potential of 5G technology as the next big growth driver for the semiconductor market. This time though, the hype is likely to become reality, not only because of the potential of proliferation of 5G, but significant improvement of some other key fundamental technologies such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), and cloud computing. As shown in Figure 2, along with the growth of 5G, the improvement of these key technologies will likely

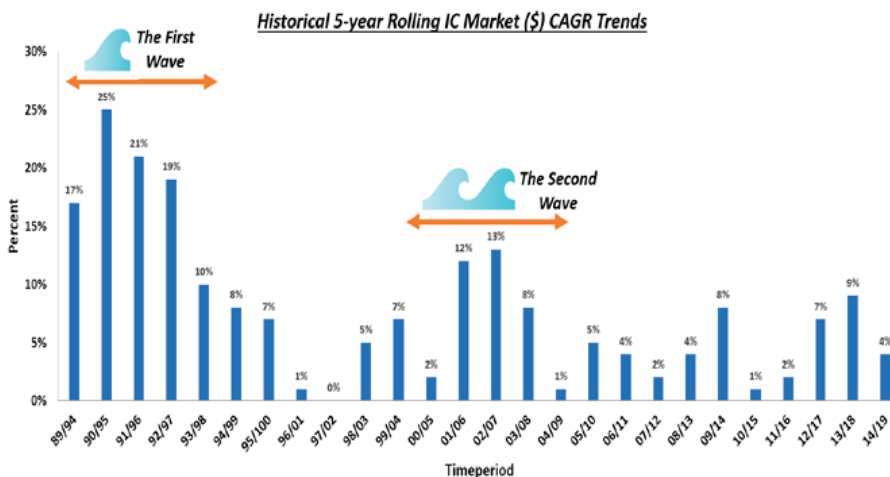


Figure 1: 5-year rolling CAGR for IC markets from 1994 through 2019. SOURCE: IC Insights

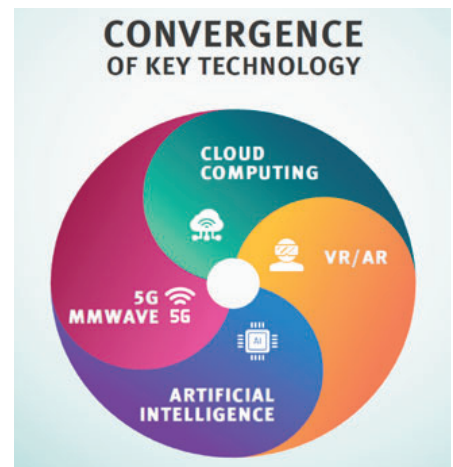


Figure 2: Development and convergence of fundamental technologies likely to fuel growth for the semiconductor market.

create a convergence that will usher in the next-generation of electronics products from true smart homes to full autonomous vehicles.

In addition to the significant improvement in the fundamental technologies discussed above, another important phenomenon is also likely to enable this convergence to create and grow next-generation products.

The unit price of all these technologies has come down over the last decade making “things” cheaper and hence more affordable.

Figure 3 shows significant decline in some of the key fundamental technologies such as power, various sensor products, and radio devices from 2012 through 2020. Sensor products, such as microelectromechanical systems (MEMS), are key to the success and growth of IoT products. **Figure 4** shows how the average sensor unit cost has declined by half from \$1.30 in 2004, to \$0.60 in 2014 and estimated to go down to \$0.38 in 2020. MEMS technology allows us to “digitize” our analog world. **Figure 5** depicts the unit price reduction of MEMS sensors from over \$3.00 in the early 2000s, to about \$0.50 in 2018. **Figure 5** rightfully predicts two possible outcomes for MEMS unit prices for the first half of this decade. It is likely that both will happen depending on MEMS integration and application. Unit prices of advanced integrated MEMS products will likely rise because of the complexity of such products, while prices for standard MEMS products will fall driven by high volume in IoT application. However, the average unit price of MEMS will continue to decline.

The most important element for the technology convergence (as shown in **Figure 2**) is the development and deployment of 5G mmWave technology. While there is a lot of buzz going around about the potential for deployment of 5G in the next two to three years, the real 5G will not be widely available until the second half of this decade. It is this real 5G that will be the very basis for the next generations of electronic applications.

The best way to look at 5G is to put this technology deployment into two phases. Phase 1 is up to the 6GHz frequency range, and Phase 2 is in the >24GHz range as depicted in **Figure 6**. The current 5G deployment that is scheduled to start by the end of 2020 is Phase 1. In this phase, most of the 4G infrastructure can be used with 5G component upgrades while consumers will have to buy new 5G handsets. In this <6GHz frequency range, while transmission will be faster than current 4G, it will not have the step function improvement as the 5G Phase 2, which is called 5G mmWave. It is in this frequency spectrum where the true benefits of 5G lie. As shown in **Figure 7**, when compared to the performance of

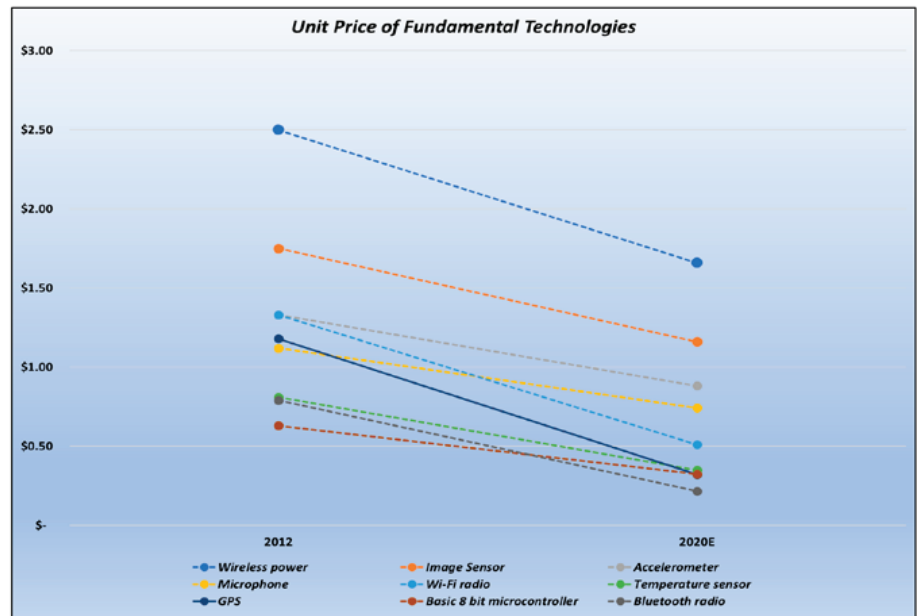


Figure 3: Unit price for fundamental technology has steadily declined in the last decade [1].

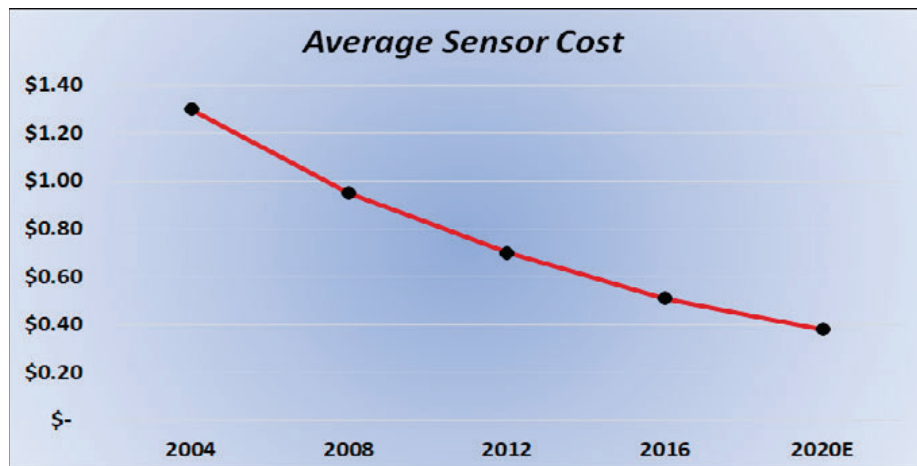


Figure 4: Average price for sensor products, key enablers for IoT, have come down significantly. SOURCES: Goldman Sachs and [2]

4G, 5G mmWave can have up to a 100X improvement in data rate, a 10X reduction in latency, and a 100X traffic capacity allowing a significantly higher number of connected devices.

5G mmWave will require brand new infrastructures as it works only with “line of sight” transmission. In other words, the cell towers will have to be much closer to each other. This will take some time to implement and most likely will not be ready in wider areas until 2024, or even later.

The significant performance improvement with the deployment of

5G mmWave technology will open new frontiers of capability and usher in the introduction and growth of advanced technologies. For example, the up to 100X transmission speed will allow seamless transmission of high-resolution 8K video enabling people to watch such video on their handsets without any interruption. This higher transmission speed along with the 10X reduction in latency is extremely important in the proliferation of autonomous vehicles. Driven by improved safety standards, a higher level of connectivity and improved

infotainment, automotive electronics and the semiconductor market have been consistently growing at 5%~8% CAGR. With the proliferation of autonomous vehicles, the amount of electronics in a car is predicted to increase significantly. **Figure 8** shows the actual growth of global vehicle production and electronic cost as a percent of total car cost from

2000, to estimated numbers in 2030. In 2030, 50% of the total cost of a vehicle is estimated to come from electronics components. As the number of electronics components grows per vehicle, so will the semiconductor content.

The technology convergence will usher in other new products and product improvements such as, 5G handsets and

infrastructures (cell towers), factory and industrial automation, advanced medical technology, autonomous vehicles, gaming, security, and of course, IoT (see **Figure 9**). Indeed, we are very likely to witness the explosion of IoT during the second half of this decade.

The explosive growth of these next-generation electronic products and devices will in turn drive the next growth spurt or The Third Wave of semiconductor market growth. This Third Wave of growth is predicted to come after 2024 and the semiconductor industry could once again see years of double-digit growth in the second half of this decade as shown in **Figure 10**. Based on the above estimate, by 2030, the overall semiconductor market could go over a trillion dollars with outsourced semiconductor assembly and test (OSAT) value going over a hundred billion dollars.

The 5G revolution will also bring significant challenges to packaging and testing technologies and will drive growth for advanced new packages. However, the growth of IoT, automotive semiconductor, gaming, etc., will also raise the demand for more common semiconductor package types. **Table 1** shows actual units produced for common package types from 2016 through 2018, and estimated units produced in 2019. The table also shows the estimated forecast of these packages for 5G Phase 1 for 2024, and 5G Phase 2 for 2030. The lead frame-based quad flat no-leads (QFN) package continues to be the most cost-effective, smaller footprint solution with generally good thermal and electrical performance. QFN and molded interconnect substrate (MIS) package demand is poised to increase significantly with an estimated CAGR of 11.3% from 2019 to 2030 because of IoT proliferation as the demand will surge for analog and sensor products. Wafer-level chip-scale packaging (WLCSP) is estimated to see the second highest demand after QFN with a 9.6% CAGR from 2019 to 2030. This includes both fan-in for standard products, and fan-out for advanced integrated, multi-functional ICs. Some of the standard surface mount device (SMD) packages will also see higher growth, such as the very popular 8-lead small outline integrated circuit (SOIC). The quad flat package (QFP) will also likely see higher demand from the automotive market. Laminate packages such as ball grid array (BGA) and land grid

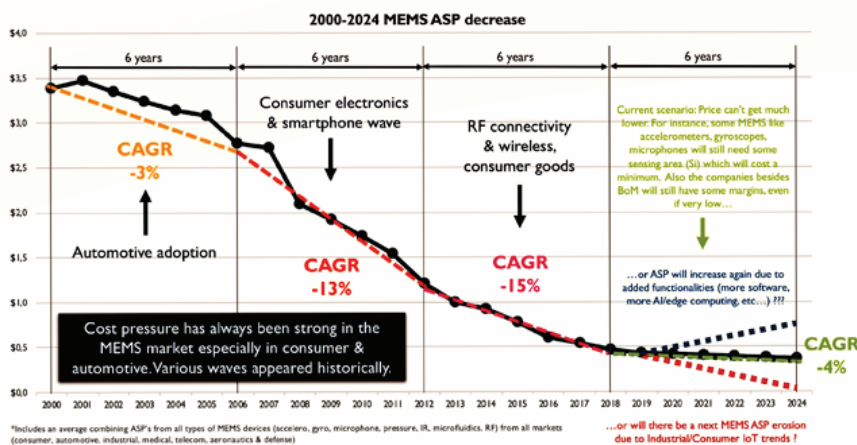


Figure 5: MEMS average selling price (ASP) evolution. SOURCE: Status of the MEMS Industry report, Yole Développement, March 2020

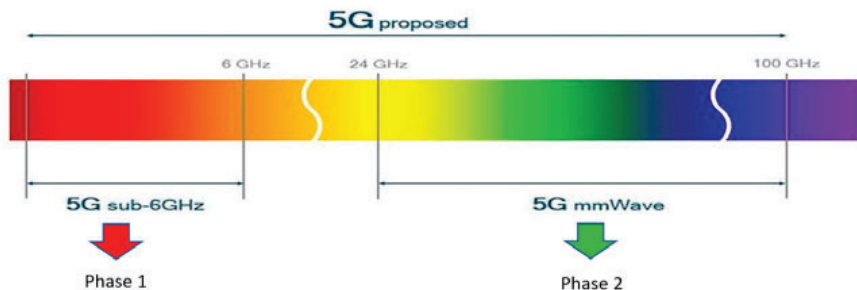


Figure 6: The two phases of 5G deployment: <6GHz in phase 1, and higher frequency, or mmWAVE in phase 2.

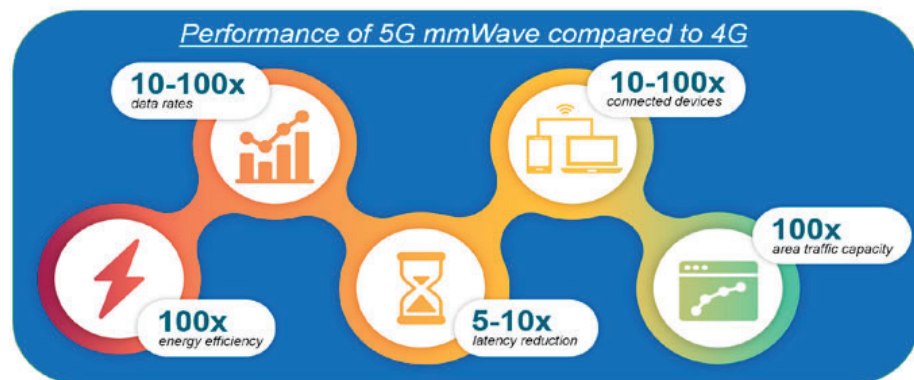


Figure 7: 5G mmWave performance summary compared to that of 4G.

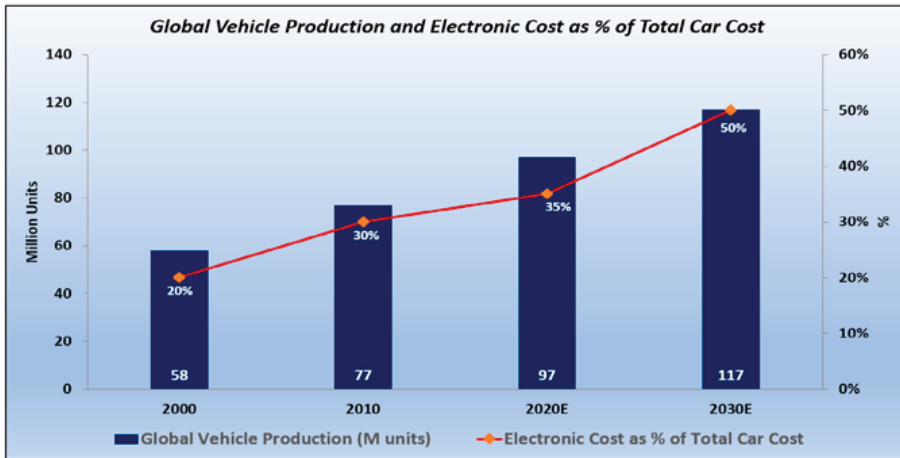


Figure 8: 2000 to 2031 global production of vehicles and the increase of electronic cost as a percent of vehicle cost [3-5].

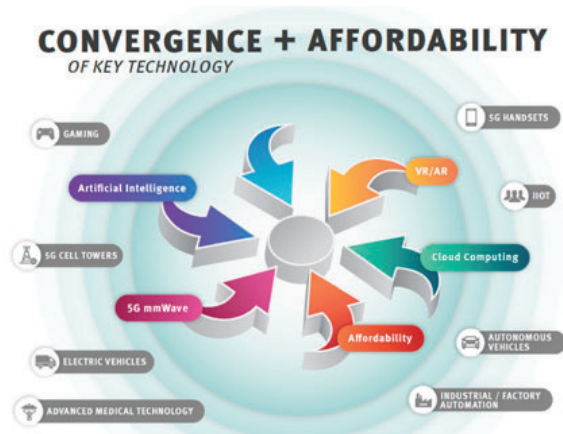


Figure 9: The convergence of key technologies, along with the significant unit price reduction of these fundamental technologies, will drive market growth in this decade.

array (LGA) will also continue to grow, especially using flip-chip interconnect technology. System in package (SIP) is expected to grow significantly because of the need for heterogeneous integration driven in turn by the need for increased functionality within the given real estate, such as in mobile phone applications.

Packaging and testing for 5G mmWave devices will require innovative thinking and perhaps even disruptive technology innovation. Historically, most IC packaging and testing had to deal with

frequencies up to the 6GHz range. For 4G solutions, the frequency range was from 450MHz to 3.7GHz. However, 5G mmWave (Phase 2) will be using a frequency range from 24GHz to 100GHz (though the industry seems to be converging towards an ~28GHz solution). These frequencies are significantly higher than what are used for the current 4G or even Phase 1 5G (at <6GHz). **Figure 11** shows the progression of RF front-end modules from 2G and provides a summary of packaging solutions required for 5G sub-6GHz and 5G mmWave. In 5G Phase 1, an extension of current packaging solutions will work. But 5G mmWave or Phase 2 will require new technologies, such as phased-array antennas and antenna-in-package (AiP). Because of the shorter wavelength of 5G mmWave technology, it has large losses at interconnects. The antenna, therefore, will need to be designed in the IC chip, or at least integrated with the RF front-end module. Testing them cost effectively will be even more challenging.

New material development will be key to produce a suitable and low-cost packaging solution for high-frequency devices. While over-molded plastic packaging is the workhorse of the industry and has the largest capacity and infrastructure in the industry, this will not be suitable for 5G mmWave RF devices. For example, the mold compound used for plastic packages has a relatively high dielectric constant and is not suitable for RF devices above 20GHz. So, unless the material supplier comes up with such a mold compound, a more expensive cavity package solution will have to be used.

Finally, there remains a lack of expertise in the assembly and test sector to effectively handle the high-frequency RF solutions discussed above. The semiconductor back-end industry would need to enlist RF engineers who understand these high-frequency requirements and can fill this knowledge gap for package design and final test.

The technology convergence because of the 5G technology revolution, improvement in artificial intelligence, virtual and augmented reality, and cloud computing, along with unit cost reduction of these key technologies will create a perfect storm that will provide the strong backwind for the next growth phase of the semiconductor industry. While 5G Phase 1 is available in a few locations and imminent in the rest of

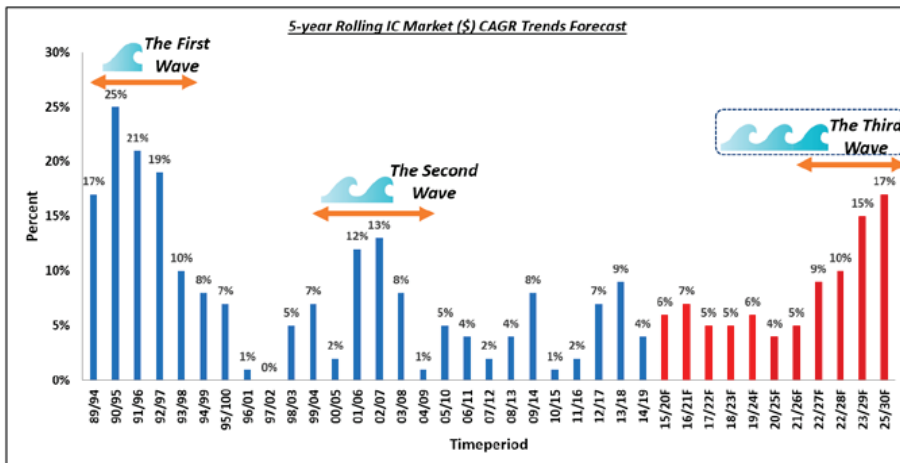


Figure 10: Driven by key technology convergence and lower unit cost of these technologies, the semiconductor industry is likely to experience double-digit growth in the second half of this decade. SOURCES: 89/94 through 14/19 data from IC Insights; 15/20F through 25/30F by Asif Chowdhury

Unit: Bn Units	2016	2017	2018	2019E	2020F	2024F	2030F	CAAGR 2016-2019	CAAGR 2019-2024	CAAGR 2019-2030
SO/TSOP/SOT/DIP	76.0	83.0	88.5	83.0	81.0	91.0	140.0	3.0%	1.9%	4.9%
QFP/LCC	13.2	14.5	15.5	14.5	14.0	15.5	18.6	3.2%	1.3%	2.3%
QFN/FC QFN/MIS	41.6	45.8	50.4	48.9	48.4	70.2	158.4	5.5%	7.5%	11.3%
WB BGA/FC BGA/PGA/LGA	1.7	1.7	1.9	1.8	1.9	2.2	3.8	1.9%	4.1%	7.0%
WB CSP/Stacked CSP/FC CSP/FC CSP for DRAM	23.4	28.2	30.7	28.6	29.5	40.5	65.3	6.9%	7.2%	7.8%
WL CSP	26.0	30.5	32.5	30.6	29.2	42.0	84.0	5.6%	6.5%	9.6%
SIP (FC and WB)	4.0	4.2	4.5	4.1	4.0	4.9	8.4	0.8%	3.6%	6.7%

Table 1: Actual and forecasted units of typical high-volume package types. SOURCE: 2016 through 2024F from Prismark; 2030F by Asif Chowdhury.

the world, the proliferation of 5G mmWave Phase 2 will occur mostly in the second half of this decade. Because this is a fundamental piece of technology for the convergence, the double-digit semiconductor market growth will likely happen in the second half of this decade as well. Cost-effective assembly and test of 5G mmWave devices will be one of the key challenges for success to ensure this third wave of semiconductor growth.

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Biography

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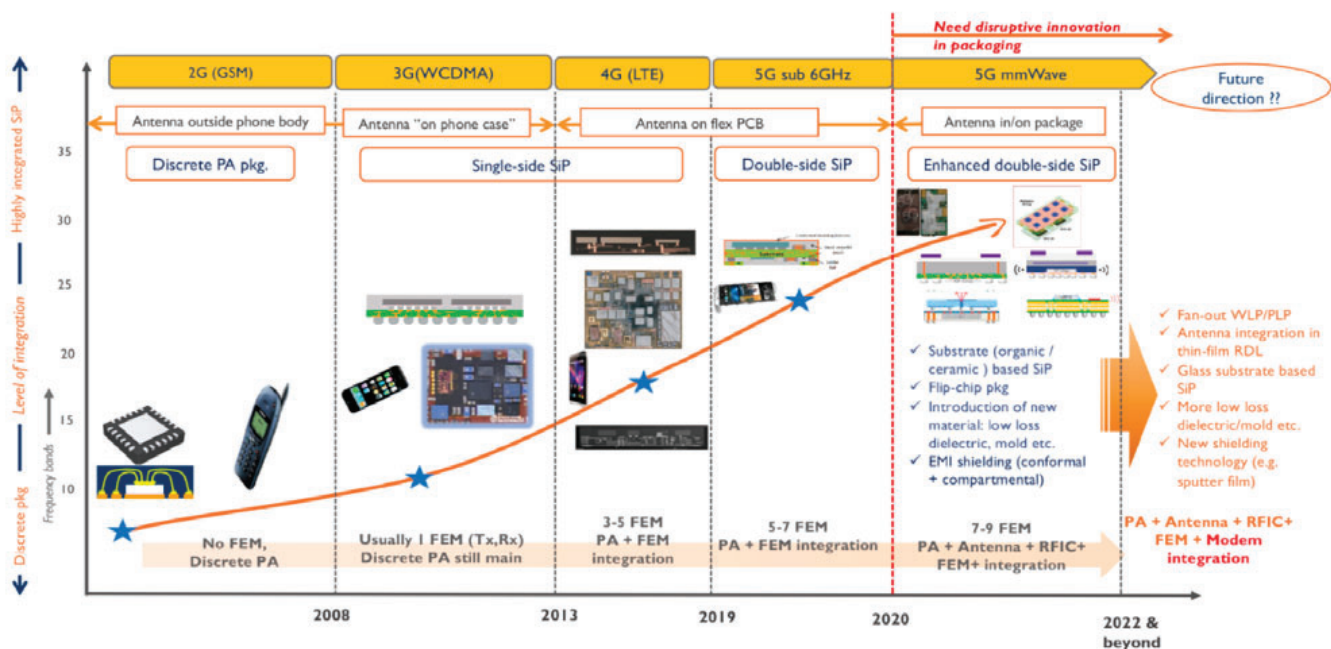


Figure 11: History and roadmap of RF front-end packaging. SOURCE: Yole Développement

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