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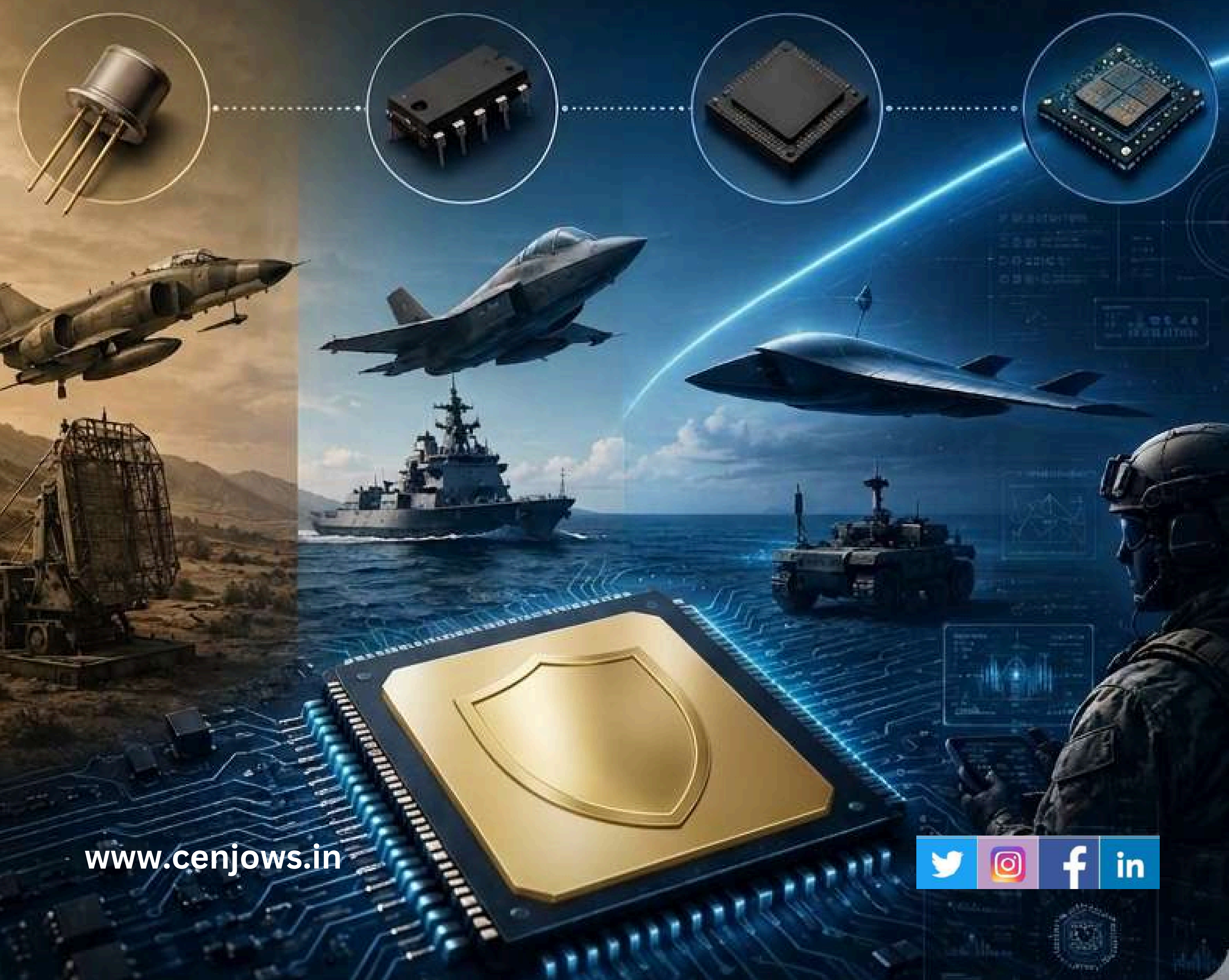
ISSUE BRIEF
IB/34/26

THE EVOLUTION OF MILITARY SEMICONDUCTOR TECHNOLOGIES

DR ULUPI BORAH



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The Evolution of Military Semiconductor Technologies

Dr Ulupi Borah is a distinguished fellow at CENJOWS

Abstract

In 1947 a groundbreaking innovation took place at Bell Labs, which gave birth to the semiconductor industry. Silicon Valley turned into a semiconductor industry at a global level. Immediately, semiconductors became extremely critical for military usage during the Cold War era. Firms like Fairchild Semiconductors and later Intel became globally known for developing technologies to support the military systems. This establishes that semiconductors, which are referred to as emerging technologies, remained the backbone of military systems ever since the beginning of the Cold War era. India too realised the importance of developing a strong indigenous semiconductor ecosystem for defence applications. Hence, New Delhi has been making significant efforts to create a self-reliant ecosystem that would be able to support the changing character of modern warfare. The article highlights the evolution of the semiconductor ecosystem with special emphasis on the military aspect. It also analysis the structural challenges and imperatives to mitigate them.

Introduction

Every age in military history has been distinguished by its technological innovation and capabilities, involving the development of simple weapons and tools to today's complex technologies. Today, semiconductors are critical components of almost every advanced military system. They power complex communication systems as well as computers for data analysis and decision-making. Precision-guided munitions, improved surveillance systems, and many more applications are made possible by semiconductor technology. They are also critical to developing technologies such as self-driving cars, artificial intelligence, and cyber warfare, which are already reshaping battlefields.[1]

Although semiconductors are regarded as the foundation of emerging technologies, they existed even during the Cold War era. It influenced power dynamics significantly through innovations in communications and defence.

The evolution of military chip design can be traced back to the 1940s–1950s, when vacuum tubes and early transistors laid the foundation for electronic warfare systems. In the 1960s-1970s, the development of integrated circuits transformed military technology by enabling more compact and efficient systems. This progress accelerated in the 1980s-1990s with the rise of microprocessors and digital signal processing (DSP) chips, which significantly enhanced the capabilities of radar, sonar, and communication systems. From the 2000s to the present, advances in semiconductor technology have led to the development of specialised chips for artificial intelligence (AI), machine learning (ML), and even quantum computing, playing a critical role in modern defence applications. [2] This evolution reflects a shift from hardware-intensive warfare to semiconductor-driven systems, where processing power, speed, and miniaturisation determine operational superiority. As a result, control over semiconductor technology has become a decisive factor in shaping military capability and global power dynamics. Moreover, the increasing miniaturisation of semiconductor components has resulted in the development of portable, secure communication devices, greatly expanding the potential of field communications, while modern semiconductor technology has improved GPS accuracy and dependability.[3]
Against this backdrop, understanding the evolution of military semiconductor technology requires examining how, in the post–Second World War period, the US emerged as a dominant player in the semiconductor sector.

The US implemented a three-pronged plan to strengthen its position. It maintained a commercial and technological advantage over all other nations. It also prevented its geopolitical adversaries access to its advanced technology. According to Chris Miller's book 'The Chip War,' the Soviet Union's failure to mass-produce semiconductors contributed significantly to their Cold War defeat.[4] The US made significant investments in research and development.[5] Furthermore, it integrated semiconductor research and development into its advanced military equipment. On the contrary, the Soviet Union had made very few investments in the name of innovation. Their rigidly organized structure never emphasized adaptability and innovation. Furthermore, the Soviet Union lacked vibrant commercial sectors that could have facilitated the use of chips in military systems and integrated them into the national economy. During that period, the Soviet Union was also known for engaging in industrial espionage, particularly to obtain semiconductor technology. They were more interested in copying designs rather than promoting indigenous research and development. This eventually put the Soviet Union at a disadvantage in the race to develop semiconductor technology.[6] The US partnered with allies and friendly nations to establish a US-led semiconductor supply chain.

This reflects that the semiconductor sector offers a strategic and economic potential for nations seeking a stronger global influence. The semiconductor trade is heavily regulated by powerful nations, like the US. The global semiconductor manufacturing and supply chain are influenced by strategic and security issues, dating back to the Cold War era, in addition to commercial imperatives.

In the above backdrop, New Delhi realises the significance of strengthening its semiconductor ecosystem for military application. It aspires to adopt a more comprehensive approach that spans from one design to manufacture. This would enable self-sufficiency in addressing domestic chip demand across civilian, defence, and aeronautics sectors. The article discusses the various stages of evolution that has happened in the semiconductor sector. It would also highlight the role of semiconductors in terms of military application. Nonetheless, this industry is undergoing certain structural challenges, and based on that, the article makes an effort to highlight a few areas where policy-related mechanisms can be initiated to mitigate them.

Applications and Design Ecosystem of Military Semiconductors

Chip design for military applications involves developing integrated circuits (ICs) that are specifically tailored to meet the stringent requirements of defence systems. These chips are engineered to operate reliably in extreme conditions, including high temperatures, radiation exposure, and electromagnetic interference. A key priority is ensuring high reliability and durability so that systems function flawlessly in harsh battlefield environments. Security is equally critical, with strong emphasis on protecting data and preventing unauthorised access. Additionally, low power consumption is essential, particularly for platforms such as drones and satellites, where energy efficiency directly impacts operational endurance. At the same time, these chips must deliver high performance, enabling fast processing speeds required for real-time decision-making and advanced analytics in modern warfare. [7] Building on these core design considerations, semiconductors find application across a wide range of military systems, some of which are discussed in the following paragraphs:

- **Sensors and Actuators**. Wireless sensors, a critical semiconductor technology product, are one of the key components that are becoming increasingly vital in the military and aerospace industries. Sensors help to improve aircraft control and weight performance by utilizing cutting-edge modelling techniques. Furthermore, the smart sensor is an important component of the internet of things (IoT), since it provides a unique identity for nearly anything, particularly when it comes to transmitting data from or about such items over the internet or an analogous sensor network.

  Actuators are components that move a system, and their relevance in the aerospace industry has constantly increased. These actuators are directly connected to flight control and autopilot systems via wireless sensor networks, triggering the appropriate responses. Thus, a government that is investing in innovation and improvement, particularly in joint warfighting, will rely more heavily on the transformative power of such advanced technologies.[8]
- **Electro-Optical Systems**. Semiconductor technology is becoming crucial in the development of electrooptical (EO) systems, notably for military purposes. EO/infrared systems have long been utilized for imaging and situational awareness, especially in low-light and nighttime conditions.9 EO is closely

linked to sensor technology and digital signal processing. Semiconductors are at the heart of signal processing.[9]

- **Microcontrollers**. High reliability integrated circuits (also known as microcontrollers) have been developed at a rapid pace in recent years. HIREL microcontrollers are used in mega-constellations, which are groupings of artificial satellites used for large-scale broadcasting, as well as nano- and picosatellites by governments and private businesses.[10]

However, specialised tools and software are required when designing chips for military purposes. Some of them are[11]:

- Electronic Design Automation (EDA) Software: Tools like Cadence and Synopsys make it easier to design, simulate, and verify integrated circuits.
- Hardware Description Languages (HDLs): Chip behaviour and structure are described using languages like VHDL and Verilog.
- Thermal Analysis Tools: It is vital to ensure that chips can resist severe temperatures, and tools such as ANSYS can aid with thermal simulations.
- Radiation Testing Equipment: Military chips must be tested for radiation resistance with instruments such as ion beam testers.

Operational Imperatives: Indian Military Perspective on Semiconductors

At the outset, it is imperative to understand that there exists a significant disconnect between the semiconductor ecosystem and the military user. Maj Gen CS Mann, Additional Director General, Army Design Bureau (ADB), at the 02nd Workshop on Energising Semiconductor Ecosystem for Defence Applications held on 7 April 2026 in New Delhi, stated:

"The industry speaks in terms of nanometers, fabrication nodes, wafers, and so on, whereas in the services, we speak in terms of operational requirements, reliability under fire, and zero tolerance for failure. These are, in a sense, two different extremes."[12]

He further stated that, traditionally, the Indian Armed Forces did not procure semiconductors as standalone components. Instead, they acquired complete systems, platforms, weapon systems, communication equipment, and integrated solutions, within which semiconductors function as embedded enablers. However, the rapid evolution of warfare has elevated semiconductors from being invisible components to becoming the central drivers of combat effectiveness.[13]

Over the past three decades, the transformation has been profound. Earlier systems, such as the VRC 353 radio sets and 123M radios installed in T-72 tanks, were based on bulky valve technologies. These systems were characterised by large size, high power consumption, significant heat generation, and the need for manual tuning. In contrast, modern military capabilities are built on miniaturized, nanometer-scale semiconductor technologies that enable advanced applications such as unmanned systems, satellite communications, and artificial intelligence-driven targeting.[14]

The tectonic shift in technology has changed the character of warfare. In the past, the number of platforms determined the combat effectiveness, which included tanks, artillery systems, and other assets. But, in the current times, it is all about the technology that is embedded with these platforms. Such technologies have enabled platform-centric warfare to transform into information-centric.

Modern battlefields are defined by the ability to collect vast amounts of information, process it at speed, and act upon it faster than the adversary. In this context, semiconductors have become as critical as ammunition, fuel, and logistics. They are no longer peripheral components; they constitute the ‘nervous system’ of military power. Any compromise in their availability, trustworthiness, or sovereign control directly translates into vulnerabilities in combat capability, making semiconductor security an operational and strategic imperative.

As highlighted in the preceding paragraphs, the chips have the ability to power sensors, including radars and infrared systems. This helps in detection and surveillance processes. “They process massive data streams using advanced processors and artificial intelligence, allowing commanders to interpret complex operational environments.

They enable secure and resilient communication networks, ensuring seamless information flow across platforms and formations. In military terms, this is reflected in the compression of the OODA loop (observe, orient, decide, and act), which can also be understood as sense, process, network, and strike. Semiconductors act as the invisible engine driving this loop, making them indispensable to modern warfighting."[15] Gen Mann also stated that from an operational perspective, the Armed Forces' requirements span multiple categories of semiconductors. These include processors and systems-on-chip, which serve as the computational backbone of military systems, ranging from simple microcontrollers to high-performance computing units. Radio frequency (RF) semiconductors, particularly those based on gallium nitride (GaN) and gallium arsenide (GaAs), are essential for radars, electronic warfare systems, and communication networks.[16]

Furthermore, it should be noted that both the volatile and non-volatile memory systems are indispensable for processing and data storage. Along with it, the hardware security elements such as cryptographic modules and secure boot mechanisms ensure integrity and credibility. In fact, they are the backbone of modern military technology.

The unique operational environment mostly shapes the semiconductor requirements of the Indian Armed Forces, from icy mountains to deserts with temperatures ranging from minus 40 to plus 50 degrees Celsius. The Indian Army in particular functions along with challenges such as humidity, icing, and wind. Conditions like these impose stringent semiconductor performance, necessitating energy efficiency. In this context, the Gen has categorised these requirements into five different domains. They are:

- **Networking and communication:** The modern battlefield is inherently networked, requiring real-time connectivity among soldiers, vehicles, sensors, and command elements, even under adversarial electronic warfare conditions. This necessitates low-power, high-frequency semiconductors capable of supporting software-defined radios, mesh networks, and jam-resistant communication systems. However, a significant gap persists, as many of the chipsets used in these systems are imported, despite the indigenous development of software.
- **Electronic Warfare (EW):** It is a domain in which the electromagnetic spectrum itself becomes a battlefield. Effective operations require high-performance

chips capable of detecting, analysing, and countering adversarial emissions within milliseconds. Technologies such as application-specific integrated circuits (ASICs) and field-programmable gate arrays (FPGAs) are critical in this domain, underscoring the need for indigenous development.

- **Surveillance and Reconnaissance.** Modern intelligence systems, ranging from satellites and UAVs to ground-based radars, significantly depend heavily on semiconductors. Components such as image processors, edge AI chips, and navigation systems enable real-time situational awareness on the battlefield. However, despite progress in indigenous platforms, there is still significant reliance on imported sensor payloads and onboard processors, which creates a critical vulnerability.
- **Precision Munitions and Guidance Systems.** Advanced weapon systems depend on inertial navigation chips, which help a system know where it is and where it is going without using GPS, seeker-head processors, and guidance control units. The integrity of these chips is paramount, as any compromise can render the entire system ineffective or even dangerous. In this context, the concept of zero-trust semiconductor supply chains becomes essential.
- **Artificial Intelligence.** AI represents perhaps the most transformative aspect of modern warfare. AI-enabled battlefield management systems support predictive logistics, autonomous surveillance, AI-assisted targeting, and real-time translation of adversary communications. These applications require specialized edge AI chips capable of operating in power-constrained and bandwidth-limited environments, without reliance on centralized cloud infrastructure.

In order to meet these diverse requirements, it is important that the military technologies adhere to performance, security, and ruggedisation. An important insight in this context is that not all defence applications require cutting-edge semiconductor nodes. Many systems can operate effectively on mature technologies such as 28 nm, 45 nm, or 65 nm nodes.[17] This presents a strategic opportunity for India to build capabilities in these segments without directly competing with global leaders in advanced fabrication, while selectively investing in cutting-edge technologies where necessary. Such an approach offers a pragmatic pathway toward semiconductor self-reliance.

India’s Semiconductor Policy and Ecosystem Development

Historical Evolution of India’s Semiconductor Ecosystem

Considering the immense significance of chips for military equipment, New Delhi is promoting the strengthening of its semiconductor ecosystem to become a global hub.

India's Amrit Kaal vision prioritises self-reliance through projects like Atmanirbharta. New Delhi aims to play the role of Vishwa Bandhu, a global friend, and achieve global renown through its vision of Vikshit Bharat. Chip technologies play a crucial role in achieving these aims. India has been producing semiconductors since the 1960s, with a few Indian electronics businesses manufacturing germanium semiconductor ships. Hindustan Aeronautics Ltd. (HAL) and Bharat Electronics Ltd. (BEL), both public sector businesses under the Ministry of Defence, were major players in the home chip industry. In 1983, Prime Minister Indira Gandhi unveiled a new electronics policy. PM Rajiv Gandhi supported the Indian semiconductor economy with several initiatives and policies to promote computer manufacture and chip production. The Semiconductor Complex Limited (SCL) was established in 1984 with a $40 million investment.[18] This was made possible through licensing deals with key players, including Rockwell, AMI, and Hitachi. In 1989, a devastating fire at the SCL complex in Chandigarh led to India losing its manufacturing lead. In 2007, the Indian government introduced its first policy on semiconductors. This policy, however, remained mostly unsuccessful until 2015.[19]

Policy Push and Institutional Framework

The India Semiconductor Mission (ISM) was launched in December 2021 as part of the ‘Program for Development of Semiconductors and Display Manufacturing Ecosystem’.[20] It will be the main entity in charge of overseeing the seamless and effective implementation of government plans to construct semiconductor and display fabs. Furthermore, in 2021-2022, the ‘Modified Semiconductor Policy’ was announced, with a $10 billion budget. The initiative aimed to promote the semiconductor design ecosystem in the country, establishing factories and ATMPS.

In 2023, Micron Technology announced the establishment of a $2.75 billion Assembly, Test, Marking, and Packaging (ATMP) facility in Gujarat, India. [21] In February 2026 this facility was inaugurated, which is supposed to convert DRAM and NAND wafers into finished memory products and has commenced commercial operations.[22] This marks India's entry into the semiconductor manufacturing value chain and strengthens its technological and strategic capabilities.

The semiconductor industry in India is expected to be worth $34.3 billion by 2023. This market is predicted to increase at a CAGR of 20.1%, reaching $100.2 billion in 2032.[23] In comparison, the worldwide semiconductor market in 2023 was $664.54 billion, which was anticipated to expand at a 12.5% CAGR and grow to $1.9 trillion by 2032. It is apparent that India is in line with worldwide project statistics in this industry. Three reasons contribute to this trend: India's growing market, strong political will, and technology capability.[24]

In 2024, Prime Minister Narendra Modi announced, "Our dream is that every device in the world will have an Indian-made chip."[25] India has already begun chip manufacturing, with an emphasis on 28nm nodes. According to Anurag Awasthi, Vice President of the India Electronics and Semiconductor Association (IESA), the majority of applications will focus on aerospace and defence, automotive, industrial, wearables, consumer electronics, and handsets. To achieve economies of scale and create jobs, we must prioritize our own markets.[26]

In fact, the strategies outlined for India's semiconductor sector are undergoing significant transition. The Semicon India Program has highlighted how this sector will remain at the heart of modern warfare tactics and national security. The global supply chain was disrupted during the COVID-19 pandemic. This reflected the fragility of this sector and has shown that global competition is not merely about traditional weapon systems but defined by technology-driven warfare.

A structural insight observed in this sector is that the design and intellectual property account for at least 70 percent of the chip's value. This is along with nearly half of the total value addition concentrated in this segment. In recognition of this, New Delhi leveraged schemes like Design Linked Incentive (DLI) to provide financial support, free access to EDA tools, and other deployment incentives. Consequently, around 100 companies have accessed design infrastructure, and 24 startups are already developing chips across domains, including communications, surveillance, and strategic applications.[27]

As such, India has made considerable progress in combining previous investments into a full-stack value chain for its semiconductor ecosystem under ISM 1.0, strengthening design capabilities and advancing fabrication, assembly, and testing infrastructure across the country. This momentum is consistent with the bigger concept of Aatmanirbhar Bharat and India's transformation from policy formulation to production preparedness. Building on these successes, ISM 2.0 aims to strengthen India's status as a dependable and competitive player in the global semiconductor network.[28]

This phase will represent a clear policy effort to strengthen local semiconductor capabilities at a time when chips underpin virtually every major digital and industrial system. ISM 2.0 will concentrate on manufacturing semiconductor equipment and materials in India, developing full-stack Indian semiconductor intellectual property, and strengthening both domestic and international supply chains. A provision of Rs. 1,000 crore ($107 million) has been provided for ISM 2.0 in FY 2026-27, with a strong emphasis on industry-led research and training facilities to promote technology development and produce a competent workforce for the future.[29]

Bridging the Gap Between Operational Realities and Technological Imperatives for Indian Armed Forces

The Bharat Secure Chip (BSC-1 and BSC-2) initiative emerges as a critical enabler in this regard.[30] They represent India’s attempt to design and deploy indigenous processors tailored for secure environments. These chips are based on Indian-owned architectures and leverage open-source instruction set frameworks, ensuring complete domestic control over design and functionality. The plan to manufacture approximately 500,000 such chips marks an important milestone.[31] Notably, at least 10 percent of this production is mandated for deployment in defence systems, directly embedding indigenous semiconductor capability into military infrastructure. This is a significant step, as modern warfare systems from surveillance platforms to missile guidance and secure communications are critically dependent on reliable and secure chips. Imported semiconductors, particularly from geopolitically sensitive regions, carry risks of embedded vulnerabilities, supply disruptions during crises, and potential cyber threats. By focusing on indigenous chip development, India is attempting to mitigate these risks and ensure operational readiness during conflict scenarios. This aligns closely with the broader objective of achieving trusted and resilient defence supply chains.

To operationalise this vision, the Government of India has introduced the Deployment Linked Incentive (DLI) scheme.[32] It provides financial support to companies involved in chip design, development, and deployment. The scheme offers upfront funding of around 20 percent of the project cost. This is mostly to reduce entry barriers and accelerate innovation. Importantly, the initiative mandates the use of 64-bit Indian-designed processors, ensuring that selected solutions meet both performance and security requirements for defence applications.[33] Companies are also required to demonstrate stability and suitability for deployment in real-world scenarios, highlighting a strong focus on practical military usability rather than purely theoretical design. The initiative builds upon India’s existing semiconductor capabilities, which have historically been limited to design and small-scale manufacturing through institutions like the Semiconductor Laboratory (SCL) in Chandigarh and research bodies such as DRDO. However, the current push aims to move beyond this limited scope and create a comprehensive ecosystem encompassing design, validation, manufacturing, and deployment.

Strategic Constraints

There exist several structural challenges while building a resilient semiconductor ecosystem for defence applications. Some of them have been discussed in the following paragraphs:

- **Semiconductor Ecosystem and Military Needs have a Structural Gap:** There exists a gap between the armed forces requirements and the semiconductor industry. As mentioned earlier, the military emphasises on reliability, survivability, and high-assurance performance. Meanwhile, companies are focusing on process efficiencies and speak in terms of nano-meters, fabrication nodes, and wafer yields. Most of the times, the Armed Forces procure the whole system rather than individual chips. This makes their engagement with the semiconductor design very limited. This means that the technologies are built without full alignment to operational realities.

- **Dependency Remains for Critical Components:** Indian Armed Forces are dependent on certain critical semiconductor components, including chipsets for communication systems, sensor payloads, etc. Despite the significant efforts to strengthen the indigenous platforms, a good portion of the critical components are being imported, which could eventually lead to supply chain vulnerabilities and potential disruptions during conflict situations.
- **Absence of an integrated semiconductor-driven architecture**. The Indian Armed Forces is going through a shift from legacy, hardware-heavy systems to AI-enabled, semiconductor-intensive, network-centric warfare. At the same time, such an evolution seems to be uneven and is dependent on older platforms alongside modern systems. This eventually creates gaps in speed, data processing, and decision-making.
- **Limited Alignment between Civilian Semiconductor Ecosystem and Needs of the Defence Sector**. A critical challenge is the limited alignment between India's rapidly evolving civilian semiconductor ecosystem and the specific needs of the defence sector. While current policies and initiatives largely prioritise commercial applications, such as consumer electronics, automotive, and industrial use, the unique requirements of military systems, including high reliability, long lifecycle, radiation tolerance, and secure architectures, remain insufficiently addressed. This gap risks creating a situation where even a growing domestic semiconductor base may not adequately serve defence needs, thereby constraining the effectiveness of military modernisation.[34]

Strategic Pathways to Strengthen Military Semiconductor Capability

- **Structured Collaboration and Co-Development**. Structured collaboration between the Armed Forces, DRDO, and the semiconductor companies should be institutionalised. More defence-specific chip standards should be encouraged that align with the military operational needs. Co-development could be one of the mechanisms to ensure validation of chips for the battlefield.

- **Reduce Dependency on Imports**: Develop indigenous semiconductor capabilities to encourage alignment between defence procurement and domestic design, fabrication, and packaging ecosystems. There should be more focus from the government to incentivise the fab and ATMP facilities and bolster the DLI initiatives for defence application. Co-development with trusted partners remains equally critical to secure a resilient supply chain.
- **Collaboration with friendly nations.** Co-development with the friendly nations like Japan, Taiwan, and South Korea in design, fabrication, and advanced packaging such as CoWoS and High Bandwidth Memory (HBM) should be encouraged. This would enable India to develop a resilient supply chain in the Indo-Pacific.
- **Ensure Seamless Connectivity Across Systems:** There should be a focus on creating a dedicated defence semiconductor roadmap that aligns platform modernisation with indigenous chip design and integration. Standardised, interoperable architectures must be developed to ensure seamless connectivity across systems and services. Additionally, stronger coordination between the Armed Forces, DRDO, and industry is essential to embed operational requirements into technology development and ensure effective system integration.
- **A Defence Focused Semiconductor Framework.** It is crucial to institutionalise a defence-focused semiconductor framework within the India Semiconductor Mission by earmarking dedicated funding, incentives, and standards for military-grade chips. Introduce defence-specific certification and testing ecosystems to ensure quality and trust. This will align the civilian semiconductor push with military requirements and enable a truly dual-use, strategically resilient ecosystem.

Conclusion

Although semiconductors are considered emerging technologies, their usage has been immense since the Cold War era. They were used in military systems of communication, radars, sensors, etc. Even today, the leadership in this sector is pivotal, as it could shape the dynamics of future warfare.

Since India aspires to secure operational advantage, creating a resilient ecosystem, especially for the defence sector, is equally important. There are a lot of areas where there is no alignment between the semiconductor industries and the defence applications. The indigenous companies are yet to scale up while catering to the needs of the Indian Armed Forces. At the same time, schemes like DLI and PLI should be encouraged to support and incentivise these industries and ensure trust and support. All the stakeholders, including the Armed Forces, DRDO, academia, and industry, should work with more collaboration and enhanced transparency.

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