THE ROLE OF SEMICONDUCTORS IN MILITARY AND DEFENCE TECHNOLOGY

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INTRODUCTION

Semiconductors have become an important geopolitical focal point between different states. There is now a need to understand the potential strategic areas for utilising high-end semiconductor technology. One such implication is on the defence industry which is dependent on semiconductors and their components for building state-of-the-art military systems. With the Indian government pushing for scaling up the domestic defence manufacturing output and simultaneously looking to increase its semiconductor supply chain capabilities, it is imperative that the government understands the role of semiconductors in helping India improve its existing military technology.

The emphasis on the economic and strategic aspects of semiconductor technology was in the spotlight during the COVID-19 pandemic. The pandemic has exposed the fault lines existing in the semiconductor supply chain resulting in a massive global chip

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shortage. China's consistent efforts to become self-sufficient in the field have also raised questions on the geopolitical implications of the Chinese state dominating the global markets.[1] Multilateral forums, such as the Quad, has prioritised semiconductor technology with an effort to launch an initiative identifying vulnerabilities and bolstering supply chain security for a diverse global market.[2] India has stressed its commitment to improving the domestic semiconductor industry as well as contributing to key technological alliances. In his keynote address at the Sydney Dialogue, Prime Minister Modi prioritised how semiconductors will be a key layer in India's technology stack. Hinting at an upcoming policy specifically for semiconductor fabrication facilities, he said that "we are preparing a package of incentives to become a key manufacturer of semiconductors".[3]

While the focus on semiconductors is evident, one of the critical areas that have seen extensive use of this technology has receded into the background. This is the role of semiconductors in shaping key military technologies. Basic semiconductor materials and components remain imperative in developing key defence systems. India, with its comparative advantages in the semiconductor value chain, needs to understand the criticality of these components in its pursuit of improving the overall national security. In the current geopolitical contestation for critical and emerging technologies, the contribution of semiconductor technology to the defence sector cannot be overlooked.

SEMICONDUCTOR—MILITARY COMPONENTS

While advanced military systems seem to utilise high-end electronics, the integral part of these systems remains fundamental semiconductor

1. John Lee and Jan-Peter Kleinhans, "Mapping China's Place in the Global Semiconductor Industry", *The Diplomat*, September 7, 2021, https://thediplomat.com/2021/09/mapping-chinas-place-in-the-global-semiconductor-industry/. Accessed on December 2, 2021.
2. Kenneth Mohanty, "Why Quad Focus on Semiconductor Chips Is All about Breaking Concentration", CNN-News18, September 20, 2021, https://www.news18.com/news/explainers/explained-why-quad-focus-on-semiconductor-chips-is-all-about-breaking-concentration-4223723.html. Accessed on December 2, 2021.
3. "India to Unveil a Package of Incentives for Semiconductor Chip Manufacturing", *Swarajya News* Brief, November 20, 2021, https://swarajyamag.com/news-brief/india-to-unveil-a-package-of-incentives-for-semiconductor-chip-manufacturing-pm-modi-at-the-sydney-dialogue. Accessed on December 2, 2021.

components. Some components have evolved from primitive single-piece devices to complex tools. There are some semiconductor components that have the ability to remain indispensable to modern-day military systems.

SENSORS AND ACTUATORS

One of the key components that are gaining importance in the military and aerospace field are wireless sensors, a key product of semiconductor technology.[4] Their impact on the structure of the aircraft as well as in optimising diagnostics and running constant health checks remain crucial while building military vehicles.

Sensors help in the improved control of aircraft through advanced simulation techniques resulting in lightweight construction for better weight performance. The use of wireless sensors in commercial airliners has resulted in the reduction of fuel consumption and in the maintenance costs of the aircraft as a whole. These sensors help in providing precise data on additional parameters for improving the efficiency and effectiveness of the vehicle. In recent years, the use of 'Smart Skin Technology' has also been adopted in the aerospace industry.[5] This revolutionary technology includes the application of over 10,000 microsensors to the exterior of the aircraft body that enables the pilot to monitor the health of the machine. It helps in sensing the wind speed, temperature, and physical strain movement allowing to improve the lifespan of the aircraft drastically.

The sensors used in automobiles, especially in the aerospace domain, are equipped with radio transceivers and an independent power supply. The combination of energy-efficient electronic components and an optimisation of protocols help in signal conditioning and GPS-aided navigation systems for precise landing.

4. Milica Pejanović Đurišić, Zhilbert Tafa, Goran Dimić and Veljko Milutinović, "A survey of military applications of wireless sensor networks", in 2012 Mediterranean conference on embedded computing (MECO), pp. 196-99, IEEE, 2012, https://www.researchgate.net/profile/Zhilbert-Tafa/publication/261267386_A_Survey_of_Military_Applications_of_Wireless_Sensor_Networks/links/5d738caaa6fdcc9961b58fb5/A-Survey-of-Military-Applications-of-Wireless-Sensor-Networks.pdf. Accessed on December 3, 2021.
5. Allison Barrie, "How 'Smart Skin' could Revolutionize Military Vehicles", Fox News, July 23, 2015, https://www.foxnews.com/tech/how-smart-skin-could-revolutionize-military-vehicles. Accessed on December 3, 2021.

The role of actuators (components that control the movement of a system) has been gradually increasing in the aerospace industry. Flight control and autopilot systems through wireless sensor networks are interfaced directly to these actuators that trigger suitable responses.[6] The use of MEMS (micro-electromechanical) systems in these components has led to lower control loads and has improved the power to weight ratio of the vehicle. Autopilot systems use actuators interfaced with complex computer software to read the aircraft's position and seamlessly guide the aircraft.

The many applications of sensors and actuators in the automotive and aerospace industries have caught the attention of military equipment manufacturers. The reduction of excess ground checks and quick part replacements due to the use of these components has created interest in the defence circles on the possible applications of high-end sensors in military vehicles and fighter jets. Complex missions, that involved a large amount of time and effort, can now be tackled with the use of such electronics that have reduced the need for routine monitoring.

MEMORY CHIPS

With advancements in the type of memory devices being manufactured, the notion of a micro-sized chip having the ability to store such large amounts of data remains mind-boggling. The growth of non-volatile (NV) memory, which are memory chipsets that can retain the data stored in it after the removal of power supply, has created interest in the possibility of using such technology in especially autonomous military vehicles.[7]

These devices have two main characteristics that make them unique: First is the retention ability of the NV chipsets which is pretty high implying that the devices can successfully retain data after

6. F. Claeyssen, P. Jänker, R. LeLetty, O. Sosniki, A. Pages, G. Magnac, M. Christmann, and G. Dodds, "New actuators for aircraft, space and military applications", in 12th International Conference on New Actuators, Bremen, Germany, vol. 324, p. 330, 2010, http://metrology-spb.ru/upload files/CEDRAT_TECHNOLOGIES/English_articles_PDF/ASM_ACTUATOR2010.pdf. Accessed on December 3, 2021.
7. David P. Castrucci, "Low-cost, high-density non-volatile memory for military and space applications", in the Seventh Biennial IEEE International Nonvolatile Memory Technology Conference Proceedings, pp. 100-100, IEEE Computer Society, 1998, https://ieeexplore.ieee.org/document/723230. Accessed on December 3, 2021.

removal of power for a considerable amount of time. The second is that of endurance which is the number of times that data can be stored in the memory cell of the device. The NV chipsets being developed in recent years have high physical limits before the degradation of the storage layer and can handle a wide temperature range mimicking the military conditions.

This has led to a new kind of memory namely NVSRAM (Non-Volatile Static Random-Access Memory) being developed based on SONOS (Silicon Oxide Nitric Oxide Silicon) technology. Military electronics manufacturers now advocate the use of NVSRAM in military equipment due to its faster read and write speeds, long-term data storage, and high reliability with the ability to withstand military-grade temperatures.[8] With the increased use of autonomous weapon systems in modern militaries, the use of memory chips for capturing critical data will become essential in the coming decade.

ELECTRO-OPTICAL SYSTEMS

The role of semiconductor technology in the development of electro-optical (EO) systems has increased its importance in the domain, especially in the military. The traditional use of EO/infrared systems has been in the concept of imaging to get better situational awareness of environments, especially in low-light and night conditions.[9]

There has been a gradual transition of EO systems to military vehicles and other military weapons. This is mainly due to the advantages it has to offer in the realm. The range of applications of EO systems in defence includes providing precise optical data for airborne security, in surveillance and patrol, for search and rescue missions, and also in reconnaissance programs. These systems are being preferred more and more in the military due to their image stabilisation and long-range imaging capabilities.

Network Centric Warfare doctrines of many countries that focus on the application of information technology and computer

8. Cypress Product Portfolio, "Radiation hardened & High-Reliability Memories", Cypress Semiconductors, https://www.cypress.com/products/radiation-hardened-memory. Accessed on December 3, 2021.
9. ReportLinker, "Global Military Electro-Optics/Infrared Systems Market to Reach $16.3 Billion by 2026", Yahoo Finance, October 25, 2021, https://finance.yahoo.com/news/global-military-electro-optics-infrared-124300542.html. Accessed on December 3, 2021.

networking to get a military advantage advocate the use of EO systems in areas like sophisticated 3D visualisation, laser radars, and infrared sensors.[10]

The modern EO systems developed have the ability to identify incoming threats from long distances and track moving targets in difficult weather conditions. This provides the defence and military forces with a better awareness of battlefields. Due to the growing number of unmanned vehicles in the military, the use of such systems has been gaining traction. Improvement of surveillance and military ISR capabilities ensure the criticality of semiconductor technology for the military.

MICROCONTROLLERS

The development of high reliability (hi-rel) integrated circuits (ICs) (or microcontrollers) has seen tremendous growth in recent years. Reliability is a major factor when dealing with military technology and specialised microcontrollers meant for extreme environments are being manufactured.[11]

Specific microcontrollers have also been developed to withstand the complexities of extraterrestrial environments such as space. Hi-rel microcontrollers are now used in mega-constellations (a group of artificial satellites meant for large-scale broadcast) of small and picosatellites by certain governments or private entities.[12] Such kind of use cases has prompted the development of similar electronic devices for military applications in space. With new frontiers of technology being breached, there is also the possibility of such technology transitioning into the military domain.

Radiation hardened ICs and monolithic microwave ICs are becoming critical components of military technology. These

10. John Luddy, "The challenge and promise of network-centric warfare", Lexington Institute, 2005, https://www.lexingtoninstitute.org/wp-content/uploads/challenge-promise-network-centric-warfare.pdf. Accessed on December 3, 2021.
11. Ross Bannatyne, "ARMed and ready", *Military Embedded Systems*, November 14, 2016, https://militaryembedded.com/radar-ew/rugged-computing/armed-ready. Accessed on December 4, 2021.
12. The Economist Staff, "Vast Satellite Constellations are Alarming Astronomers", *The Economist*, November 27, 2021, https://www.economist.com/international/2021/11/25/vast-satellite-constellations-are-alarming-astronomers. Accessed on December 4, 2021.

specialised microcontrollers consume very low power and need enhanced fabrication processing to immunise the component against any kind of latch-up when exposed to extreme radiation or temperature. They are also built-in with error detection and correction systems that can automatically correct its flipped bits and ensure reliable operation even in the presence of radiation particles.[13] This is known as "antifuse technology" which is slowly gaining prominence in aerospace and military platforms where the reliability and security of the system cannot be inherently compromised.

LOGIC DEVICES

A programmable logic device (PLD) is an electronic component used to build reconfigurable digital circuits like logic arrays. Latest logic devices such as Field Programmable Gate Arrays (FPGAs) are being developed keeping in mind the requirements of the military forces. The American company, Xilinx, has been at the forefront of research concerning 'defence grade' programmable logic chips.[14]

The military-grade logic devices currently under development include the expanded use of machine learning and artificial intelligence (AI) applications. This is apart from the security features at the network edge level. Considering the sensitivity of data being transmitted or stored from these devices, there has also been the addition of anti-counterfeiting features to ensure secure communications. Other than the security aspect, these devices have also undergone high reliability (hi-rel) tests to ensure that the systems in use operate for decades without any failures.

Some of these logic devices have already been integrated into some of the world's most lethal frontline weapons such as the F-35 fighter jet used by the United States military. These are used in tandem with other autonomous systems that are hack-proof and must process

13. John Keller, "The Evolving World of Radiation-hardened Electronics for Space", *Military and Aerospace Electronics*, June 28, 2021, https://www.militaryaerospace.com/home/article/14205860/the-evolving-world-of-radiationhardened-electronics-for-space. Accessed on December 4, 2021.
14. James Morra, "Xilinx Rolls out Rugged Versal Families for Aerospace and Defense", *Electronic Design*, September 13, 2021, https://www.electronicdesign.com/technologies/embedded-revolution/article/21175156/electronic-design-xilinx-rolls-out-rugged-versal-families-for-aerospace-and-defense. Accessed on December 6, 2021.

data locally.[15] Leveraging the applications of emerging technologies like machine learning through military electronic components, such as the 'defence grade' programmable logic chips, showcase the inevitable and principal need for semiconductor technology in modern military systems.

DISCRETE DEVICES

Generally, when talking about discrete electronic devices, there is just talk about single semiconductor devices like diodes and transistors with a single input-output (I/O) interface. But with these discrete I/O interfaces being so common, even in military technology, these devices have evolved from basic on/off activity to more sophisticated and intelligent systems. This is especially needed for the design of complex military control systems.

These devices with advanced discrete interfaces are now being used in commercial engine and power control systems, data distribution systems, geopositioning, and motion control systems. A gradual transition to military applications might be soon on the cards for these devices. With more advanced I/O interfaces, the devices can now handle a wide range of input voltage levels. This can help in preventing misfires by effectively ignoring any spurious input signals that may be interpreted as a real signal. Applications in smart munitions, which are basically precision-guided weapons, are also under development with the help of such devices.

Implementation of advanced discrete semiconductor devices has been recognised in subsystem communications that incorporate faster response times. It also has been used in the development of the 'Built-In Self-Test' (BIST) that helps in avoiding event failures while monitoring the health and status of equipment.[16] These applications remain imperative for all military-grade equipment hence improving

15. Dan Gardner, "Programmable Logic: Understanding the risks in Military and Aerospace Applications", *Military and Aerospace Electronics*, October 1, 2005, https://www.militaryaerospace.com/computers/article/16708179/programmable-logic-understanding-the-risks-in-military-and-aerospace-applications. Accessed on December 6, 2021.
16. Amir Shafy, "All Discretes are not Created Equal", *Military Embedded Systems*, September 16, 2011, https://militaryembedded.com/radar-ew/signal-processing/all-discretes-not-created-equal. Accessed on December 6, 2021.

the chances of this type of semiconductor technology being adopted into the defence forces in the near future.

Further, the rising demand for lighter, rugged and advanced display screens in military systems or equipment means that discrete semiconductor devices like LEDs, LCDs, and OLEDs now have a massive market in the militaries of different countries.[17] With constant innovation in the field of discrete devices including electronic displays, the industry remains paramount for militaries across the globe looking to upgrade their equipment.

BOOST TO INDIA'S DEFENCE MANUFACTURING

As per the data published by the Swedish research centre, Stockholm International Peace Research Institute which tracks military expenditures and global arms trade, India was the third-largest spender on military and defence in the world accounting for 3.7 per cent of the world's military expenditure share in the year 2020. India's expenditure saw a 2.1 per cent growth from the previous year with 2020 seeing total spending of 72.9 billion dollars.[18]

The military budget of India is provided as a whole with no substantial information on the breakdown of fund allocation. It is the total funding assigned for the Indian Armed Forces. The budget covers employee salaries (including all the costs for training army personnel), maintenance of defence facilities across the country and additional capital for any upcoming missions. It also includes the development, manufacturing and procurement of new defence technologies, equipment, weapons and vehicles.

However, even with the allocated military budget consistently hovering around 2.5 per cent of India's total GDP, the majority of the expenditure is spent towards salaries, pensions and maintenance of cantonments. The expenditure on arms, ammunition and other

17. Military Aerospace Staff, "Rugged LCD Monitors for Aircraft, Ships, Submarines, and Land-based Military Applications Introduced by EIZO", *Military and Aerospace Electronics*, April 14, 2021, https://www.militaryaerospace.com/computers/article/14201235/lcd-monitors-rugged-aircraft. Accessed on December 6, 2021.
18. Krishn Kaushik, "India Third-highest Military Spender in 2020", States Data published by Stockholm International Peace Research Institute, *The Indian Express*, April 27, 2021, https://indianexpress.com/article/india/india-third-highest-military-spender-in-2020-7290118/. Accessed on December 6, 2021.

defence-related equipment, however, has been gradually increasing. The defence sector was mapped as one of the critical areas to boost 'Atmanirbhar Bharat' with indigenous defence manufacturing being one of the key commitments by the government. A vision of 5 billion dollars in exporting aerospace and defence equipment by the year 2025 has been set for which the capital outlay has been increased in the 2021-2022 budget to encourage defence modernisation.[19]

The government has taken some steps to create a robust ecosystem for defence equipment manufacturing in the country. The Ministry of Defence (MoD) has prepared a list of around 209 military items on which import embargos would be placed after a specific amount of time. This is to provide opportunities for the local industry to manufacture these items. There is also the support of the defence sector in building long-term strategic partnerships with global equipment manufacturers for technology transfers to help Indian manufacturing infrastructure and supply chains.[20] This has provided an opportunity for the private sector defence manufacturing companies to contribute more to the growing demand.

The increased focus on semiconductor manufacturing by the government also comes into the picture here. While previous efforts to set up a fabrication facility in the country have failed, the push provided by the government this time seems to have that extra quantum of effort and investment. There are also recent reports of possible tie-ups with Taiwanese companies to build a semiconductor manufacturing centre in the country.[21] With the government curating policies to encourage defence manufacturing and start semiconductor manufacturing in the country, this is the time for a confluence of both in India's national interest.

19. Invest India, National Investment Promotion and Facilitation Agency, Government of India, Defence Manufacturing, https://www.investindia.gov.in/sector/defence-manufacturing. Accessed on December 6, 2021.
20. Ibid.
21. Shruti Srivastava and Miaojung Lin, "India Accelerates Talks with Taiwan on $7.5-billion Chip Plant, Trade Deal", *The Economic Times*, September 27, 2021, https://economictimes.indiatimes.com/news/economy/policy/india-accelerates-talks-with-taiwan-on-7-5-billion-chip-plant-trade-deal/articleshow/86549579.cms. Accessed on December 6, 2021.

Even if the government manages to attract a foreign firm to set up a fabrication facility in the country, the number of electronics manufacturing firms in India do not possess the capacity to utilise all of the chipsets that might get manufactured domestically. This would result in relying on exports of domestically manufactured chipsets to cover the costs. Instead, indigenous defence manufacturing companies could be the single biggest customer. Considering the necessity of semiconductor technology in developing advanced military systems, defence manufacturing in India will see a massive boost with the help of semiconductor manufacturers.

Tie-ups between the domestic private sector involved in defence manufacturing as well as government-owned PSUs along with major semiconductor manufacturers can help address the issue of the supply of critical semiconductor materials and products. At the same time, fabrication facilities can strike a deal to manufacture specific components solely meant for the military and defence industry. This collaboration between the two industries can help in the modernisation of the Indian military with the help of critical, advanced technologies which are dependent on semiconductors. It can also help in the reduction of any additional investment necessary for the manufacture of key equipment.

INDIA'S FOCUS

While the importance and necessity of semiconductor technology for the military has been detailed along with the possible partnership between defence manufacturers and semiconductor manufacturers, there is the question of what must be India's focus areas when using semiconductor components to manufacture military-grade equipment. A number of military applications exist but prioritisation is imperative when dealing with semiconductor technology. It would be better for the Indian defence industry to focus on the manufacture of existing applications rather than invest in research and development. With military modernisation the need of the hour for India, the domestic defence industry must look to leverage the most out of semiconductor technology with already developed applications.

There might be some military applications of semiconductor technology that the defence industry can benefit from in the short term:

- **Power Systems.** Semiconductor components remain critical in the design of military power supply units. One specific use case which has been seen is the use of these materials and components in the development of the Airborne Warning and Control System (AWACS) used in the aerospace domain. This is an airborne, advanced radar system used to detect threats in the form of aircraft, missiles and other incoming projectiles at long ranges.[22] This system acts as the command and control when airspace remains the battlefield along with helping direct offensive strikes by fighter aircraft.
- **Communication Systems.** The use of semiconductor materials and components in systems specifically meant for communications has been seen for a long time. Radiofrequency (RF) systems remain integral in developing platforms, which utilise radio waves and microwaves for communication, like RADAR and other electronic warfare (EW) systems. A specific area that can prove to be a game-changer for the military is in the development of jamming systems. These jamming systems help defence forces in gaining a crucial advantage in the electronic warfare domain by preventing any wireless communications from taking place on the battlefield.[23] The other area of semiconductor usage is in the development of control tower systems that remain essential in relaying instructions and getting feedback on the battlefield during military operations.
- **Geopositioning.** In the era of first-strike capability advantage warfare, the ability of military systems to detect and track any

22. Rajat Pandit, "India Plans Major Indigenous Project for Six Powerful 'Eyes in the Sky' AWACS", *The Times of India*, December 16, 2020, https://timesofindia.indiatimes.com/india/india-plans-major-indigenous-project-for-six-powerful-eyes-in-the-sky-awacs/articleshow/79766365.cms. Accessed on December 6, 2021.
23. Shesh Vardhan and Anubhav Garg, "Information Jamming in Electronic Warfare: Operational Requirements and Techniques", in 2014 International Conference on Electronics, Communication and Computational Engineering (ICECCE), pp. 49-54, IEEE, 2014, https://ieeexplore.ieee.org/abstract/document/7086634. Accessed on December 6, 2021.

threat provides an upper hand to any defence force. The extensive use of semiconductor technology in developing high-end navigation systems (both airborne and underwater) showcases the improvements that can be made to existing technology used by the armed forces. A critical area of geopositioning that utilises semiconductors which the defence industry must focus on is in developing high precision systems meant for detection and tracking. These systems combine the existing global navigation satellite systems like GPS with real kinematic (RTK) technology to provide real-time data of location and movement during military operations.[24] This is especially useful when integrated with military vehicles which can provide a strategic advantage to the defence forces.

Apart from the focus on existing applications, the defence industry along with the semiconductor industry can invest in the research and development of composite semiconductors' (like Gallium Nitride (GaN)) applications in the military domain. With the talk of diversification of supply chains, the defence industry can be bolstered with increased innovation in the emerging fields of semiconductor technology. In this way, both can complement each other's growth.

CONCLUSION

It is clear that the existing and potentially new semiconductor technologies will play a major role in the design of advanced military systems. Semiconductor components and materials remain integral to developing defence technology. With the dual approach of the Indian government in supporting both indigenous defence manufacturing and domestic semiconductor fabrication, it is an opportune time for collaboration between the two interconnected industries. The focus of India's future defence technology hinges on the country's ability

24. Amrita Nayak Dutta, "Army to Buy GPS-Guided Munitions to Hit Target Instead of Target Area, Cut Collateral Damage in Precision Strikes", CNN-News18, December 4, 2021, https://www.news18.com/news/india/army-to-buy-gps-guided-munitions-to-hit-target-instead-of-target-area-cut-collateral-damage-in-precision-strikes 4513451.html. Accessed on December 6, 2021.

to source its own semiconductor components. The strategic aspects of semiconductor technology are at the forefront and cannot be ignored. The defence industry can benefit massively from the growth of India's semiconductor capabilities and vice versa.