China Chipmaking Industry's Countermeasures Toward U.S. Sanctions and the Most Recent Achievements

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Abstract. The Sino-US technology war has greatly impacted China's technological sector, including the semiconductor industry, which is instrumental in the production of technological products that are crucial in commercial and military technology. Previous research has failed to explore the specific development situation and development prospects of the leading emerging technology companies in China. Hence, this research aimed at addressing the identified gap in the literature on the Sino-US technology war, using a case study approach that focused on three main companies in China's RF chip industry: Maxscend, Vanchip, and Microgate. Generally, the results reveal that although China's domestic RF chip industry has grown rapidly in preparation for self-sufficiency, local companies in the industry are still facing several obstacles that are hindering self-sufficiency, mainly competition from the US, Japan, and other developed RF chip industries. Consistent with previous research, this case study urges the Chinese government to continue providing subsidies to its semiconductor industry and ensure that local technology companies have adequate funding for their development projects. Additionally, this case study proposes that the Chinese government should collaborate with local technology companies to increase human capital, since inadequate human capital is identified as a key barrier in China's progress toward achieving self-sufficiency. Furthermore, China should make improvements in explicit knowledge transfers, as advancements in aspects such as intellectual property theft will assist local companies in keeping pace with the competition in the global semiconductor industry.

Keywords: Economics; Finance; Chipmaking; China semiconductor.

1. Introduction

The United States has put constant sanctions on China's high-tech industry ever since year 2019, with its first action of blacklisting Huawei and its affiliates over security concerns by the Trump administration. One month later, The US Commerce Department decided to blacklist another five Chinese tech companies, including Higon and Sugon, preventing them from buying US-made chips and components. In May 2020, the U.S.-China tensions ramped up as the Washington and the Department of Commerce announced to restrict Huawei from accessing global chip shipment. Until now, the U.S. sanctions toward China's technology industry are not removed. The cut-off restrictions are a lethal blow to Chinese telecom companies such as Huawei. In complying with Washington's decision, the U.S. tech conglomerate has suspended business with Huawei, including the transfer of hardware, software and key technical services. In 2020, Huawei quickly made response that Huawei had enough stockpiles to deal with this U.S. sanction crisis, however, it is confirmed that the sanctions on China have taken much longer than Huawei expected, and the stockpile that Huawei has prepared is no longer sufficient to maintain its production. The U.S. sanction against China can be a double-edged sword, in that it brought a severe shock to the development of China's domestic smartphone industry as well as helping China supercharge its domestic chipmaking industry. China's chip industry is growing faster after the U.S. sanction, and many chip firms are seeking a way to make contribution to the China's self-sufficient movement in chip production.

Smartphones are one of the most important downstream markets for chips. Among the Chinese smartphone industry, Chinese tech giant Huawei is leading the charge when it comes to granted 5G patent applications worldwide. The published white paper from Huawei pointed out that by the end of 2020, Huawei held more than 100,000 valid authorized patents worldwide. But after a series of US technology sanctions against China, Huawei has become the top smartphone manufacturer that has the most 5G patents but cannot connect to 5G signals. The main reason for this obstacle is the lack of domestic 5G chip manufacturing technology in China, which makes China unable to achieve self-sufficiency after the US technology sanctions. As the matter of fact, after years of scientific research efforts, China is not unmanageable in the manufacturing of all chips. For example, China has mastered advanced technology in baseband chip technology and power management. However, in terms of 5G radio frequency (RF) chip technology, China still relies heavily on imports from American companies, including Broadcom, Qorvo, Qualcomm and Skyworks. The 5G radio frequency chip is the key technology to the field of modern telecommunication and helps to determine whether a smartphone can receive and transfer 5G signals.

Demand must be one of the leading factors in the rise of a market, and China's chip manufacturing industry is no exception. Yeung explains his observation that the pivoting of chip-making capacity toward East Asia came from the heavy investment of leading domestic semiconductor firms, rather than the international relocation of American or European semiconductor firms [1]. Since 2019, China's serious RF chips shortage problem and huge demand for it in particular smartphone industries have driven China's RF chip industry to grow rapidly. The Ministry of Industry and Information Technology of China has successively issued a series of policy documents to support the chip industry, emphasizing the urgency and importance of local companies to develop advanced chips. In response to the government’s call, emerging Chinese companies headed by Maxscend, which focus on the research and development of RF front-end chips, have been established and received investment and fund support from the Chinese government.

The major theories used in studying the reasons for the Sino-US technology war include hegemonic stability theory and power transition theory [2], which suggest that the US sanctions on China are intended to undermine China’s growing governance in global science and technology [3]. China, on the other hand, has maintained that the imposed sanctions are part of America’s efforts to contain its rising superiority in global science and technology.

The impacts of the technology war on China have been largely felt in the country’s technological sector, including the semiconductor industry, which produces technological products that are crucial in the country’s commercial and military technology [4]. As a result of the war, there have been changes in the trade flows of semiconductors, with research revealing that some Chinese technology companies have been forced to adopt strategies to mitigate collateral damage, as historically, China has been heavily reliant on American foreign semiconductor technologies [5]. These strategies mainly include decoupling between the US and Chinese economies [6], de-Americanization of semiconductor value chains [4]; Chen et al.[7], as well as the development of new corporate and national alliances [5]. However, VerWey [8] argues that even though China’s has clearly-defined plans for future success, with efforts concentrated on critical subsectors of the semiconductor industry, these efforts will fail to attain their desired success primarily because of inadequate human capital and intense competition.

Several researchers argue that the move to ban Chinese companies from purchasing most US technology without a license might actually be a blessing in disguise, as the technology war has prompted an aggressive effort by the Chinese government to promote and fund the development of China’s technology in critical sectors [5,10]. As a result, there has been an unprecedented flourishing of chip-related companies within China over the last few years, with the Chinese government keen on becoming self-sufficient in the semi-conductor industry [4]; Kwan, 2020; [6]. Additionally, the funding provided by the Chinese government aims at not only attracting key investment and technology transfer into China but also obtaining crucial technology oversees, mainly through acquisition initiatives, such as Made in China 2025, supported by the government [5,9]. Therefore, the Chinese government has been keen on injecting large sums of money into the semiconductor industry in order to promote the advancement of China’s innovation in the semiconductor industry.

Despite a few recent studies focus on studying the countermeasures in China, literature on the Sino-US technology war is yet to explore the specific development situation and development prospects of the leading emerging technology companies in China. With the Chinese government recently prioritizing indigenizing advanced semiconductor manufacturing equipment, technology companies in the countries have been more empowered to make leading edge-chips. However, the fact that the US still holds a sizeable bulk of intellectual property suggests that the development prospects might be hindered, while the aggressive efforts by the Chinese government suggest that these development prospects might be successful. Therefore, there is a need for in-depth research on the specific development situation and development prospects of the leading emerging technology companies in China.

2. Overview of China's RF-chip top leaders

The RF front-end mainly includes four types of devices: Filter, Power Amplifier (PA), RF Switch (Switch/Tuner), and Low Noise Amplifier (LNA). The value of filters and power amplifiers accounts for a high proportion. The global leaders mainly adopted the IDM model, and the China domestic enterprises mainly adopted the Fabless model in the early stage. RF front-end devices use special manufacturing processes, such as compound semiconductors, SOI, surface acoustic waves, and bulk acoustic waves, with high process barriers. Overseas leaders have a long history and mainly adopt the IDM model to achieve close integration of design and manufacturing. China domestic manufacturers have been established for a short period of time and do not have the strength to build production lines. In the early days, Chinese companies mainly adopted the Fabless+Foundry model. After accumulating a certain amount of capital strength, some China domestic manufacturers also began to build their own production lines and moved towards the IDM or virtual IDM model.

Currently, The RF front-end market is dominated by American and Japanese giants, with a high degree of concentration. The top four manufacturers, which are Skyworks, Qorvo, Broadcom and Murata together account for about 85% of the market share. Skyworks has a relatively complete product layout in the RF front-end, and the development of modular capabilities is at the forefront, and it has a leading share in the PA and RF switch fields; Qorvo has leading technology in the BAW filter direction, and also has a more comprehensive RF front-end layout. Each field has a certain share; Broadcom mainly occupies an absolute leading share in BAW filters; Murata provides a variety of RF chips, leading in SAW filter share. These giants are the biggest competitors on the road of localization for Chinese local enterprises. China domestic manufacturers mainly produce discrete devices, and the current market share is insufficient 10%.

The localization rate of different devices in China from high to low is: switch, low noise amplifier LNA, power amplifier PA, SAW filter, BAW filter. The size of the process barrier is related to the maturity of the corresponding foundry process. For PAs, switches, and LNAs, compound semiconductor and SOI processes are used in the mainstream, and the foundry process is relatively mature, so the Fabless+Foundry model can work well, as long as it maintains a good relationship with downstream foundries to maintain production capacity in special periods supply. However, high-end filters mainly use SAW and BAW special processes. Since filter leaders have their own production lines, there is no excellent foundry in the market, So IDM mode or virtual IDM mode is the only way for the current high-end filter. In this paper, three main companies in RF chip industry are studied, which can basically represent the current status of each device technology of China's RF chips.

Table 1. Comparison of 4G and 5G mobile phone's RF chip use (Source: Skyworks, Qorvo)

	4G	5G
Filter	35	75
PA	6	9
Switch	10	16
Tuner	3	7
LNA	5	9

2.1 Maxscend

Maxscend was listed on GEM on June 18, 2019. The company focuses on research, development, and sales in the field of RF front-end chips. It mainly provides RF switches, RF low noise amplifiers, RF filters, and other RF front-end discrete devices and application solutions for various modules to the market. It also provides external low-power Bluetooth microcontroller chips and IP authorization services. Maxscend is currently a scarce RF front-end target in the capital market. With excellent scientific research technology, high-quality products, and efficient and perfect services, Maxscend has gradually developed into a leading RF device and wireless connection chip design company in China. It has established stabilized partnerships with mobile smart terminal manufacturers, such as Samsung, Huawei, Xiaomi, Vivo, and OPPO.

The company adopts the Fabless model, as the chip design is responsible for the independent design of the RF front-end chip. At the same time, it adopts the combination of direct sales and agency sales and sells chips mainly in the form of direct sales. Some companies in wafer manufacturing mainly purchase wafers from well-known wafer manufacturers such as TowerJazz and TSMC. Maxscend has established long-term cooperation with well-known packaging and testing companies such as Riyuexin and Jiasheng. The company has a solid cooperative relationship with the upstream supply chain and actively expands new suppliers to ensure the security of the supply chain. Since the major wafer manufacturers are all overseas, the company is also actively cooperating with domestic wafer manufacturers, including SMIC and HG, while also actively expanding domestic new suppliers, such as Jcet in the packaging and testing end.

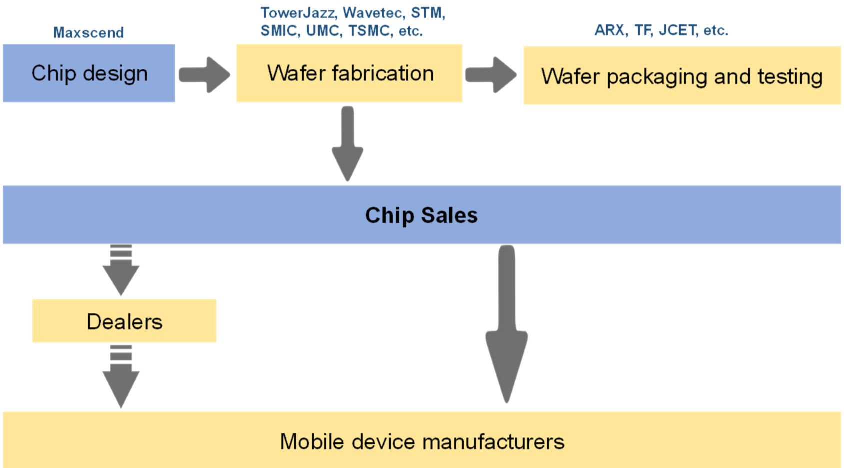

Fig. 1 The Fabless model of Maxscend (Source: Maxscend)

The company's current main products of RF front-end chips are RF switches and RF low-noise amplifiers, accounting for about 88% of revenue. Maxscend occupies a solid leading position in the Switch, Tuner, and LNA markets:

(1) Switch: As a global leader, the company’s share continues to increase from 2018 to 2021. The switch is mainly dominated by Maxscend and Qorvo. Maxscend occupied 33% of the global share in 2018. In 2019-2021, driven by factors such as Sino-US trade relations and the company's IPO listing, the company's share of Android customers is still fast. It has grown and now occupies a leading supplier position among customers such as S, M, H, O, and V.

(2) Tuner: Qorvo dominates in the 4G era. Maxscend catches up in the 5G era. After entering the 5G era, the size of the Tuner market has increased rapidly. In 2019, Maxscend's market share began to increase rapidly. By 2021, Maxscend has occupied a relatively high share in the tuner market.

(3) LNA: Possessing strong synergy with Switch, Maxscend is the domestic leader. Due to the small size of the LNA market, there are currently no manufacturers focusing on LNA products in the market, only as supporting products. The market structure is relatively scattered. The synergistic effect between LNA and Switch is strong. LNA will also use SOI as the mainstream process. It is often matched because Maxscend has strong competitiveness in the LNA market.

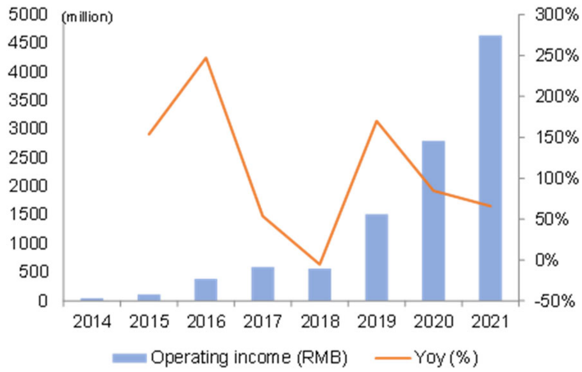

Fig. 2 Maxscend’s 2014-2021 operating income (Source: Maxscend)

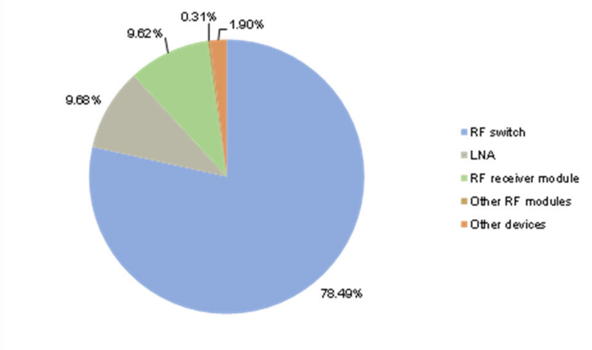

Fig. 3 Maxscend’s 2014-2021 operating income(Source: Maxscend)

Maxscend is actively deploying other RF front-end components, including RF filters, RF power amplifiers (PA), and RF front-end modules. The company launched discrete SAW filter products in 2018. The market strategy for filter products is still based on integration. The company is also actively deploying RF PA products, currently mainly for WiFi-side RF power amplifier products. The main product form is integrated into the module. The company's RF front-end module products are mainly receiver modules and WiFi front-end modules: The receiver modules include DiFEM, LFEM, and LNA Bank, which is an important milestone in the company's module technology, mainly used in mobile phones. The company's filter, PA, and RF module product development direction is synergistic and is expected to become the company's new growth point. The company has a complete technical platform reserve, especially in the comprehensive technical layout of the receiving module, which has laid the foundation for the development of the RF front-end module.

The company has entered high-end RF front-end devices through the fixed increase in the layout of SAW filter production lines. In 2020, the company raised 3 billion RMB through a fixed increase to invest in high-end SAW filter research, development and production line construction, 5G base station radio frequency device research, development, and production line construction, of which the total investment in the SAW filter project reached 2.27 billion RMB. This fixed increase project makes Maxscend's SAW filter layout at the forefront of its domestic counterparts. The construction of the company's production line is progressing successfully. It has been capped in June 2021 and has been put into production on a small scale. At the same time, the company has introduced personnel with technical management experience, technical process research, development experience, and many years of rich production and manufacturing management experience from domestic and foreign leading enterprises for the industrialization construction project of Xinzhuo Semiconductor. The high-performance filter design and manufacturing process are now controlled by foreign IDM manufacturers. The foundry's manufacturing process in the filter field has not been developed well. To ensure the successful progress of the high-performance filter research and development project, the company optimized and adjusted to build its own production line in the company's own workshop in August 2021. DiFEM modules produced by the company's own production line are expected to be mass-produced in 2022. DiFEM is mainly composed of a SAW filter and Switch. The difficulty lies in the SAW filter. Maxscend has achieved small-scale mass production of DiFEM modules. In 2022, with the mass production of a self-built SAW filter production line, the share of DiFEM is expected to continuous increase.

2.2 Vanchip

Vanchip is an integrated circuit design enterprise focusing on the R&D, design, and sales of RF front-end chips. It mainly provides customers with RF power amplifier module products, RF switch chips, Wi-Fi RF front-end modules and receiver modules, and other integrated circuit products that are widely used in various terminal products with wireless communication functions, such as smart phones, tablets, wireless routers, as well as smart wearable devices. The company is one of the earliest domestic integrated circuit design companies engaged in the R&D, design, and sales of RF front-end discrete devices and modules. Since its establishment, Vanchip has firmly caught up with leading manufacturers and has gradually narrowed the gap in the development process with other competitors. In the subdivision field of RF power amplifier discrete devices and module products, the company closely follows the latest development in communication technology, consistent with its strong technical strengths and competitive advantages. In 2021, the company's cumulative shipment of 4G RF power amplifier modules exceeded 1.2 billion, while the cumulative shipment of 5G RF power amplifier modules exceeded 100 million. According to the "China Chip Design Enterprise List 2020" released by CB Insights, the company's 4G RF power amplifier product shipments ranked first among domestic manufacturers.

Vanchip operates in the Fabless modem but does not engage in production work itself. Instead, it focuses on R&D and design. The manufacturing, packaging, and testing work is mainly completed by professional wafer foundries along with packaging and testing companies, while the testing work of some products is done by Vanchip.

The RF power amplifier is the core device of the RF front-end signal transmission and is mainly used in the transmission chain. Its function is to amplify the weak RF signal of the RF front-end transmission channel. Its signal can be successfully received by the communication base station so that the mobile device has higher communication quality and longer battery life. In terminal devices such as smartphones, PA chips are usually integrated with other RF front-end chips to form module products for the application. According to the type and quantity of integrated chips, PA modules can be divided into low, medium, and high integration modules, generally divided into four types: SMSB/SMMB PA, MMMB PA Tx Module, and L-PAMiD/L-PAMiF. RF power amplifier modules (PA modules) are the most important production products of Vanchip, as the revenue accounts for more than 95% of the company's main business revenue. After the development of communication technology and years of R&D investment and product iterations, the integration of the PA modules of Vanchip has been continuously improved. Presently, the company has developed the PA module products with the integration degree in MMMB PA and TxM. In addition, the company has achieved mass production and sales of products, such as the highly integrated L-PAMiF.

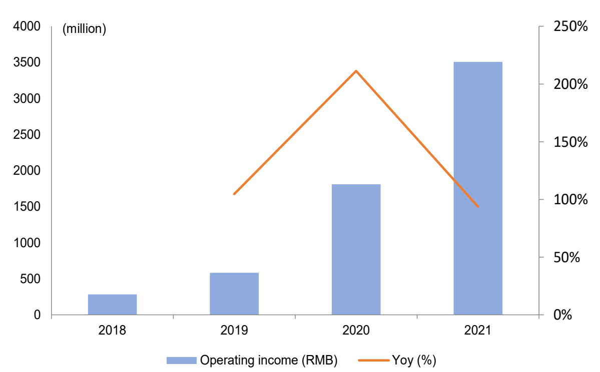

Fig. 4 Vanchip’s operating income (Source: Vanchip)

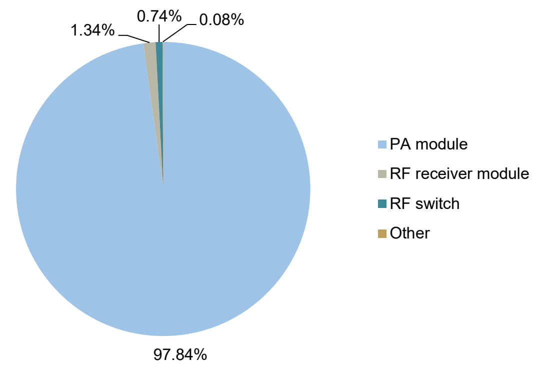

Fig. 5 Income structure (Source: Vanchip)

The main business of Vanchip is the RF power amplifier (PA) module, Wi-Fi RF front-end module, RF switch, and receiver module. Among them, the PA module accounts for the highest revenue, surpassing 95% of the total revenue. Presently, 4G modules have the highest revenue ratio among PA modules, accounting for about 88.59%. 5G modules account for 10.54%, far exceeding 3G types. With the development of technology and the progress of the times, 5G modules will reflect higher development and revenue potential in the foreseeable future.

From the view of the competitive situation, the major players in the global RF front-end market are dominated by American and Japanese manufacturers, with the vast majority of shares being occupied by Skyworks, Qorvo, Broadcom, and Murata. In terms of international competitiveness, the domestic RF design level is still at the low-end level. In addition to Vanchip, the main domestic companies in the RF front-end market include Maxscend, UNISOC, ONMICRO, Smarter Micro, Lansus, HD Shoulders, Huaying Electronics, etc.

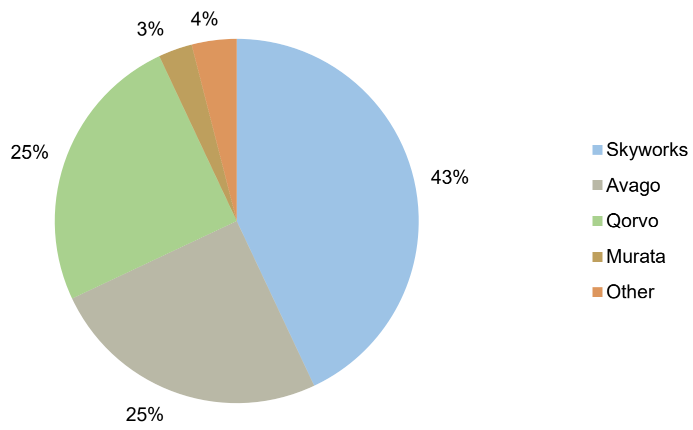

Fig. 6 The Global RF PA market share in 2020 (Source: Yole)

In the subdivision of RF power amplifier discrete devices and module products, the company keeps up with the latest development in communication technology and has strong technical strength and competitive advantages.

2.3 Microgate

Microgate was listed on the Growth Enterprise Market in 2012. Since it came into the market, the company has continuously expanded its business scope and market share through multiple mergers, acquisitions, and production expansion. The company's main business covers chip power inductors, filters, chip LTCC radio frequency components, other electronic components, and LCM display module devices. Its products are widely used in communications, consumer electronics, automotive electronics, industrial equipment, and other fields. The company has established good cooperation with domestic and foreign first-class enterprises such as Lenovo, Samsung, Amazon, Google, Huawei, and Xiaomi.

In 2021, Microgate announced that it will issue shares to specific objects and raise funds for listing on the Growth Enterprise Market, which will be mainly used for the expansion and research, and development of various businesses. After the expansion project is completed, the company will add an annual output of 1.1 billion high-end LTCC RF components, 800 million CSP SAW filters, and 600 million WLCSP SAW filters, laying the foundation for growth momentum in the next three years. In terms of R&D projects, the company will focus on the research and development of TC-SAW, RF front-end modules, and other high-end electronic components that the company has core advantages in.

The filter is the most important part of the RF front end and it is no surprise that its value ratio is constantly increasing. In the RF front-end, the filter allows signals with specific frequencies to pass, suppresses unwanted frequency signals, and can also solve the problem of signal interference between different frequency bands and communication systems. It is widely used in base stations and terminal equipment, as well as in RF signal processing system, which is the most important part of the RF front-end. According to Qorvo's forecast, the terminal share of filters in the RF market will rise from 54% in 2017 to 66% in 2023.

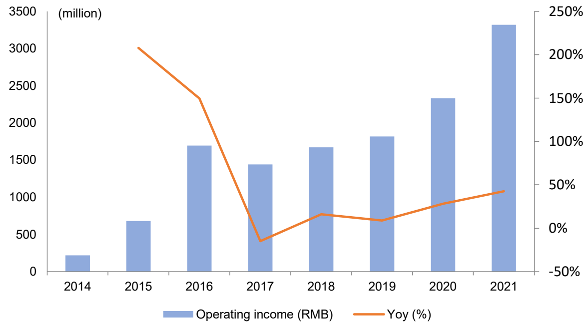

Fig. 7 Microgate's operating income (Source: Microgate)

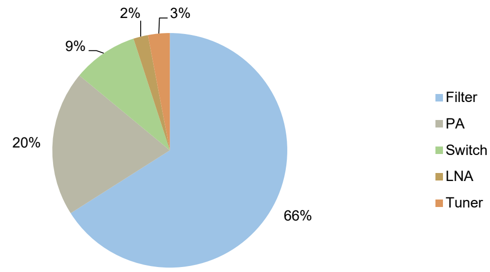

Fig. 8 2023 market share forecasting of RF segments (Source: Qorvo)

After many mergers and acquisitions, American and Japanese companies have presented a competitive pattern of "the strong keep going strong". According to Yole's data, the global SAW filter market in 2018 was mainly occupied by Murata (47%), TDK (21%), TaiyoYuden (14%), and Skyworks (9%), accounting for 91% in total. While BAW filters in the field, Avago almost takes the dominant position with 87% market share. In addition, overseas companies have a strong accumulation of filter patents. According to KnowMade data, more than 600 patent applicants around the world had published more than 6,500 invention patents for acoustic wave filters as of July 2017. Domestic companies are facing technological breakthroughs. Under the long-term monopoly of foreign giants, the total share of domestic manufacturers in the market is quite low. There are only a handful of domestic filter companies that can supply filters in batches. Since the Sino-US trade dispute, the government has continuously introduced measures to vigorously support the progress of localization of RF chips. The SAW products jointly produced by Microgate Technology and CLP 26 have entered Huawei, TCL, Wingtech, and other enterprises.

Microgate's diversity RF module technology has broken through L-FEM. The company's DiFEM applied to 4G has been supplied, and the L-FEM developed for 5G has also passed some customer certifications in 2021. It was expected to form small-scale sales in the fourth quarter of 2021. In the future, the company will continue to track the development trend of the RF industry and make breakthroughs in transmitter modules such as PAMiD. For modules, Microgate Technology has two strategies. The first is direct production, in which part of the module products has been verified by end customers. In addition to direct production, the company's strategy includes cooperative production, whereby the company provides filter products to partners who form the final module products.

In recent years, Microgate's R&D expenses have continued to rise. In 2021, Q3 R&D expenses reached 110 million, and R&D expenses accounted for 4.45%. Continued R&D investment has enabled the company to make breakthroughs in mid-to-high-end product technology. In 2021, Microgate achieved cooperation with the Huaxin Wireless team that successfully developed the first mass-produced Full B41 BAW filter in China, and set up “Microgate Rockchip Technology Co., Ltd.” to engage in the R&D and production of BAW filters. Vanchip invested 55%. In June 2020, Huaxin announced that the mass-produced B41 194MHz BAW filter has been successfully taped out, supporting the Power Class2 standard. All parameters have reached the international level of similar products. With the subsequent mass production of BAW filters, the company is expected to break the foreign monopoly and build a complete product line of LTCC+SAW+BAW filters, which can cover the full frequency range of communication systems from low to high, and also help the company's RF model in further development.

3. Discussion

The upward trend of the technology companies in China’s RF chip industry can mainly be attributed to subsidies from the Chinese government, so as to help accelerate the localization of crucial device technologies in the RF front end. Therefore, it could be argued that the Chinese government is on course to fulfil its promise to provide billions of dollars in subsidiaries to local companies operating in the semiconductor industry for the next few years. Additionally, this case study confirms that the move by the Chinese government to prioritize indigenizing advanced semiconductor manufacturing equipment has greatly empowered local technology companies in China, as companies in the RF chip industry have already set plans to localize the production of key devices in the RF front end.

In addition to government subsidies, the upward trend in China’s RF chip industry could also be attributed to the strategic collaborations and partnerships between local Chinese technology companies and other organizations. For example, Maxscend has established stabilized partnerships with mobile smart terminal manufacturers, such as Samsung, Huawei, Xiaomi, Vivo, and OPPO. Additionally, Maxscend has established long-term cooperation with well-known packaging and testing companies such as Riyuexin and Jiasheng. Moreover, the company possesses a solid cooperative relationship with the upstream supply chain while also actively expanding new suppliers to ensure the security of the supply chain. Furthermore, since the major wafer manufacturers are all overseas, the company is also actively cooperating with domestic wafer manufacturers, including SMIC and HG, while also actively expanding domestic new suppliers, such as Jcet in the packaging and testing end. Therefore, it could be argued that in addition to government subsidies, strategic partnerships and collaborations have been instrumental in promoting the recent growth and developments witnessed in China’s domestic RF chip industry.

However, although China’s domestic RF chip industry has grown rapidly in preparation for self-sufficiency, local technology companies in the industry are still facing sizeable obstacles that are hindering the desired progress. One of the major challenges identified in the case study involves the intense competition from developed countries with advanced RF chip industries, mainly the US and Japan. With the RF front-end market largely dominated by American and Japanese giants, local RF chip companies in China are finding it challenging to compete with many resourceful and experienced companies. The top four manufacturers in the RF front-end market, Skyworks, Qorvo, Broadcom and Murata, together account for about 85% of the market share, which presents a considerable challenge for local Chinese companies in the RF chip industry. Therefore, even though the Chinese government is empowering local companies in the semiconductor industry to localize the production of commercial chips, the development prospects for local companies are greatly hindered by intense competition from the US and Japan, which are the dominant players in RF front-end market.

Besides, the development prospects of local companies in China’s semiconductor industry have also been hindered by insufficient human capital, which has mainly hindered the mass production of key devices in the RF front end. The case study reveals that even though local technological companies have been empowered by government subsidies, these companies are yet to achieve the mass production of specific device technologies that are crucial in the FR front end. For example, Maxscend is yet to achieve mass production of DiFEM modules, with the company only managing to achieve small-scale mass production of DiFEM modules. Additionally, Vanchip is incapable of engaging in the production work itself, with the company's human capital enabling it to fully focus only on R&D and design. As a result, the company has assigned the manufacturing, packaging, and testing work mainly to professional wafer foundries along with packaging and testing companies. Hence, the case study reveals that insufficient human capital is among the key challenges hindering the development prospects of local companies in China's semiconductor industry.

Therefore, this case study supports the argument that even though China's has clearly-defined plans for future success, with efforts concentrated on critical subsectors of the semiconductor industry, these efforts might fail to attain their desired success primarily because of inadequate human capital and intense competition [8]. Correspondingly, this case study confirms that although the Chinese government has recently prioritized indigenizing advanced semiconductor manufacturing equipment and subsequently empowered local companies in the RF chip industry, the fact that the US still holds a sizeable bulk of intellectual property is a sizeable barrier in China's progress to achieve self-sufficiency in the production of advanced commercial semiconductors.

Crucially, this case study reveals that achieving self-sufficiency is not an impossible objective for local companies in the RF chip industry, as there are several strategies and approaches that can be adopted to address the highlighted challenges and reduce China's overdependence on the US for access to critical technologies in the RF front end. As Hunt et al[5]. argues, China's substantial resources along with its political are factors that can drive the country's semiconductor industry closer to the leading players in the industry. Additionally, this case study proposes that the Chinese government should collaborate with local technology companies to increase human capital, since inadequate human capital is identified as a key barrier in China's progress toward achieving self-sufficiency. As revealed by Hunt et al. [5], semiconductor companies in the US, Japan, and the Netherlands enjoy not only a bulk of the intellectual property but also a sizeable percentage of world-class engineers, which make it extremely challenging for new technology companies to gain a foothold in the industry. Hence, increasing human capital will help local technology companies in China to keep pace with the competition in the RF front end market. Moreover, as recommended by Hunt et al. [5], China should strive to enhance tacit know-how transfers, as Chinese nationals working outside the country often bring valuable engineering know-how when they return to China. Furthermore, China should make improvements in explicit knowledge transfers, as advancements in aspects such as intellectual property theft will assist local companies in keeping pace with the competition in the global semiconductor industry.

4. Conclusion

This research aimed at addressing the identified gap in the literature on the Sino-US technology war, using a case study approach that focused on three main companies in China's RF chip industry: Maxscend, Vanchip, and Microgate. Generally, the results reveal that although China's domestic RF chip industry has grown rapidly in preparation for self-sufficiency, local companies in the industry are still facing several obstacles that are hindering self-sufficiency, mainly competition from the US, Japan, and other developed RF chip industries. Importantly, the research reveals that there are several approaches that could help China to address the existing challenges and catch up with the leading countries in the production of advanced commercial semiconductors, including increasing human capital and enhancing collaboration between local Chinese technology companies and chip fabrication facilities.

The case study first reveals that the country's domestic RF chip industry is experiencing growth even after the US imposed sanctions on China, preventing major technology companies from purchasing most US technology. The upward trend of the technology companies in China's RF chip industry is mainly attributed to subsidies from the Chinese government, as the case study reveals that companies in the RF chip industry have received a large amount of funding in the past few years to help accelerate the localization of crucial device technologies in the RF front end. In addition to government subsidies, the upward trend in technology companies in China's RF chip industry is also attributed to the strategic collaborations and partnerships between local Chinese technology companies and other organizations. Hence, the research argues that in addition to government subsidies, strategic partnerships and collaborations have been instrumental in promoting the recent growth and developments witnessed in China's domestic RF chip industry.

However, although China's domestic RF chip industry has grown rapidly in preparation for self-sufficiency, the case study also reveals that local technology companies in the industry are still facing sizeable obstacles that are hindering the desired progress. One of the major challenges identified in the case study involves the intense competition from developed countries with advanced RF chip industries, mainly the US and Japan. Besides intense competition from the established giants in the FR front end market, the development prospects of local companies in China's semiconductor industry have also been hindered by insufficient human capital, which has mainly hindered the mass production of key devices in the RF front end. The case study reveals that even though local technological companies have been empowered by government subsidies, these companies are yet to achieve the mass production of specific device technologies that are crucial in the FR front end.

Generally, this case study supports the argument that even though China's has clearly-defined plans for future success, with efforts concentrated on critical subsectors of the semiconductor industry, these efforts might fail to attain their desired success primarily because of inadequate human capital and intense competition. Correspondingly, this case study confirms that although the Chinese government has recently prioritized indigenizing advanced semiconductor manufacturing equipment and subsequently empowered local companies in the RF chip industry, the fact that the US still holds a sizeable bulk of intellectual property is a sizeable barrier in China's progress to achieve self-sufficiency in the production of advanced commercial semiconductors.

Crucially, this case study reveals that achieving self-sufficiency is not an impossible objective for local companies in the RF chip industry, as there are several strategies and approaches that can be adopted to address the highlighted challenges and reduce China's overdependence on the US for access to critical technologies in the RF front end. Consistent with previous research, this case study urges the Chinese government to continue providing subsidies to its semiconductor industry and ensure that local technology companies have adequate funding for their development projects. Additionally, this case study proposes that the Chinese government should collaborate with local technology companies to increase human capital, since inadequate human capital is identified as a key barrier in China's progress toward achieving self-sufficiency. Furthermore, China should make improvements in explicit knowledge transfers, as advancements in aspects such as intellectual property theft will assist local companies in keeping pace with the competition in the global semiconductor industry.

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