Investigating the Global Trend of Semiconductor Industry by Reviewing the Digital-Analog Converters

Bing Han
Department of Physical Electronics
Tokyo Institute of Technology
Tokyo 152-8552, Japan
hanbing@ssc.pe.titech.ac.jp

Akira Matsuzawa
Department of Physical Electronics
Tokyo Institute of Technology
Tokyo 152-8552, Japan
matsu@ssc.pe.titech.ac.jp

Jianguo Ma
School of Electronic Information Engineering
Tianjin University
Tianjin, China
majg@tju.edu.cn

***Abstract*— DAC (digital-analog converter) is widely used in mixed-signal system and is also the typical integrated circuit device in semiconductor products. The statistical analysis on DAC papers and semiconductor market show that science and technology promote market rising prosperity and market demands expedite progress and innovation of scientific and technological. Now the research on DAC and the semiconductor market development in Asia-Pacific are gradually becoming more prominent, showing the globalization trend of semiconductor industry.**

Keywords*— *DAC; Semiconductor market

I. INTRODUCTION

The worldwide semiconductor sales reached 27.15 billion U.S. dollars on June 2010, following 24.01 billion U.S. dollars sales record on May 2010, reached an all-time high. In the past 30 years, the semiconductor industry has experienced several large fluctuations, and the major regions of the semiconductor market are gradually shifting. There are many factors influencing the industry, such as the global economic fluctuation. One of the important factors is the development of modern high technology. (1) Technology development underlies market trends and depends on the market development. In this paper, the semiconductor market trends can be reflected by the research on DAC (digital-analog converter). (2) The market needs cheap and useful products which drives the global outsourcing of semiconductor industry and the specialization of technology industry. This trend is directly responsible for the development of the semiconductor market and the rapid growth of technology in Asia-Pacific (excluding Japan) recently.

In this paper, more than 700 papers relevant to DAC research are statistically analyzed. The status and the growth rate of the semiconductor market are analyzed and summarized. The focus of the research on DAC changes with the demands of the market. Corresponding with the changes, the semiconductor market continues to introduce new products. For example, PC (Personal Computer), mobile phone, digital camera, HDTV (High Definition Television), MP3 (Moving Picture Experts Group Audio Layer III) were introduced. The papers were published mainly by research institutes and industries in America and Europe in the past. Now Asia-Pacific is gradually becoming more prominent, showing the globalization trend of DAC research. From January to June 2010, semiconductor market sales in Asia-Pacific were 78.36 billion U.S. dollars, amounting to 54% of the worldwide semiconductor market sales. Market and technological development complement each other. This trend will become more obvious in the future semiconductor industry.

II. STATISTICAL ANALYSIS OF DAC

In this paper, the data are taken from IEEE journals and IEEE conference from 1966 to May 2010, including IEEE Journal of Solid-State Circuits, IEEE Transactions on Circuits and Systems, IEEE Transactions on Instrumentation and Measurement, IEEE Transactions on Consumer Electronics, IEEE Transactions on Industry Applications, IEEE Transactions on Electronic Computers, IEEE International Solid-State Circuits Conference, IEEE Asian Solid-State Circuits Conference, IEEE International Symposium on Circuits and systems and so on. The DAC papers are collected and analyzed. The research purposes, laboratory conditions and the performances of DACs are classified and analyzed. The development of DAC shows the globalization trend of semiconductor technology. America, Europe, Asia-Pacific and Japan are becoming the core of the semiconductor technology.

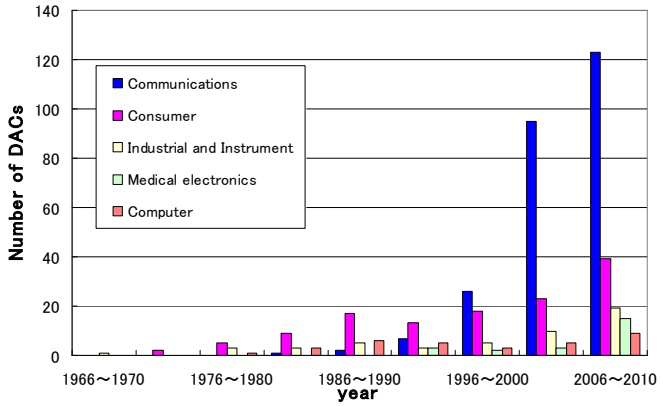

Figure 1. The application segment of DACs

A. *The applications of DAC*

The performances of DACs change with product requirements. According to the application, DACs can be classified into communications, consumer, industrial and

instrument, medical electronics and computer. There are not very clear boundaries between the classifications. For example, the communications includes wired and wireless system, mobile, RF (Radio Frequency), connectivity solution (Bluetooth, GPRS...), telecommunications, traditional telecom equipment, home networking equipment. The consumer includes automotive, entertainment, radio, TV, VCR (Video Cassette Recorder), personal or home appliance, camera, games. The industrial and instrument includes lab, test, control and measurement. Some DACs [1], [2], [3], [4], [5], [6], can be applied not only in communications products, but also in consumer products.

Fig. 1 shows that in the 70's and the 80's of the 20th century, majority of the researches on DAC were done around the consumer, instrumentation and computer products. The features of DACs at that time were high resolution (10 to 15bits) and low speed (1 Mega Samples per Second). In the 90's, the telecommunications and medical electronics have been the focus. High and low speed (100KSPS to 100MSPS) and high resolution (10 to 15bits) DACs were developed at that time. In the 21st century, communication, consumer and medical electronics developed rapidly. From 2000 to 2010, there was an increase in communications-related DAC papers of 560% above that of the 90's. The increase in medical electronic-related DAC papers was 260%. The DACs at that time were focused on high speed (1 Giga Samples per Second or higher), both high and low resolution (5 to 15bits) and low power consumption (a dozen mW). The semiconductor market analysis later also shows the transformation of product application leads to the changing of semiconductor market.

B. The regional distribution of DAC

According to the location of author's laboratory or the company the author worked for, the DAC papers were classificated by the region. Fig. 2 shows that from 1966 to 1980, the number of DAC papers published by Americans and by Europeans kept ahead at the top. Various universities contributed most of the papers. The universities included University of California Berkeley, Massachusetts Institute of Technology, Stanford University, Columbia University, University of Toronto and so on. Meanwhile American and European companies also contributed to the research on DAC, such as Bell Laboratories, IBM Corporation, Intel Corporation, Analog Devices Incorporated, Texas Instruments Incorporated, Motorola Incorporated, National Bureau of Standards, Burr-Brown Corporation, the Philips Research Laboratories.

In the 80's, America and Europe were in the lead in terms of their research on DAC. At the same time, the research on DAC in Japan was also significant. In the 80's, the DAC papers published by Japan consisted of 25% of the worldwide DAC publications. Most of the papers were published by large companies. Also some papers were published by some universities. There are some outstanding companies and universities in Japan, such as Hitachi Ltd, Sony Corporation, Toshiba Corporation, NTT Corporation, SANYO Electric Co. Ltd, Matsushita Electric Industrial Co. Ltd, Fujitsu Microelectronics Limited, Mitsubishi Electric Corporation, Ibaraki University, Shizuoka University, Hosei University, etc.

From the 1990's to the 21st century, the research on DAC spread around the world. In particular, into the 21st century, the development of the research in Asia-Pacific was very prominent. In the 80's, DAC papers published by Asia-Pacific consisted of only 5% of the worldwide publications, in the 90's, the share reached 11%. Since 2000, the share is as high as 22%. The countries and the regions that performed well in Asia-Pacific include China, Taiwan, Korea, Singapore and India. The research on DAC in China is based on the universities. The universities include University of Science and Technology of China, Southeast University, Fudan University, Tsinghua University, The Chinese University of Hong Kong, Xidian University, Chinese Academy of Sciences, University of Macau, Zhejiang University, The Hong Kong University of Science and Technology, Wuhan University of Science and technology, Nanjing Electronic Devices Institute. Also the research has been done by some companies, such as China Electronics Technology Group Corp. The research on DAC in Taiwan is based on the universities too. The universities that performed well are National Taiwan University, National Chiao-Tung University, National Cheng Kung University, National Taipei University of Technology, National Taiwan University of Science and Technology, etc. Samsung Group acted as the core contributor on DAC research in South Korea's. Some universities also have made outstanding contributions. The universities and the companies include Korea Advanced Institute of Science and Technology, Seoul National University, Inha University, Sogang University, Dongguk University, KAIST, Korea Advanced Institute of Science and Technology, LG Electronics. The research on DAC in Singapore is done mainly by the universities. The universities mainly include Nanyang Technological Institute, National University of Singapore and so on. DAC research in India is based on Indian Institute of Technology mainly. Indian Telephone Industries Ltd. also published a small number of DAC papers.

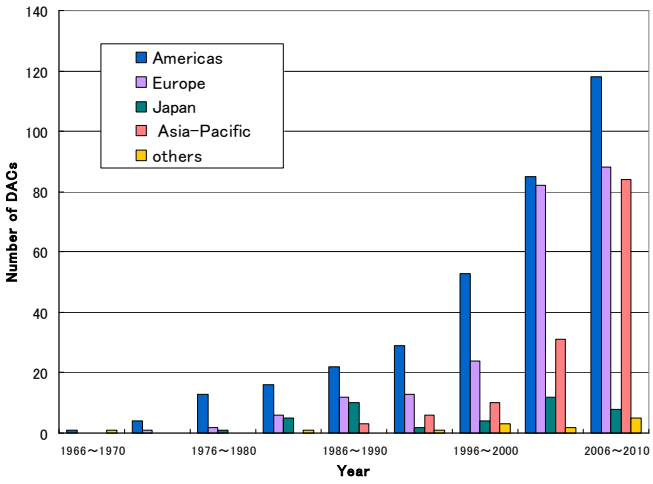

Figure 2.DAC by region

From 2006 to 2009, the number of DAC papers published by Asia-Pacific had an increase of 170% above that of 2001 to 2005. This increase was higher than the increase in America and Europe, which was 23%. Into the 21st century, other regions, including Brazil, Australia, Egypt and Iran, published a few DAC papers too.

The research and development status of DAC confirm to the globalization trend of semiconductor technology and America, Europe, Asia-Pacific and Japan is gradually acting as the core.

III. SEMICONDUCTOR MARKET ANALYSIS

William Shockley in Bell Labs invented the transistor in 1949, opening the door to today's semiconductor-based industries and changed the world. Since the 70's to present the semiconductor products have become a key component of all electronic products. The statistic analysis of semiconductor market sales from 1986 to 2008 are made in this paper. In 1995, 2000 and 2007, global semiconductor sales reached peaks separately. In 2010, a greater achievement of global semiconductor market can be expected.

A. The Applications of Semiconductor Products

The semiconductor industry is developed by the constantly emerging of new applications. For example, from the 80's to the 90's, computer-related products occupied more than half of semiconductor market sales. With the development of technology and market demands, the communication and consumer market sales increased rapidly. The share of communication products had an increase from 15% in 1995 to 20% in 2009. Mobile phones shared 16% of the worldwide sales in 2009, acting as the main product in communications. The share of consumer products had an increase from 23% in 1995 to 27% in 2009, including the products such as automotive and medical electronic, DVD (Digital Versatile Disc) player/recorder, video game console, MP3/Digital media player, Digital still/video Camera and so on. Especially in 2006, consumer products experienced rapid growth, reaching a growth of 20% above that of in 2005. In 2007, semiconductor sales reached a peak. The consumer and communication products were the main factors of the peak. The annual growth rate of cell phone sales is 12%, and the Digital TV and MP3/PMP (Portable Media Player) in consumer products sprung up at that time by 50% and 23% above that of 2005 respectively. From 2001 to 2007, the market share of industrial and instrument changed little, except in 2008. In 2008 the growth rate of industrial and instrument market maintained 13%, while the other application products had negative growth.

In general, similar to the research on DAC, the development of semiconductor products in different applications and in different periods is changing according to the market demands.

B. The regional distribution of the semiconductor market

In the 80's, relying on DRAM, Japan occupied half of the semiconductor market in the world. At that time America and Japan dominated the semiconductor market. The integrated circuits sales by two countries accounted for about 90% of the worldwide production.

Fig. 3 shows that from the 90's, Asia-Pacific semiconductor market has been rapidly developed. In 1995, the global semiconductor market was 144.4 billion U.S. dollars, while Asia-Pacific shared 29.5 billion accounting for 20% of the total. Into the 21st century, Asia-Pacific semiconductor market developed steadily. In 2000, the global semiconductor market sales reached 204 billion U.S. dollars. Asia-Pacific occupied 51.3 billion U.S. dollars accounting for 25% of all. The global semiconductor market sales in 2007 reached the peak of 255.6 billion U.S. dollars. Asia-Pacific occupied 123.5 billion U.S. dollars accounting for 48% of total. In 2008, because of the financial crisis, global sales fell to 248.6 billion U.S. dollars, instead of down, Asia-Pacific rose to 124 billion U.S. dollars, shared the proportion of 50% for the first time. In 2009, global semiconductor market sale continued to fall to 226.3 billion U.S. dollars. Asia-Pacific reached 119.6 billion U.S. dollars occupying up to 53%.

The global top ten semiconductor manufactures in 2009 were Intel (USA), Samsung Electronics (Korea), Texas Instrument (USA), Toshiba (Japan), Taiwan Semiconductor Manufacturing Company Limited (Taiwan), STMicroelectronics (Europe), Renesas technology (Japan), Hynix (Korea), Sony (Japan) and Qualcomm (USA). United States held three companies, Korea had two, Japan had three, Europe had one and Taiwan had one. In 2010, the semiconductor market is resuming. In June, semiconductor market sales in Asia-Pacific reached 144.7 billion U.S. dollars accounting for more than half the total, up 53.2%. In June 1990, the share was only 14 %. Now that the semiconductor market share of Asia-Pacific is three times than that of Americas and Japan. The center of the global semiconductor market has changed from advanced countries to emerging countries. The global semiconductor market is gradually reforming.

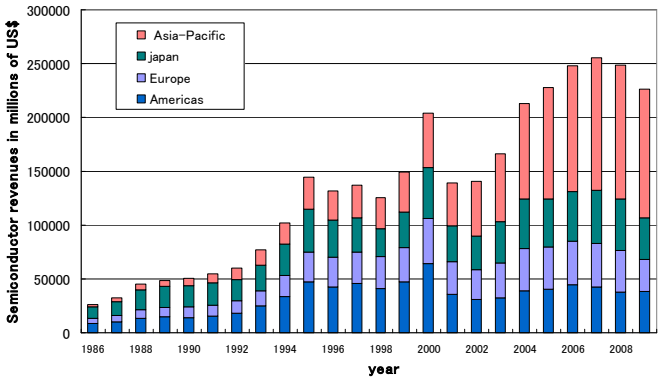

Figure 3.Semiconductor market by region

Source: WSTS, Graphics: Han Bing

IV. TECHNOLOGY AND MARKET PROMOTE THE GLOBALIZATION OF THE SEMICONDUCTOR INDUSTRY

Scientific and technological progress is a decisive factor for the development of market economic, and the market demands lead the development of science and technology. In 1966, RCA (Radio Corporation of America) developed the integrated circuit TV. In 1979, Intel introduced 5MHz 8088 microprocessor. In the same year, the first 8088-based PC in the world was introduced by IBM. The first cellular phone was introduced by Motorola in 1983. In 1990, internet users reached a climax of over 100 thousand users. In 1991, GSM (Global System for Mobile Communications) were put in use in Europe. In 1994, Kodak released the first commercial

digital camera DC40 in the world. In earlier 1996, DVD prototype was born. In 1998 the first MP3 player was introduced by Saehan in South Korea. In 2000, the first GPRS (General Packet Radio Service) mobile phone was introduced by United States.

These typical products were the results of technology and market co-produced development. The common development of technology and market will bring more and more good products for consumers in the future.

A. Market demands and technological development

The semiconductor industry changes dramatically. There is a fluctuation cycle almost every ten years. Particularly, there was a pronounced tendency before 2005. A typical example was the development of memory IC industry. From 1983 to 2003, many companies have witnessed the trend. In 1983, Samsung developed 64K DRAM (Dynamic Random Access Memory), formally entering the DRAM manufacturing market. In 1985, 256-kbit DRAM slumped. In the same year, Intel pulled out of DRAM. In 1995, the semiconductor market resumed and TSMC entered DRAM manufacturing. In 1996, 16-Mbit DRAM price dropped and in 1998 TI pulled out of DRAM. In 1999 the situation was recovering, NEC and Hitachi formed a joint venture in the DRAM market and Infineon Technologies was established in the same year. In 2000, the semiconductor market declined rapidly and in 2001 Toshiba pulled out of general-purpose DRAM. In 2002, the market environment improved and Renesas Technology and NEC Electronics were established.

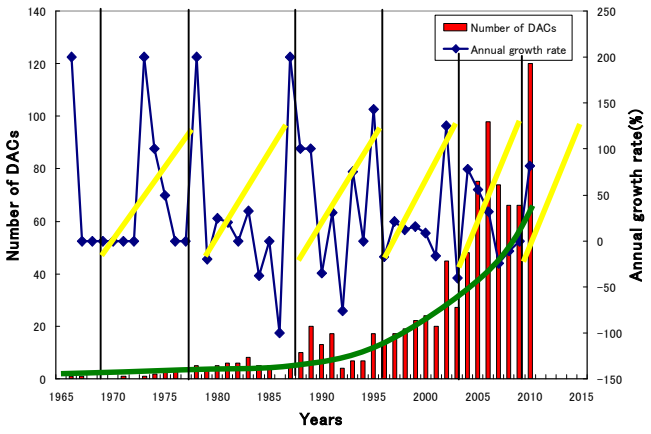

Figure 4.The trend of the research on DAC

Fig. 4 shows the trend of the research on DAC from 1965 to 2010. The green curve shows an upward curve with fluctuating of the total situation. From 1965 to 2005, there was a very clear fluctuation cycle every seven to ten years. The cycles were getting shorter the closer the date is to present. Fig. 5 shows the trend of the worldwide semiconductor market from 1985 to 2010. The overall trend shows an upward curve with fluctuation too. From 1985 to 2005, there was a very significant fluctuation cycle every seven to ten years. Also the cycles were getting shorter the date is present. The curves of the research on DAC and of the semiconductor market development conform to each other.

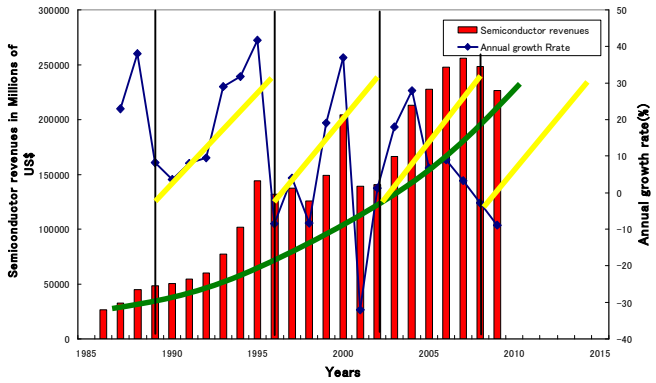

Figure 5.The trend of worldwide semiconductor market

Source: WSTS, Graphics: Han Bing

In particular, there were some very important events, which brought huge effects on the development of technological and the semiconductor market. In 1995, with the flourishing of WWW (World Wide Web), the integration of advanced technology for personal computers and networks formed a strong market impact. Both the research on DAC and the semiconductor market sales reached a small climax in that year. Also there was a slump of the personal computer market during 1995 to1996 and the world semiconductor market and the research on DAC were impacted during the period and assumed negative growth. The Asian financial crisis began in July 1997 and spread to the world quickly causing stagnation in the research on DAC and semiconductor market. In 2000, communication networks quickly developed and the increase demands for communication equipments caused the rapid research and development on DAC and the world semiconductor market. In 2001, IT (Information Technology) bubble burst, which led to the great depression of semiconductor. After the depression, the market gradually recovered and reached a peak in 2007. From 2008 to 2009, the market showed adjustment situation because of the financial crisis and both the research on DAC and semiconductor market sales decreased. In these particularly periods, technological development and market trend showed great consistency.

B. Regional distribution of technology and market

The early semiconductor market and the related technology development were mainly held in America and Europe. In the 80's, Japan gradually emerged and both the technology development and the market sales were outstanding. Japan has made a breakthrough by consumer products at first. In 1988, 16MBDRAM semiconductor industry entered into VLSI (Very large Scale Integrated circuits), Japan became the leader of that area. At that time, parts regions of Asia-Pacific gradually entered the semiconductor industry. In 1983, Samsung Semiconductor was established and 64KBDRAM was developed. In 1987, Taiwan's TSMC (Taiwan Semiconductor Manufacturing Company Limited) was established, which is now one of the largest independent semiconductor foundry businesses in the world. In 1989, China Huajing Electronics Group Corp was established. The corporation focuses on the design of integrated circuits, discrete devices and the wafer

manufacturing, test and packaging of the two kinds of products.

In the 90's, Asia-Pacific developed rapidly. Considering the number of DAC papers and the semiconductor markets sales, Asia-Pacific can be further sub-divided into China, Taiwan, South Korea, Singapore and India. The processing industries are flourishing in Taiwan. Taiwan attached great importance to technological development in recent years and many high level papers were published in journals and conference of the related fields. Samsung and other companies is the centre of semiconductor industry in South Korea, which always timely introduce new products to meet the market's demands. China put a heavy emphasis on global enterprises and cooperation. There are many investors currently in China. OEM (Original Equipment Manufacturer) developed quickly in China. China has a big potential for consumer market and is also actively promoting scientific and technological advances. In Singapore and India, the researches are based on the universities holding a leading post.

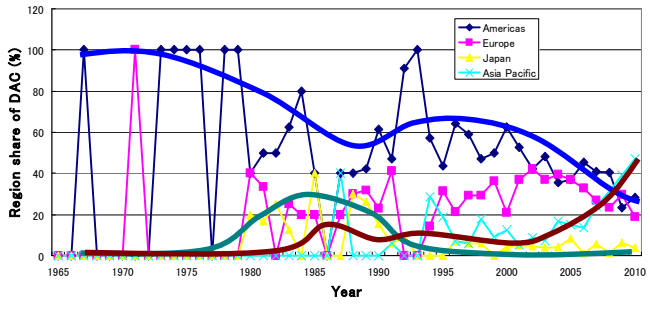

Figure 6.Region share of DAC

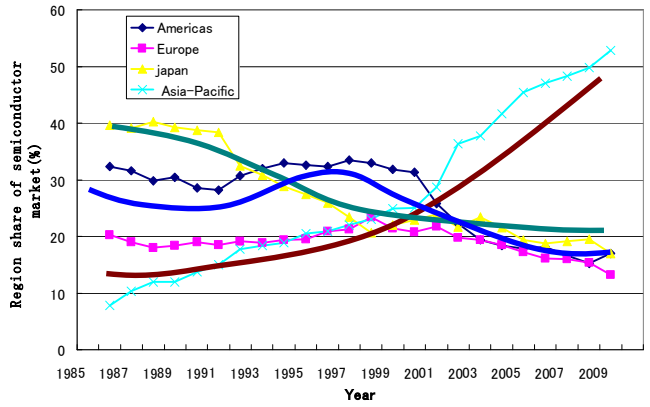

Figure 7.T Region share of semiconductor market

Source: WSTS, Graphics: Han Bing

Fig. 6 and Fig. 7 depict the proportion of different times in different regions of DAC papers and semiconductor products. The blue curves show the trend in Americas and Europe, the green curves represent the trend in Japan and the brown curves represent the trend in Asia-Pacific. The figures show that technology and market have similar trends. In the late 80's the proportion of America and Europe gradually reduced both in the research on DAC and the semiconductor market although there has been mid-90's glory. Japan reached its peak in the 80's. After that, Japan has been in decline. Into the 90's, Asia-Pacific increased steadily. Since 2000, the proportion of the DAC papers and the semiconductor market share in Asia-Pacific were inconsistent with each other. The market share assumed higher than the proportion of the published papers because of that OEM and market were developed faster than circuit design in Asia-Pacific. Especially since 2002, OEM and market shifted to China and Taiwan rapidly, making these areas grow faster in terms of semiconductor consumption.

C. Technology and market prospects

The DAC papers show that high speed, such as 32GSPS DAC [7], high resolution, such as 24bit DAC [8] (the market has been used to 16 to 18bits) and low power consumption, such as 150uW DAC [9], could be the future development trend of the research on DAC. Also, different applications require different DAC. As shown in Fig. 8, some DAC can reach the FOM (Figure of merit) of 78.0E +14.

$$FOM = 2^{bits} \times f_{sample} / P_{dis}$$

With the development of technology, the dimensions of semiconductor process tend to be smaller in size. From March to June in 2010, semiconductor products using 60nm or smaller process accounted for 38% of all. Based on the semiconductor process technology, and also design technology, packaging and testing technology, it is possible to develop super-fast, low power consumption, smaller area, low cost and high degree of integrated circuit products.

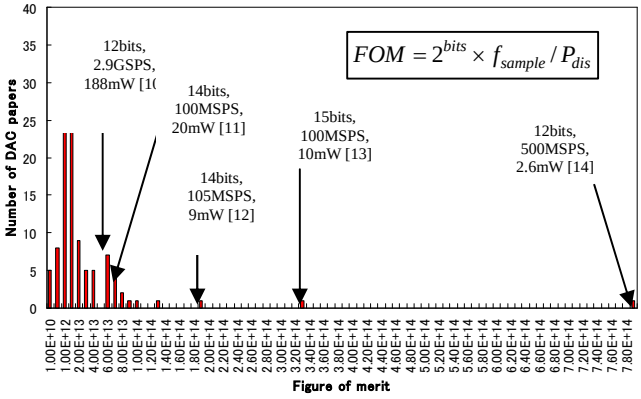

Figure 8.FOM of DAC

The popular products in the near future will be mainly audio-visual entertainment products (digital television, HDTV, HD DVD, DVD recorder), mobile wireless applications (MP3, cell phone, PDA), electrical, water and power metering devices, medical electronics and automotive industrial applications products, enterprises network and other mature terminals markets etc.

The future semiconductor industry will no longer simply focus on the production line construction and the market sales. The design will occupy an increasing share. Independent innovation capability, chip production technology and product design and development capabilities as well as independent high-level design talent and professional training program will impact the semiconductor industry. The rapid growth in market demands in Asia-Pacific results in the large amount of local effort in research and development of semiconductor

industry. In Asia-Pacific the development of technology has gradually increased its impact to the world. Positive achievements can be expected from Asia-Pacific in the future. Combining of technology and market, the semiconductor industry will make more contributions to society.

V. CONCLUSION

The statistic analysis on DAC papers and semiconductor markets show that science and technology attaches to the market economy. Furthermore, science and technology promotes the progress and development of the market economy and modern society. This can be seen from the development trend. (1) Market develops fast which appropriate to the new emerging of science and technology. (2) The development of science and technology promotes the semiconductor market and points out market direction and possibilities. With technology development and market prosperity, the semiconductor industry grows steadily now and its globalization gradually spreading.

REFERENCES

[1] D. Mercer, "A 16-b D/A converter with increased spurious free dynamic range," IEEE Journal of Solid-State Circuits, Issue 10, Vol. 29, pp.1180 – 1185, October 1994.

[2] Yonghua Cong, R.L Geige, "A 1.5-V 14-bit 100-MS/s self-calibrated DAC**,"** IEEE Journal of Solid-State Circuits, Issue 12, Volume 38, pp. 2051 – 2060, December 2003.

[3] Ji Hyun Kim, Kwang Sub Yoon, **"**An 8-bit CMOS 3.3-V 65-MHz digital-to-analog converter with a symmetric two-stage current cell matrix architecture**,"** IEEE Transactions on Circuits and Systems II, Issue 12, Volume 45, pp.1605 – 1609, December 1998.

[4] M.P. Tiilikainen, "A 14-bit 1.8-V 20-mW 1-mm^2 CMOS DAC**,"** IEEE Journal of Solid-State Circuits, Issue 7, Volume 36, pp.1144–1147, July 2001.

[5] Y. Matsuya, K.Uchimura, A.Iwata, T.Kaneko, "A 17 bit oversampling D-A conversion technology using multistage noise shaping**,"** IEEE Journal of Solid-State Circuits, Issue 4, Volume 24, pp.969 – 975, August 1989.

[6] Weining Ni, Xueyang Geng, Yin Shi, Foster Dai, "A 12-bit 300 MHz CMOS DAC for high-speed system applications**,"** IEEE International Symposium on Circuits and Systems, Page(s):4 pp, 21-24 May 2006.

[7] M.Nagatani, H.Nosaka, S.Yamanaka, K.Sano, K.Murata, "A 32-GS/s 6-Bit Double-Sampling DAC in InP HBT Technology," Annual IEEE Compound Semiconductor Integrated Circuit Symposium, pp.1 – 4, 2009.

[8] I.Fujimori, A.Nogi, T.Sugimoto, "A multibit delta-sigma audio DAC with 120-dB dynamic range," IEEE Journal of Solid-State Circuits, Issue 8, Volume 35, pp.1066 – 1073, August 2000.

[9] E.Ozalevli, C.M.Twigg, P. Hasler, "10-bit programmable voltage-output digital-analog converter," IEEE International Symposium on Circuits and Systems, Vol. 6, pp.5553 – 5556, 23-26 May 2005.

[10] C-H. Lin1, F.van der Goes, J. Westra2, J. Mulder2, Y. Lin2, E. Arslan2, E. Ayranci2, X. Liu2, K. Bult, "A 12b 2.9GS/s DAC with IM3 <-60dBc Beyond 1GHz in 65nm CMOS," IEEE International Solid-State Circuits Conference, SESSION 4 / HIGH-SPEED DATA CONVERTERS / 4.1, February 9, 2009.

[11] M.Tiilikainen, "A 1.8V 20mW 1mm^{2}14b 100Msample/s CMOS DAC**,"** IEEE Solid-State Circuits Conference, Proceedings of the 26th European, pp.435 – 438, Sepember 2000.

[12] D.Giotta, P.Pessl, M.Clara, W.Klatzer, R.Gaggl, "Low-power 14-bit current steering DAC for ADSL2+/CO applications in 0.13/spl mu/m CMOS**,"**IEEE Solid-State Circuits Conference, Proceeding of the 30th European, pp.163 – 166, 21-23 September 2004.

[13] J.W Yang, K.W.Martin, "High-resolution low-power CMOS D/A converter**,"** IEEE Journal of Solid-State Circuits, Issue 5, Volume 24, pp.1458 – 1461, October 1989.

[14] K.Virtanen, J.Maunu, J.Poikonen, A.Paasio, "A 12-bit Current-Steering DAC with Calibration by Combination Selection**,"** IEEE International Symposium on Circuits and Systems, pp.1469 – 1472,27-30 May 2007.

[15] http://ieeexplore.ieee.org/Xplore/dynhome.jsp

[16] http://www.analog.com/en/index.html

[17] http://www.ti.com/

[18] http://www.maxim-ic.com/

[19] http://www.wsts.org/

[20] http://www.sia-online.org/

[21] http://www.tsmc.com/english/default.htm

[22] http://www.google.co.jp

[23] http://www.seaj.or.jp/

[24] http://www.idcjapan.co.jp/Report/oversea/index.html

[25] http://www.connectorsupplier.com/

[26] http://www.21cem.com/

[27] http://www.gsaglobal.org/

[28] http://www.csia.net