Emerging Digital Technology as a Window of Opportunity and Technological Leapfrogging: Catch-up in Digital TV by the Korean Firms

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Abstract : This paper has examined the leapfrogging thesis with the case of catch-up in digital TV by the Korean firms. Despite the disadvantages implied by the technological regime of digital TV and the risks facing early entrants in trajectory choice and initial market formation, the Korean firms had achieved a "path-creating catch-up" in the sense they chose a different path from the Japanese forerunning firms. As they have been closely watching the technological trends and the standard setting process, there was less risk of choosing the right or wrong technological trajectory. Also, despite the lack of sufficient capability and core knowledge base, the Korean firms had some complementary asset, such as the experience of producing analogue TV, and were able to develop the prototype digital TV and the ASIC chips, given the accesses to the foreign knowledge via overseas R&D posts and acquisition of a foreign company. To secure the initial market size, the Korean targeted the US market from the beginning, and their sources for competitive advantages were the speedy setting up the production system for mass production of products at the initial stage. The initial failure of the Japanese firms and the success of the Korean firms do suggest that the period of paradigm shift, like this toward digital technology, can serve as a window of opportunity for late-comers while penalizing the forerunner.

Keywords : digital technology; emerging technology; paradigm shift; high-tech; technological regime; catching-up pattern ; Manufacturing strategy, policy and economics;

1. Introduction

Information technology that emerged in the 1940s is now pervasive worldwide. One of the most evident phenomena of the information technology in the 1990s is the shift in technological paradigm from analogue to digital. From toys, phones to machines, all analogue products are being or have been usurped by digital versions. In addition there have been swarms of totally new products such as PDAs, scanners, MP3 players, etc. Even retail sales and delivery of goods are increasingly relying on electronic commerce and computerized data processing.

This emergence of digital technology is also an opportunity for the latecomers to catch-up with the forerunners as the thesis of leapfrogging suggests. Perez and Soete [1], Freeman and Soete [2] and Freeman [3,4] emphasise the importance of utilising emerging technological opportunities in the process of catching up.

In the mid 1990s, Korean companies emerged as the world leader in several innovative digital products. Korea was the first country in the world to develop the CDMA (Code Division Multiple Access) based digital mobile telecommunication. Also, it was via an LG product that the UK enjoyed its first digitally broadcast TV programmes, and via Samsung products that Americans watched the historic launch of the space-shuttle, Discovery. Samsung and LG command numerous world-firsts in terms of technologies and licences in related fields of digital technology. Samsung and LG enjoyed no. 1 market share either in the UK or in the US since the late 1990s in some electronics goods. Samsung has world 1st market share in memory chips and TFT-LCD displays. LG Electronics is the world 1st developer of core chip set for digital TV in 1997. Now, 66% (650 million dollars) of the total exports (979 million dollars) of colour TV by Korea is accounted by export of digital TV, surpassing that of analogue TV. This signified the shift from analogue to digital goods as the main export item in Korea.

This study examines the leapfrogging thesis in the case of digital TV industry and the related catch-up by the Korean firms. The period of analysis is from the early 1990 to the recent years of 2002 or 2003. We have conducted a detailed case study, based on the interviews of R&D staffs of the leading firms, like Samsung Electronics and LG Electronics, and materials from newspapers and governmental documents and reports, as well as researchers in governmental research institutes.

This study, however, takes up new issues, beyond the three aspects of production capacity, human resources, and locational advantages, which has been discussed in the literature on leapfrogging. We emphasize the following two risks facing the catching firms. The first kind of risk is that of choosing right technologies out of several alternative technologies or standards, and the second risk is how to create the initial market after the choice of technology to produce new goods. Thus, the study focus on what kinds of advantages and disadvantages the Korean firms had in this story of catch-ups, and also on how the risks of the early entry to emerging industry were tackled by the Korean firms. We find that the special feature of digital TV, such that the standards were fixed before the market formation, was important in reducing the risks by the Korean firms.

In providing an analytical narrative of the digital TV case, we utilize the model of technological and market catch-up proposed in Lee and Lim [5], which have introduced the idea of technological regime [6,7] in the context of catch-up by the late-comer firms. In the model, the building of technological capability and successful innovations by the late-comer firms is explained in terms of technological regimes, the competitive advantages of the innovation outcomes in the market, the foreign and domestic knowledge base, the government policies and firm strategies. The firms assess the probability of the actual development of target products, as well as the expected marketability (competitiveness) of to-be-developed products, and the determined the amount of R&D effort. Technological regimes enters the model as determinants of the expected chance for product development, whereas such factors as cost edge, product differentiation, and first-mover advantages enter as determinants of the expected competitiveness of the to-be-developed products.

Applying this model to the case of digital TV development by the Korean firms, we find this case of digital TV can be considered as a "path-creating catch-up" among the three types of catch-up proposed in Lee and Lim[5,8]. We also find that this case is very similar to the case of the development of CDMA mobile phones in the sense that access to foreign knowledge base was very critical for the success.

Section 2 reviews the literature and introduces our theoretical framework. Section 3 examines the technological regime of the digital TV technology and the initial resource base of the Korean firms. Section 4 provides a detailed analysis of the process of leapfrogging, namely how it was possible in spite of the disadvantages. Section 5 put the case into some inter-sectoral and inter-national comparisons, especially with the Japanese experience. Concluding section summarizes the contributions and policy implications.

2. The Literature and Theoretical Framework

The origins of the leapfrogging thesis goes back to Gerschenkron [9,10] that emphasised the advantages of the catching-up countries, such as economy of scale in plant sizes in steel and semiconductor industries, owing to the fact that these countries started to use the technology only after it become matured enough to have the standardized capital goods suitable for mass production. However, this discussion was confined to the catching up in the mature technology. It is Freeman and Soete [2] and Perez and Soete [1] that apply the idea with focus on the role of the new technological paradigm which brings forth a cluster of new industries. It is observed that emerging technological paradigms serve as a window of opportunity for the catching up country, not being locked into the old technological system and thus being able to grab new opportunities in the emerging industries.

A new technological paradigm can be represented as technological trajectories at the level of a specific industry. This is the approach we take in this paper. A technological trajectory is the pattern of "normal" problem solving activity (i.e. of "progress") on the ground of a technological paradigm [11] . For example, the emergence of a new technological paradigm with the invention of a steam engine is represented in the technological trajectories of steam engine locomotive, steam engine machine, steam engine vehicles and others.

Perez and Soete's argument on leapfrogging has an element of the product life cycle model [12, 13] as they emphasize the advantages of early entry into the new industries, such as low entry cost. As conditions for successful entry by the catching-up economies, Perez and Soete [1] looks at the productivity capacity, human resources and locational advantages, such as distance to critical supplies and knowledge and so forth. The argument is as follows, for example. First, since the equipments to produce new industry goods are not developed yet, general-purpose machines should be utilised and production volume is small. Therefore the entry barrier associated with economy scale does not exist. Second, in the initial stage of new technological paradigm, the performance of technology is not stable and not parochial to a firm. Therefore, if there are only the human resources who could access the sources of knowledge and create new additional knowledge, entry into emerging technology can be easier than during the later stage of technological evolution. Third, catching-up countries can be said to be in a rather advantageous position as they are not locked into old technologies. The advanced country tend to be locked into old technologies due to the sunk costs of their investment.

As an extension of this view, we observe that there are additional issues other than the three aspects of production capacity, human resources, and locational advantages. We emphasize the following two risks facing the catching firms. The first kind of risk is that of choosing right technologies out of several possible emerging standards, and the second risk is how to create the initial market after the choice of technology to produce new goods. In the early stage of technological paradigm, there tend to be available alternative technologies, among which one dominant or successful technology shall show up eventually in the later stages. Therefore if the catching up country invests in wrong technologies, the country shall fail in gaining returns from investments. Next, even after the catching up country becomes successful in choosing the right technology, it still need to be successful in competition with other competitors from the advanced country. As for this aspect of the risks, there has been a rare empirical research.

This study examines the leapfrogging thesis in the case of digital TV industry and the related catch-up by the Korean firms. There has been shift of the technological trajectory, from analogue to digital since the 1990s. The 1990s was the period when the digital technology were extensively diffused and applied to the various industrial sectors. This period must be an important era of change in the 5th techno- economic paradigm period which was presumed to have started from 1971 with a big bang [14] . Thus, this study can be considered as examining the leapfrogging thesis at the industry level. The study will focus on what kinds of advantages and disadvantages the Korean firms had in this story of catch-ups, as well as on how these two kinds of risks facing in their early entry into the emerging technology were tackled by the Korean firms.

We utilize the model of technological and market catch-up proposed in Lee and Lim [5], which identified thee types of catch-ups in terms of its relation to the trajectory of the forerunning firms, namely path-following, stage-skipping, and path-creating catch-ups. Lee and Lim [5] have introduced the idea of technological regime [6,7] to the context of catch-up by the late-comer firms. As one of the determinants of the chance for successful product development by the late-comer, they have first added the predictability of technological trajectory, arguing that it is an important dimension of the technological regime relevant for catching-up. Lee and Lim [5] also take into account the access to the external knowledge base (technology transfer) since it also affects the latecomer's R&D prospect. In the model, the technological capability of the late-comer firms is determined as an outcome of interaction of the available R&D resources and the amount of R&D effort (or technological effort). The available R&D resources consist of the internal and accessible external knowledge base, as well as financial and other resources. This access can come in diverse forms including informal learning, licensing, FDI, strategic alliance, co-development, and so on. In the model, the amount of a firm's R&D efforts depend on the probability of success of the R&D effort. The firms assess the probability of the actual development of target products, as well as the expected marketability (competitiveness) of to-be-developed products. Hence the physical development of products is separated from their success in markets. Such separation is needed because the market success of products is not guaranteed even if the target product is developed. Technological regimes enters the model as determinants of the expected chance for product development, whereas such factors as cost edge, product differentiation, and first-mover advantages enter as determinants of the expected competitiveness of the to-be-developed products

Thus, applying this model to the case of digital TV development by the Korean firms, we first examine the technological regime of the digital TV technology and then the initial knowledge and resource base of the Korean firms in the following section. After this, we will provide a detailed story of the development of digital TV sets with focus on how the difficulties and risks were overcome or reduced. Based on this, we will see that the pattern of catch-up in digital TV is a kind of a path-creating catching-up which deviates from following the technological trajectory of the forerunning firms like Japan. In relation to this issue, we also examine the hypothesis proposed in Lee and Lim [5] that a path-creating catching-up is likely to happen by a public-private collaboration when the technological regime of the concerned industry is featured by a more fluid trajectory and high risk.

3. Technological Regimes of Digital TV and the Initial Resource Base of the Korean firms

1) Technological Regimes of Digital TV Technology

The origin of digital technology goes back to the scientific invention of binary computing in the 1940s. Based on this, computers and other information processing technologies had emerged. The so-called 'digital revolution' in the 1990s has two aspects. The one is substitution of the existing electronic products with those embodied with digital technology, and the other is an emergence of new products based on technological fusion of internet, software, telecommunication, electronics, and computers. Therefore digital revolution in the 1990s is different from other 'radical' innovation in that this represents applications or fusions of diverse scientific discoveries [15]. CDMA and digital TV are products applying digital technology to mobile communication and TVs.

Digital TV means transmitting everything, including video, audio, and data, via digital transmission method after digitally processing them. Digital processing refers to conversion of analogue signals into digital signals composed of 0 and 1. A converted signal is compressed, along with other information, and transmitted via the digital transmission method. The transmitted signals is then separated into the original video and audio signals, and then again decompressed (demultiplexing & decoding) at the receiver. In other words, all information is converted into numbers and then sent and received.

The technological regime of digital TV technology can be discussed in terms of technological opportunity, appropriability, the property of the knowledge base, and the required conditions for infrastructure investments. Technological opportunity of digital technology is immense as it is featured by frequent innovations. Table 1 shows that the numbers of US patents registered in the two technologies has increased much faster than those in other areas. Immense technological opportunity implies more competition in this field, but the point is who get the returns from innovation, namely appropriability conditions.

[table 1: patent and regime]

Appropriability of innovation outcome in IT is specially influenced by the standard settings. Producers of the products adopting more dominant or successful technology standard can appropriate returns from R&D investment more easily than others. In this competition for standard setting, forming alliances, cultivating partner and ensuring compatibility are critical [16]. Owing to the network externality, competitive advantage of my product depends not only on the performance and price of my products but also those of complementary products made by collaborative partner firms and governments who share the same technological standards. Since cultivation of enough big market size earlier than others or rivals and the losses to the losers are substantial, eg. the R&D, the involved parties want to set the standard first before putting their product to markets and them under anarchic competition.

As the digital TV technology is featured by very frequent innovations and the special importance of standard setting and complementary products, speedy timing to market and speedy formation of collaborative partners are critical for success. In addition, building an infrastructure compatible with your technology standard is essential in digital TV industry as the performance rely heavily on the quality of the infrastructure, such as broad casting system What are the implications of these technological characteristics of the digital TV for catching-up by the late-comer firms? The answer is that catch-up would not be easy, and risks are especially high. In other words, the earlier stage a catching-up firm enters the industry, the higher is the risk.

In this regards, one important counter-balancing fact, as noted above, is that digital TV shares with other telecommunication industries the feature that the technological standard is fixed before the market is formed [17,18,19]. Initially standards for CDMA wireless communication and digital broadcasting system were established in the US or in the EU even before the market was formed. In the case of CDMA, the TIA (Telecommunications Industry Association) adopted CDMA as North American digital standard owing to Qualcomm's efforts in 1993 before any market toward CDMA communication is formed. In Europe, following a similar steps, GSM was adopted as the standard in Europe. In Digital TV technology, the standard was formed by the so-called "Grand Alliance" in the US in 1993 and later evolved to be finalised by FCC in 1997. This is in contrast to what happens in traditional industries, such as automobile and other consumer durable goods, where the standard or the dominant design are established as a result of competition in the market [13,20].

Given the feature of 'standards before markets," future technological trajectory can be assessed more easily even at an early stage of technological evolution. This feature tends to reduce the risk of the early entrants and hence the catch-up by the late-comers. What the catch-up firms, like Korean firms, should do was simply to develop products compatible with that standard although the details were more complicated than this, as explained below.

2) Setting the Standards for the Digital TV: the First Risk

Japanese firms were the leader in R&D activities of analogue HD TV since as early as the 1980s. Japan created, for the first time in the world, the analogue HDTV system in the 1980s under the leadership of NHK and the Japan Broadcasting Corporation. In 1991, Japan adopted Hi-Vision/MUSE as the national HDTV standard [21]. In contrast, it was only in 1990 that a company in the US, GI (General Instrument), demonstrated the feasibility of digital television signalling [22].

After this event, the FCC (Federal Communications Commission) in the US government took up the issue of the HD TV standard upon the inquiry by the ACATS(The Advisory Committee on Advanced Television Services). In 1991 there were 6 proposals for HD TV standard. There were proposals for 4 digital HD TV standard and 2 for analogue HD TV standards. One analogue standard was from NHK and the other was from the consortium of Philips/Thomson/Sarnoff/NBC. Among the four digital HD TV standards, the two were from the alliance between General Instrument and MIT, and two others were from the alliance between Zenith and AT&T, and the consortium of Philips/Thomson/Sarnoff/NBC, respectively. After the NHK team withdrew their proposal, in spring 1993, the so-called "Grand Alliance" was formed among those three teams remained [23]. In 1993, Grand Alliance evolved into a large committee, including the ATSC (Advanced Television Standard Committee). After the long consultation with the computer industry people, the FCC declared the digital TV standards decision in 1997 [23].

Although the GI and the Zenith were the foreruners in digital HD TV, they needed to prove commercial feasibility of digital TV. Differently from analogue TV, digital TV technology requires software, digital tuning, digital signalling, and transmission technology to transform, compress, send and receive data. It was evident that neither GI nor Zenith can do everything, ranging from producing digital TV sets to broadcasting equipments, set-top boxes, and other components and software makers. Along this background, it is understandable the fact that as early as 1990, Zenith allowed LG to own a minor share of it (15%). In other words, there was room for the other firms with the strong experience in manufacturing, to be involved in this potentially big market. GI, a cable TV equipment maker, also invited Samsung in the process of developing prototype of digital TV at the early 1990s.

3) The initial Resource Base of the Korean firms

Maybe the biggest advantage of the Korean firms with regard to the development of digital TV was the fact that Korea lagged behind Japan and others, and did not have much incentive to stick to analogue technology led by Japan. Thus, Korea was very prompt and decisive in investing in digital TV technology as the Korean firms and government regarded emergence of digital TV as an opportunity to catch up with Japan [24].

In terms of human resources, Korea did not have sufficient human resources for commercially successful production of digital TV at the beginning of the 1990s when Korean firms entered into digital TV. Korea was also distant from the main sources of the related knowledge, namely the US and the Europe. However Korea did have human resources for interpreting R&D trend of foreign firms and applying the knowledge from the foreign sources into developing digital TV. Korean companies can also be said to have some engineering capability in digital TV in that roughly 60% of the production process of digital TV sets is as same as that of analogue TV [25]. Also to be noted is the fact that Korean firms and the government have had an important tradition of successful the public-private R&D consortium, originating from the TDX (telephone exchange system) development [26], 256 Mega bit D-RAM [5], and more recently world first development of CDMA mobile phone system [5, 27,28]. Accumulated knowledge and experience from these project must have been useful for the case of digital TV, too, as the involved parties are all the same private firms, government ministries and research institutes.

Not having strong human resources for digital TV technology, the Korean firms had to rely on newly recruited manpower. LG Electronics did not have human resources who were knowledgeable about digital signal receiving and sending and compression of images. They recruited internally those engineers who were knowledgeable about electronics in general and who have an experience in developing TV and other electronics products in the firm. Although it recruited Ph.D.s from both the US and Korea, the main leading research group were those from LG who intensively absorbed new knowledge on digital TV and carried out R&D activities [29]. Samsung also did not have human resources. When Samsung's research team was established, all the members except for the project leader were newly recruited researcher [25]. One interesting thing about the Samsung' domestic research team was the fact that they recruited in 1989 only those engineers who has no experience with analogue TV but had majored in digital signalling in Korean or foreign schools. This practices can be considered as an "unlearning" along Nonaka [31,32] such that any new project had better be started with personnel free from the influence of old routines or pre-conceptions [33]. The leading researchers were recruited from those of the US firms to the US branch of the firm.

Locational advantages for digital TV did not exist in Korea, either. Domestic market did not exist at the time of the start of production of digital TV sets in 1998. Thus, all the products were made for foreign market, and it can be said that the local market was not the driver of R&D activities.

The discussion so far indicates that the Korean firms did not have sufficient capability to be the leader in this new industry. Now, the next section elaborates how the Korean firms overcame this difficulty.

4. The Process of Leapfrogging: Overcoming the Disadvantages

1) The initial Initiatives by the Public-Private Consortium

Initial actions toward HD TV by the Korean government and firms were heavily influenced by the Japanese lead in analogue HD TV. The Japanese group came to Korea during the 1988 Seoul Olympic games, and staged a promotion tour of their achievement in the hope that the Koreans will come along their way as in the past. Recognizing that HD TV will be a next generation hot consumer items with immense technological and market potentials, the Korean government first established the Committee for Co-development of HDTV in 1989 [30]. This committee had a participation of three ministries (Ministry of Commerce, Industry and Energy, Ministry of Information and Communication, and Ministry of Science and Technology) and 17 institutions comprising private firms, government research institutes (GRIs), and universities.

The Korean government wanted to promote HD TV as one of the most important export items for the next generation, the 21st century. The government initiated a grand research consortium for HD TV. It was led by the Video Industrial R&D Association of Korea, the Korea Electronics Technology Institute (KETI) and the Korea Institute of Industrial Technology (KITECH), joined by Samsung, LG, Hyundai, Daewoo Electronics and other private firms. The Video Industrial R&D Association of Korea took a role of supervising the progress of whole research projects. It evaluated technical aspects of the project and coordinated opinions among firms involved in R&D consortium and collected research proposals and details on the progress of each research projects from firms. Administrative work for the whole research project was carried out initially by Korea Institute of Industrial Technology (KITECH) and later Korea Electronics Technology Institute (KETI), a spin off institute from KITECH. The administrative work included preparing reports for the progress of the research project and for reporting details of R&D expenditures and administrative work for technical licensing fees. In addition, KITECH and ETRI carried out both coordination of smaller consortiums and R&D in two specific fields of the whole project.

The research project was first to interpret and absorb the foreign knowledge and eventually to develop HD TV sets [30]. The total budget for the 5 years, between 1990-1994, was 100 billion Korean Won (roughly 100 million US dollars) with the government and the private sector to each pay a half of the total.

Right after the Korean start with the project, GI, a leading American firm in digital TV technology, staged a historic demonstration of the possibility of digital TV in 1990. The head of the research team at the GI was a Korean American, named Dr. Woo-Hyun Paik who joined later in 1998 the LG electronics as the CTO (Chief Technology Officer). At the turn of this event, the Korean research project for HD TV decisively fixed, in spring 1991 , digital HD aimed at US markets as its target, leaving aside Japanese-or European-led analogue HD TV. But, the problem was the fact that US standard was not yet determined at this time. In this regard, one interesting strategy by the Korean team was the decision to develop several alternative standards simultaneously, with different private companies in charge of different standards. At that time, there were identified four leading standards in the US. Thus, Samsung was chosen or assigned to develop the standard by GI and MIT coalition, LG, that by the Zenith and AT&T coalition, Daewoo, that by the RCA, and Hyundai, that by Faroudja.

This public-private coalition encouraged private firms to stick to this risky R&D activities by channelling R&D funds and forming a network of researchers from firms, universities and governmental research institutes [30]. In the project, there was a clear division of labour among the participating units. As shown in table 2, the whole project is divided into digital signalling (satellite and terrestrial), display (CRT, LCD, PDP) and ASIC chips (application-specific integrated circuits chips, encoding, decoding, demultiplexer, display processor). Each unit, GRI or private firm, is assigned to different tasks with some intentional overlaps among them, namely two unit to take the same task to avoid the monopoly of the research outcomes.

[table 2 ; division of labor]

While each unit is supposed to share the results with other firms, the private companies are observed to have tended to do research on diverse aspects of the digital TV technology and to keep important or core findings within themselves. While this kind of behaviour might possibly undermined the cost-effectiveness of the collaborative research, it was inevitable to a certain extent and to be balanced against the benefits of the consortium, and it also symbolized the dynamic spirit of competition. As a matter of fact, the R&D staffs of both Samsung and LG acknowledge one important benefit of such consortium, especially the role of the government. The government-led consortium had the effect of providing the private companies the legitimacy of the project, and without this, they admitted, their project would have stopped because the private companies cannot just keep pouring money into project with uncertain cash outcomes [25]. Furthermore, the consortium provided the firm's R&D team with the opportunity to meet and collaborate with university and other public sector researchers. The R&D staffs, upon their interview, acknowledged that particularly helpful was the interaction with university professors, especially those who just returned from the US with a Ph D degree in digital technology related fields.

However, core research activities were conducted by the two private companies, Samung and LG. According to the patent data, more than 90 percent of Korean patents related to digital TV and registered in the US are were by either LG and Samsung (see table 3).

[Table 3 Korea's digital TV patents in the US]

2) Samsung and LG: Accessing the Foreign Knowledge Base and Cultivating their Own

Korean firms have been closely watching the technological activities of the GI and other leading firms in the US. In the case of Samsung, it was as early as September1989 that it first established an R&D team for digital TV and a US branch (AML: Advanced Media Lab) in Princeton, New Jersey in the US. This lab served as a channel for accessing the knowledge sources in the US as this overseas lab recruited engineers and scientists, with knowledge about digital signalling and ASIC designs, from the US companies such as DSRC and RCA. Korean researchers were sent to the US branch for learning the technology on digital signal processing [25].

Although it was very short (only 6 months), there was also a collaborative project for digital TV between GI and Samsung in 1991. Such collaboration was realized because GI needed a partner in developing prototype digital TV. But, Samsung R&D staff indicated that the collaboration was not formal and thus they were not able to learn much from the GI. In their words, the GI persons told them to do this and that small things, namely teaching "leaves" but not teaching the whole "tree." Thus, their main role was to provide hardware-level assistance in GI's R&D activities.

In the case of LG, according to an interview, in-house research team for digital TV technology was established in 1990. As early as 1990, LG had a minor share of 15% in Zenith, and a research lab in Chicago, and thereby was able to send several researchers to Zenith. For digital TV, except for digital signal receiving and retrieval part, the existing technology on analogue TV, especially monitor technology, can be used. Thus, the research by the Korean firms focused on digital signal receiving and retrieval and related software, with a view to develop a prototype. The core technology related to digital signalling was owned by Zenith, namely VSB technology. With its minor share in Zenith, LG was able to get some help and use the technology without the fear of patent violation.

As the "Grand Alliance" was formed in 1993 to coordinate the basic standard for digital TV technology, it became less uncertain for the Korean to finalize the specifications of the prototype TV sets [29]. Finally, it was in October 1993 (eight month earlier than the proposed deadline of June 1994) that the consortium, with Samsung and LG as the de facto leader, first demonstrated publicly the technical possibility of digital TV broadcasting and receiving with a prototype at the Daejon EXPO (an international convention event).

In reaching to the point of this achievement, an important part of the LG's and Samsung's research seemed to be done mainly within Korea but complemented by research in the US. As a matter of fact, as shown in table 3, one digital TV patent by LG has included a person residing outside Korea as an inventor, and about a half of the Samsung' patent has included as an inventor a person residing outside Korea. However, it also implies that there was some role played by the overseas R&D centers in the case of Samsung, and the fact of no non-Korean resident as inventor in the case of LG imply that LG might have less need for overseas R&D center owing to the patents held by its overseas subsidiary, Zenith.

However, we were also told by an interviewee, an executive of LG, that Zenith's contribution to LG's development of TV sets was not that heavy as might seem from the outside because many former staffs of Zenith left Zenith upon LG's acquisition. Also, it was in 1994, two year before the LG's acquisition of a major share of Zenith, that the Korean team succeeded in demonstrating a prototype digital TV. Only in 1996 LG's share increased to more than 50% and finally to 100% in 2000. From LG's point of view, too, the main purpose of the acquisition was the use of Zenith-held patents related to the critical VSB (tuning) technology and other digital broadcasting standards. Overall, we can still say that the access to foreign knowledge base in the form of either overseas R&D outposts or acquisition of a foreign firm had been important.

While the development of the prototype was an impressive achievement, however, there was a long way to go from this proto-type. The October 1993 prototype was not a really marketable product as it consisted of several cabinet size systems. What they have done is a minimum demonstration of the physical feasibility. The critical next step was to pack all the functions into small ASIC chips. In other words, without the chip, commercialisation can be said to be impossible. Thus, despite that the government regarded the project as a success and once wanted to declare the successful end of the consortium, it was the private companies that persuaded the government to launch its second stage to develop the chips right after the end (June 1994) the first-stage 5 year project. The new 4 year project to develop the ASIC chip started from December 1995. As shown in figure 1, there was again a division of labour among the firms. For example, LG is supposed to be in charge of a chip for video decoder, whereas Samsung, of audio and channel decoder. However, later it turned out that each company had developed the chips assigned to other companies. This phenomenon reflected again both the limits of the consortium as well as the rivalry between these two companies. Anyway, both companies succeeded in developing a set of chips by 1997 (world first), and the consortium took their products for the various tests in the US. After these tests, Samsung and LG revealed their market-ready product at the CES (Consumer Electronics Show) in January 1998. Samsung's brand was Tantus with a 55 inch screen, and LG used Zenith as its brand name in their 64 inch screen products. At the CES, Japanese firms revealed only "digital ready" TV, without digital tuner.

[figure 1 : ASIP chip development]

It was reported that Dr. Paik, the research head at the GI who first time proved the feasibility of digital signalling in 1990, was surprised and impressed at the new of LG's development of ASIC chips in 1997. After the development of ASIC chip in 1997, LG's R&D turned its focus to MPEG and TV-related software. It was during this final stage that Dr. Paik joined LG in 1998 as a CTO. In other word, his role has been mainly played during the later stage of developing market –ready TV sets. After this, LG's overseas R&D center was established in 1999 in New Jersey, with name Triveni, with a view to develop broadcasting equipments, not TV sets.

In sum, while the initial core technology was owned by the US firms, digital signalling by the GI and digital tuning (VSB) by Zenith, the Korean firms were able to develop a prototype digital TV and eventually a commercially successful digital TV owing to their command of complementary technologies, such as ASIC chips, HD level MPEG, display (PDP, LCD), and related software to be embedded in TV sets. These two firms are producing digital TV, either a "built-in" digital TVs with a digital tuner [34] or "digital ready" TVs without digital tuner (which can receive digital TV programs only with a set-top box). Out of these two-stage-based research consortia, Samsung and LG have emerged as the world leader in not only digital TV set but also in related display technology, TFT-LCD, projection displays and plasma display panel [35]. These could sell a variety of digital TVs of different display methods. These complementary technologies were especially important for the commercialisation of the initial core technology.

However, the Korean government was slow in building infrastructure for digital TV broadcasting. By the time of domestic production starting in 1998, the government did not even declare the standard for digital broadcasting. Thus, initial market for the Korean-made digital TV set was to be found in other countries, which was critical for eventual success of this venture.

3) Securing First-Mover Advantage and Reducing Market Risk

While Samsung and LG started to produce digital TV sets as early as 1998, it was not for the domestic market but for the US and European market. The domestic market was not there until digital TV broadcasting started in 2001. Thus, 100% of production during the 1998-2000 period was for export market. The export products were mainly digital TV set top boxes, LCD and PDP TVs without digital receivers, which are compatible with digital receivers and digital TVs.

The risk of securing the initial market was relatively small, given that emergence of the US market was somewhat guaranteed owing to the declaration by the FCC on April 21, 1997. The FCC issued its Fifth Report and Order, requiring that top 10 commercial stations must begin broadcasting digitally by May 1 1999, and those in markets 10 to 30 must do so by November 1, 1999. All other commercial stations must have a digital signal on air by May 1, 2002, and non-commercial stations, irrespective of the size of their markets, have until May 1, 2003, to begin digital broadcasting [36]. In addition, the FCC established a target date of 2006 for the cessation of analogue broadcasting.

Despite the FCC initiatives, however, digital TV market had not been expanding rapidly. The market was still at an early stage, and consumer responses were not enthusiastic, let alone the high costs of HD TV. In consideration of this situation, Korean firm's strategy has been mainly selling set top boxes and digital ready TV which does not have a receiver for digital signal but can easily install them [37]. The strategy of selling the so-called "digital-ready TV" (digital TV without digital receivers) was implemented because there had not been a critical mass formed of digital TV broadcasting.

The Korean-made digital TV also tried to attract consumers by the continued reduction of the prices. Especially the Korean firms were able to beat the prices of other competitors owing to its successful development of powerful ASIC chips, new display device ,and other core components (see the appendix table for comparison of chips by several producers). Table 4 compares the prices of digital TV sets by several producers. When RCA first started to sell 55" rear-projection type digital TV (with brand and model name RCA P5500) in early 1999 the price was 6,999 dollars. But, within a year by early 2000, Samsung reduced the price of the comparable product to 4,999 dollars. In the case of 61" rear projection digital TV the price of the RCA product (with brand and model: ProScan PS61000) was 7,999 in early 1999. The prices of Samsung's 65" digital TV set was 6,999 dollars in early 2000.

[table 4: prices]

Since then, export of Korean Digital TV has been exploding. The total exports in 2002 increased to 974 million dollar, compared to 268 million dollar in 2001, as shown in table 5. The drivers of export are PDP and projection TVs. 42% of the exports was for North America and 28% was for Europe. Although the exact market share of the Korean firms is not available, according to GFK, a European research company, LG electronics ranked number one in the UK with a sales of 1,265 units, or 16.7 percent of the total volume in 1999, while Philips and Sony lagged behind with 1,001 units and 939 units, respectively [38]. In 2002, the share of digital TV in the Korean export of all colour TV sets showed 49.8%, and rose to 66% in August 2002 [39].

[table 5: export figures]

5. Synthesis and Comparisons

1) Recapitulations

The technological regime of digital TV technology is featured by high technological opportunity with very frequent innovations and high fluidity given its young age of technology. Also, the risks for the early entrants are high, in terms of choice of right technology and the need to secure the initial market. These features underscore the importance of standard setting, the role of complementary products and infrastructure, and speedy timing to markets. All of these imply that catch-up by the late-comers would not be easy. However, it was fortunate for the late-comer firms that the standards for digital TV was fixed before the products was developed and markets were formed. Thus, as the public-private consortium in Korea have been watching the technological trends and the standard setting process, there was less risk of choosing the right or wrong technological trajectory. Also, despite the lack of sufficient capability and core knowledge base, the Korean firms had some complementary asset, such as the experience of producing analogue TV and monitors, and thus were able to develop the prototype digital TV and the ASIC chips, given the various accesses to the foreign knowledge, such as overseas R&D posts and acquisition of a foreign company. The second risk of securing the initial market was reduced by targeting the US market from the beginning, and the sources for competitive advantages of the Korean products were mainly the first mover advantages, and, secondarily the cost advantages supported by the development of powerful ASIC chips.

In sum, the Korean firms had achieved a "path-creating catch-up" in the sense they chose a different path from the Japanese forerunning firms. The initial failure of the Japanese firms and the success of the Korean firms do suggest that the period of paradigm shift, like this toward digital technology, can really serve as a window of opportunity for late-comers while penalizing the super-forerunner.

2) Comparison with Japan

The reasons why Japanese digital TV producers became laggard to Korean digital TV producers can be discussed in terms of the followings.

First, Japan was locked into analogue HD TV since the 1980s while the digital TV technology emerged in the early 1990s. Japan created the first HDTV system in the 1980s under the leadership of NHK and the Japan Broadcasting Corporation. In 1991, Japan adopted Hi-Vision/MUSE as the national HDTV standard [21]. Although Japanese government tried to shift to digital TV in 1994, the effort was baffled by the resistance from the firms locked into analogue TV. When a Japanese official offered a shift to digital TV in 1994, NHK and manufacturing firm fiercely resisted and he had to change his word [21]. Especially NHK and manufacturers who invested in 1.3 billion dollars in analogue HD TV were reluctant to move to digital technology [40] . It was only in 1998 that Japan announced its plan of introducing digital terrestrial broadcasting [23]. Japan officially started the development of digital TV in 1994 three year later than Korea.

Second, the R&D resources of the Japanese firms has been diffused over a wide range of digital devices ranging from DVD, digital camcorder and digital broadcasting equipments and so on as their initial strategy was to make their analogue HD TV compatible with these digital devices. They did so because they expected a slower market growth, and they were not aggressive in R&D for technology for receiving digital signals and digital decoding. Thus, the Japanese firm produced and sold only the digital-ready TV without digital tuner but can be linked DVD [25]. At the CES(International Consumer Electronics Show) at Las Vegas in 1999, Japanese firms revealed the digital ready TV, home networking products, and DVD, and Samsung was the only company which showed digital TV with digital tuner [30].

Until now, it seems that Korea is ahead of Japan in digital TV sets. However it is too early to judge whether the competition between Korean firms and Japanese firms is finished. Recently Japanese firms have been aggressively investing and marketing Japanese digital TVs. Digital TV market is still at an early stage of growth.

Anyway, the story of the early start and lock-in by the Japanese firms signifies the disadvantages and risk of the technological pioneer. Japan was the forerunner in taking initiatives toward HD TV but along the trajectory of analogue technology. However, her merits turned into a debt as the US and others accepted the digital TV as the standards, and the late-comers decided to follow this trajectory. In this sense, this case shows eloquently that shift of technological paradigm can penalize the leader while serve as a window of opportunity for late-comers.

3) Comparison with the Case of the CDMA

The story so far about the digital TV indicates that this case is very similar to the case of

CDMA mobile phone development. First, technological regimes of the both industries are featured by high technological opportunities and innovations and uncertainties given its young ages. Therefore, the chances for the catch-up firms should be low. However, both cases are the successful leapfrogging as the public-private R&D consortium took advantages of the shift of the industry-level trajectory from analogue to digital technology and created a new path different from the forerunning firms in Japan (digital TV) or in Europe (CDMA case). In the CDMA case, the European leaders chose the TDMA-based GSM as the standards, while in the digital TV Japanese firms went initially for analogue standards. In this sense, both cases can be considered as a path-creating catch-up [5], rather than a path-following catch-up along the trajectory of the forerunning firms.

Both cases show the importance of access to the foreign knowledge base (or seed technology) and speedy commercial product development by utilising emerging technologies and investment in production facilities. In the case of CDMA, a small company (Qualcomm) provided the seed technology to the Korean firms, and this firm joined with the Korean firms in their co-development to commercially viable CDMA mobile system. In the case of digital TV, the pioneering technology was proved also by a small firm called GI and core technology was owned by Zenith. The Korean firms interacted with these firms from the very early days of the emergence of the technology, and eventually acquired one of them.

In terms of the initial market formation, the Korean market was there as the government declared the CDMA as the exclusive national standards. Similarly, for the digital TV, the US markets were there as the US standards were decided in favour of digital TV rather than analogue TV. Both cases share the feature that technological standards were fixed before the market. In sum, the cases of digital TV and CDMA mobile phones show that the late-comer firms could overcome the various disadvantages by collaborating with foreign partners in marketing, R&D activities and/or standard setting.

The common pattern of catch-up in both CDMA and digital TV industry is consistent with the hypothesis proposed in Lee and Lim [5] that a path-following catching-up is likely to happen largely by private initiatives in industries where innovations are less frequent and the technological trajectory is less fluid, and thus the catching-up target is more easily identified, whereas a path-creating catching-up is more likely to happen by public-private collaboration where the involved technology is more fluid and the risk is high.

6. Concluding Remarks and Policy Implications

This study has verified the leapfrogging thesis with the case study of digital TV, and, combined with the findings in Lee and Lim [5], thus further strengthened the argument by showing how the emerging new technological paradigm can serve as a window of opportunity for the catching-up firms. The study has also identified the disadvantages and risks facing the catching-up firms, and elaborated how these can be overcome by the public-private R&D consortium. Also verified is the hypothesis, originally proposed in Lee and Lim [5], that a path-creating catching-up is likely to happen by public-private collaboration when the technological regime of the concerned industry featured a fluid trajectory and high risk.

What we have found in this study also signals some departure from the existing literature. First, while the literature on technical change [41,42] observes that innovation processes tend to be local in the early stages of technological evolution, this study finds that innovation process and its success might depends upon conducting the technological search activities and international interaction from the beginning stage. Precisely owing to this global watch activities and interaction, the Korean companies were able to become the leaders in spite of insufficient conditions for catch-up. The whole process was really international. In the cases of not only digital TV but also CDMA, the original core technology was invented in the US, and then actual development of the products and/or commercialisation was done by the Korean firms, and finally the initial test markets was the US and UK in the case of digital TV sets and was Korea in the case of CDMA. Second, the story of digital TV seems to be also different from what is argued in the literature on the stage model of technological capability building [43,44]. According to the stage theories of technological development, the catching up country moves from 'internalisation stage' to 'generation stage' to produce 'new knowledge' to the world. Although the cases of the digital TV and CDMA mobile phone shows the catching-up firm reaching the frontier of technology, they are not producing really 'new knowledge' in the senses that what they have done is to combine their commercialisation capability with the seed technology from the forerunning firms. This observation is consistent with the findings by the Albert [45], from his study on patenting trends in the US, that Taiwan and Korea emphasises fast commercialisation of information technology as the patents by these countries show much shorter technology cycle time than those by Japan and cite less scientific literature [46]. Although what the late-comer firms developed is a new product, it was possible by applying the foreign sourced sciences and the seed technology to the specific development target. The implication is that the stage theory of technological development is more relevant in the context of technological development within the given technological paradigm or trajectory. So, in this stage theory, the issues of technological standards and the associated risks has no place, whereas in the case of leapfrogging during paradigm shift, the technological standards takes a central place. Standard setting is a critical factor in the market success of the innovations in digital technology.

This study has the following implication for government policy and firm strategies.

First, a long list of success with the public-private R&D consortium, from TDX, D-RAM, CDMA and finally to digital TV in Korea, confirms the positive role of the government and the government research institutes in technological catch-up by the late-comer firms. Although the collaboration and knowledge sharing among the private firms has certain limits within the framework, the private firms all acknowledged the important function of the government in providing the legitimacy to the big projects that are often difficult to be supported by private firms. The consortium also served as a field to pool together the domestic resources from various sources, especially resources in the universities that is often a reservoir of new scientific findings. Contribution of the GRI's is also critical in conducting the role of "technology watch" to interpret and monitor the state-of-the art trend of R&D activities in foreign countries. It was the ETRI who identified the small firm like Qualcomm as the R&D partner and carried out R&D activities, and the KITECH and ETRI that carried out R&D activities and coordinated the consortium of the research projects in two specific fields of the whole project.

Second, the experience of digital TV, besides CDMA, underscore the importance of getting access to the global knowledge base, without which leapfrogging catch-up is almost impossible as the late-comer firms cannot generate radically new technologies themselves. In addition, we want to emphasize the change in the channels for knowledge access. While in the past or in the path-following catch-up, the main channels has been license or FDI, the current cases of a path-creating or leading catch-up during the paradigm shift period show the importance of new channels such as co-development with, and acquisition of, foreign firms as well as collaboration based on complementary assets owned by late-comer firms. Horizontal collaboration with forerunning firms is possible only when the late-comer firms have something to give in return. While absorption capacity was emphasize in the old story of technology transfer via license or FDI, now complementary assets, which have been created with speedy R&D activities and investment in production, seems to be important in these new ways of accessing knowledge.

Third, when the involved catch-up is in the area of information or other emerging technology, the critical role of standard setting should be emphasized. Isolated development without paying attention to the issue of standards might lead to a failure of the whole project. In standard setting, collaboration and getting partnership with rivals or suppliers of complementary products are important. Also important is who create and get to the market first as the size of the market determines the success or failure of one standard against other. Again, in this competition for standard setting and market creation, the role of the governmental can be noted as it can plays the role of facilitating the adoption of specific standards and thereby influencing the formation of markets at the right times.

	R&D areas		Research organization
Digital Signal Processing	Satellite broadcasting		Korea Institute of Industrial Technology
	Terrestrial broadcasting		LG Electronics Inc.
			Daewoo Electronics Co., Ltd.
			Samsung Electronics Co., Ltd.
			Hundai Semiconductor Inc.
Display	Direct-view CRT	G/B	Hankuk Electric Glass Co., Ltd.
			Samsung Corning Co., Ltd.
		S/M	Goldstar M/C
		CRT	LG Electronics Inc.
			Samsung SDI Co., Ltd.
			Orion Electronic Comapny
			Korea Institute of Industrial Technology
	Projection CRT		Korea Institute of Industrial Technology
	Projection LCD		LG Electronics Inc.
			Orion Electronic Company
			Korea Institute of Industrial Technology
	PDP		Orion Electronic Comapny
ASIC	ASIC Chip		Goldstar IT (= LG)
			Samsung Electronics Co., Ltd.
			Hyundai emiconductor Inc.
			Electronics and Telecommunications Research Institute

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Table 1 Annual Number of the Selective Patents Registered in the US

Annual Patents	CDMA	Digital TV	Whole
1991[A]	1	59	107,259
2002[B]	267	151	184,530
B/A	267.0	2.6	1.7

Source: Author's calculations using the data from the USPTO site

Note: 1. year 1991: the first year that a Korean firm registered its first digital TV patent in the US.

2. Figures for digital TV: number of patent whose abstract contains 'digital' and 'TV or television'

3. Figures for CDMA: number of patent whose abstract contains 'CDMA'

Table 2 Division of Labor in HDTV development projects in Korea

Source: KETI (2000: 426).

Table 3 Digital TV Patents by the Nationality of Patent Owners

Year	US	Japan	Korea	Samsung Electronics		LG Electronics		Zenith	
				total	non-Korean	total	non-Korean	total	Korean
1991	26	13	1	1	0	0	0	0	0
1992	32	11	0	0	0	0	0	3	0
1993	35	8	5	5	0	0	0	8	0
1994	37	5	7	7	2	0	0	2	1
1995	29	7	7	5	2	0	0	2	0
1996	61	10	10	6	5	0	0	3	0
1997	51	13	10	6	2	1	0	3	0
1998	60	18	15	13	9	2	0	1	0
1999	49	19	15	15	9	1	0	1	0
2000	44	21	13	11	6	2	0	2	0
2001	50	27	28	17	6	11	0	1	0
2002	70	26	24	16	11	8	0	2	0
Total	544	178	135	102	52	25	0	28	1
				100.0%	51.0%	100%	0%	100%	3.6%

Source: Author's calculation using the data from the Web Site of the US Patent and Trade Mark Office

Note: 1. Figures are the number of patents whose abstract contain 'digital' and 'TV or television'

2. Non-Korean counts the number of the patent whose inventors include persons not residing in Korea

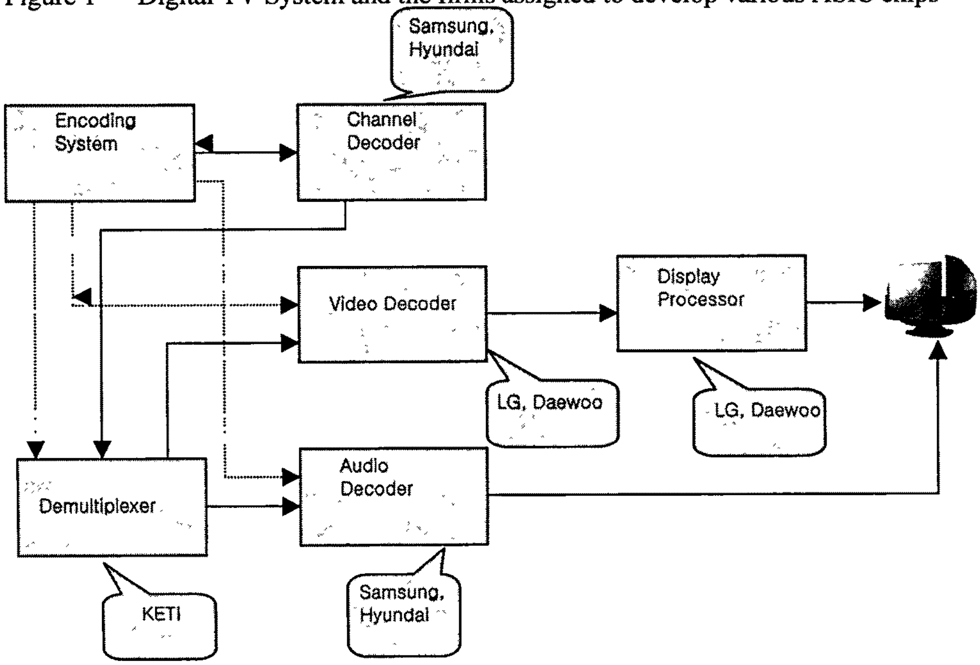
3. 1991 is the first year that a Korean firm registered its first digital TV patent in the US.

Table 4 Prices of digital TV by the Korean firms

Product / company		Model	Display type	Screen	Price (US$)
Digital-ready TV	Samsung Electronics Co., Ltd.	HCJ552W	7"CRT Rear DTV	55", 16:9	4,999
		HCJ652W		65", 16:9	6,999
		PCJ534RF		53", 4:3	3,499
		PCJ614RF		61", 4:3	3,999
	LG Electronics Inc.	Pro900X	7" CRT Front DTV	variable	12,600
Integrated DTV (Tuner-inside)	Samsung Electronics Co., Ltd.	HCJ555W	7"CRT, Rear DTV	55", 16:9	7,999
		HCJ655W	9"CRT, Rear DTV	65", 16:9	11,000
	LG Electronics Inc.	IQB56W10	7"CRT, Rear DTV	56", 16:9	8,499
		IQB64W10	9"CRT, Rear DTV	64", 16:9	9,999

Source: CEA (Consumer Electronics Association), DTV Guide (March 2000); recited from KETI (2000:394)

Figure 1 Digital TV System and the firms assigned to develop various ASIC chips



Source: KETI (2000: 353)
Notes: KETI is the Korea Electronics Technology Institute

Table 5: Korean Export of Digital TVs

(thousand dollars)

	2001	Weight	2002	Weight
Total	268,236	100%	974,279	100%
PDP-TV	89,435	33%	313,838	32%
Projection TV	85,032	32%	331,637	34%
CRT-TV	60,873	23%	153,910	16%
LCD-TV	32,896	12%	174,894	18%

Source: Electronics Industries Association of Korea 2003 "Export of Digital TV in 2002"

Appendix Table Comparisons of Specifications of VSB Channel Chips by several producers

Items	Samsung	Philips	Lucent	MATSUSHITA
Number of Chips	1-chip	1-chip	1-chip	digital 1-chip analog 1-chip
Use of 16VSB	8/16 both	8 only	8/16 both	8/16 both
Embedded ADC	embedded 10-bit	external	external	External
AD input signal	Low IF			baseband
Sampling clock rate	21.52 MHz			10.76 MHz
Carrier recovery	digital			Analog
Timing recovery Pll	embedded			
AGC & STR DAC	embedded	external		embedded
NTSC rejection filter	embedded	none	embedded	none
EQ. Tap coef. Output	available			not available
Ghost canceling range	-4~+20 μs	-2.3~+10.5 μs	-3~+17.8 μs	-5.7~+18 μs
μ p interface	I^2C			
Application circuit	simple		complicated	
Package type	160 PQFP	64 QFP	160 MQFP	128 QFP
Voltage	3.3V			
Model No.	KS1402	TDA8960	AV8100	MN88431

Source: KETI (2000: 410)

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