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The Dismantling of the Japanese Model in Consumer Electronics: The Case of the digital Amplifier

by

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Abstract:
This paper addresses an issue of great importance for the future organization of the consumer electronics industry: the "battle" of control over component-based digitization. We are now witnessing the dismantling of the Japanese Model that has prevailed in consumer electronics over the past 30 years. Specialized and large-scale component suppliers have taken the lead in most component-based innovations and have obtained increasingly powerful positions in the value chain of consumer electronics. This paper provides an in-depth study of the strategic and structural ramifications of one such component-based innovation, the current transformation of sound amplification from conventional to digital amplifiers. We study the early formation of this new technology as especially reflected in the particularly dynamic cluster of innovation in Denmark and extend the analysis to the global strategizing around this new technology. A framework is developed to explain the reluctance of most of the large consumer electronics giants in developing/adopting this new technology.

Key words: Consumer electronics, Industrial dynamics, Open Innovation

JEL Codes: L6, L68, O32

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1. Introduction

For nearly half a century following World War II, the Audio/Visual (AV) core of the consumer electronics industry, including providers of home stereo equipment, TVs, CD players, car audios, and video recorders, enjoyed high and steady growth. During the first 25 years, US-based companies dominated innovation and commercial applications, but from the late 1960s and onwards, Japanese companies took over and have maintained the global leadership role through the last decades of the twentieth century - along with Dutch Philips and a few Korean latecomers. However, in recent years growth rates in the traditional product segments have become flat and stability has been replaced by emerging structural changes that pose distressing challenges to the dominant players. Specifically, rapid product price erosion due to fierce price competition from new entrants, especially manufacturers operating in China and other low-cost Asian countries, shrinking product life cycles and increasing digitization of the technology base driven by dedicated component suppliers. In addition, we are witnessing an expansion of the domain of the AV industry both in the number of different AV product categories as well as in the number of the underlying technologies.

Gerard Kleisterlee, CEO of Philips[1] recently called for a fundamentally new business model in the consumer electronics industry, envisioning flexible organizations, partnership networks and cooperative competition, rapid and continuous innovation and new multi-functional and multi-technological cross border product categories. Kleisterlee foresees Philips leading the way by moving "*away from being a vertically integrated manufacturing monolith to focus on sales and marketing, with technology leadership*". [2] If Philips and other leading Original Equipment Manufacturers (OEMs) in the industry in actuality are able to translate such rethorics into strategic redirection, the industry is likely to come to resemble forms of industrial organization that have become prevalent in many industries. Other electronic industries such as the semiconductor, computer, telecom, communication and network industries, have seen the incumbents making the transition from being vertically integrated and doing nearly everything in-house, to becoming so-called Global Flagship Network organizations[3] or system integrators, *"increasingly coordinating somebody else's activities"*[4] (Hobday et al., 2003, p. 1)

through extensive outsourcing and networking. Borrus and Zysman have located these changes in a new mode of competitive strategy that they term "Wintelism"[5] and its industrial organization counterpart termed "Cross-national Production Networks". According to their analysis *"competition is shifting away from final assembly and vertical control of markets by final assemblers toward the struggle over setting and evolving de facto product standards in the market, with market power lodged anywhere in the value chain, including product architectures, components and software*" (p...). The notion of Cross-national Production Networks "*signifies the consequent dis-integration of the industry's value chain into constituent functions that can be contracted out to independent producers wherever those companies are located in the global economy*". (p.....). These strategic and organizational reshufflings have been driven by the interrelated dynamics of technological change and modularization in a context of increasing liberalization of global trade. Even if these dynamics have also in recent years been important features of the AV industry, leading companies have so far been reluctant to embark on this new path.

During the 1980s much of the literature on consumer electronics was occupied with explaining why the American consumer electronics industry - having pioneered such basic product innovations as the transistor radio, color TV and video recorder - was being systematically out-competed by Japanese followers pursuing strategies of tight vertical integration between production, development and incremental product and component innovation[6]. The Japanese model definitely prevailed, yet it came under increasing strain as growth rates leveled-out, price-competition intensified and ongoing technological change penetrated the different product markets during the 1990s. The academic literature on consumer electronics has been remarkably silent on these issues in recent years, mostly occupied with the phenomenal prospects of digital convergence as an innovation strategy aligning large incumbents in consumer electronics, telecom, computer and software industries.[7] Yet apart from a few notable exceptions such as Sony's PlayStation, the new convergence products have not provided the large AV-oriented incumbents with the fundamental relief from their traditional core markets troubles.

This paper addresses the much under-emphasized issue of great importance for the future organization of the consumer electronics industry: the "battle" for control over component-based digitization of consumer electronics. Clearly, the dominant OEMs have realized that despite their large in-house component portfolios, specialized and large-scale component suppliers have taken the lead in many component-based innovations and have obtained increasingly powerful positions in the value chain of AV consumer electronics. Over the last years we have seen typical IT/telecom-based components, formats and standards e.g. hard disks and network cards, MP3 music format and Wi-Fi standards making their entry into AV products such as DVD players and TVs. Texas Instruments' new Digital Light Processing technology or Intel's Liquid Crystal on Silicon (LCOS) technology for TVs and flat screen displays are current examples of dedicated component suppliers introducing new components into the traditional AV area. This development threatens to undermine the business model upon which the large Japanese companies established their world dominance within consumer electronics.

One such component-based innovation relates to the current transformation of sound amplification from conventional amplifiers to switched/digital amplifiers. This paper provides the first in-depth study of the strategic and structural ramifications of these innovative processes. In the pioneering phase of this emerging technology, one of the most vibrant clusters of innovation was located in Denmark. During the second part of the 1990s, path-breaking scientific research was carried out at the Technical University of Denmark. This research paved the way for two business ventures that came to play major roles in the early attempts to commercialize switched/digital amplification. We first draw the picture of the formation of this cluster of innovation based on interviews with its leading agents and extend the analysis to the global context in order to better understand the broader strategic and organizational dynamics involved in commercializing and controlling this new technology, and in particular the strategic positioning game among the small specialized component and technology suppliers, the dedicated assemblers, the large-scale component suppliers, and the large AV OEMs.

Section 2 provides an analysis of the recent structural and corporate dynamics of the global consumer electronics industry. Section 3 identifies the critical technological trajectories characterizing AV consumer electronics and especially the particular trajectories associated with sound amplification leading up to the current transitions. Section 4 gives an outline of the pioneering stage in the formation of the new amplifier business, illustrated by the Danish case of transformation from university research to early venturing in the second half of the 1990s. In section 5 the maturation of the business through interaction and integration between the early start-ups and large component providers is examined. Section 6 offers a differentiated explanation of the large AV OEMs' comparatively slow and low-key response to this radical component-based innovation. Finally, the concluding section 7 raises the question of whether this case reflects a more general pattern in the dynamics of consumer electronics that signals the undermining of the Japanese Model. The case study is based primarily on interviews with some of the leading pioneers in this new amplifier technology (see Appendix).

2. The transformation of the consumer electronics industry

Intuitively one tends to think of the AV-oriented consumer electronics industry as strongly dominated by a small group of large providers of end-user products including CD and DVD players, stereos, TVs, VCRs, portable audio and home theater systems, the most well known being Sony, Matsushita (with the Panasonic, National, Technics and JVC brands), Philips, Samsung, Sanyo and Sharp. However, the important role of companies that are less visible to the public should not be forgotten; the small specialized suppliers of components and modules, the broad-scoped electronic component providers, and the dedicated manufacturers and assemblers of components and systems. Figure 1 shows this more elaborated picture of the industry. The large and globally renowned system integrators, strongly devoted to innovation, manufacturing, marketing and distribution of AV products and a large array of other consumer electronics products, also possess large in-house component portfolios and associated industrial research, design and manufacturing (particularly Philips, Sony and Matsushita).

Figure 1. Mapping Component Providers, System Integrators and Manufactures in Consumers Electronics

	Component providers	OEM system integrators	Manufacturers
Narrow	**Specialized suppliers** (i.e. in digital amplifiers: Apogee, ICEpower, Powerphysics, Tripath, Pulsus, NeoFidelity)	**High-End suppliers** (i.e. Bang & Olufsen, Harman Kardon, Krell, Mark Levinson, Kiss Technology)	**Original Design and Manufacturing (ODM) providers** (i.e. Asustek, Benq, Compai, Quanta)
Broad	**Large-scale component Providers** (i.e. Motorola, Crystal Semiconductor STMicroelectronics, Texas Instruments)	**Large-scale OEMs** (i.e. LG Electronics, Philips, Matsushita, Pioneer, Samsung, Sanyo, Sharp, Sony)	**Electronics Manufacturing Services (EMS) providers** (i.e. Celestica, Flextronics, Jabil, Sanmina-SCI, Solectron)

With none of the globally dominating providers of AV products any longer American, rather Japanese (Matsushita, Pioneer, Sanyo, Sharp and Sony), South Korean (LG Electronics and Samsung) or Dutch (Philips)[8], US-based companies now primarily play important roles as component suppliers. Some prominent examples are Texas Instruments, Motorola, National Semiconductor, Intel and Analog Devices. Large Japanese players (especially Hitachi and NEC) and European-based STMicroelectronics and Philips are also important large-scale electronic component providers, supplying components and other products to many other parts of the electronics sector outside of the AV industry. For example, Motorola provides semiconductors as well as terminals for broadband and satellite TV Networks and mobile phones.

The lack of large American AV OEMs reflects the historical dismantling of the US-based AV companies from the late 1960s and into the 1980s, a consequence of Japanese companies' government supported export and leap-frog strategies. These were based on highly integrated R&D and manufacturing strategies with a strong focus on imitation and incremental product innovation adapted to flexible manufacturing systems.[9] On top of that, the Japanese OEMs (and even more so Philips) built strong technology bases underlying their increasingly broad-scoped portfolios of components that were, at least

for many critical components, proprietary to their end-products. The American companies were renowned for their superior industrial research and capacity for radical systems innovations such as the transistor radio and color TV, yet lost out in the end due to weak performance in manufacturing, incremental product innovation, design and a failure of U.S. industrial policy.[10] The exceptional US-renaissance since the early 1990s in creating new avenues in information and computer technologies was founded in new modes of organizing corporate R&D[11] and related dynamics of vertical disintegration through outsourcing, venture-based start-ups and innovative networking.[12] This demonstrates that successful business models are historically context-specific and that the huge challenges of the new decentralized and networked information technologies could not have been successfully managed within the vertically integrated and proprietary corporate framework - neither the traditional US-based structure nor the more recent Japanese version.[13]

Another category of OEMs typically address high-end product market niches (for examples see Figure 1). Firms range from very small OEMs dedicated to products for the small niches of high-income groups and/or HIFI enthusiasts and professional sound studios, to medium-sized firms (such as Bang & Olufsen) offering a combination of exclusive design and high quality AV products. Compared to the large-scale OEMs these firms have a narrow product portfolio and have more extensively outsourced component design, production and a larger share of product assembling. In recent years start-up OEMs have made substantial inroads in the DVD-related products markets both in the cheap mass markets (e.g. Apex Digital) and in the mid-segments (e.g. Kiss Technology).

Figure 1 furthermore points to two categories of dedicated electronics manufacturers, the US-dominated Electronic Manufacturing Services (EMS) providers, such as Flextronics and Samina-SCI, which have experienced tremendous growth rates for more than a decade, and the Taiwan-dominated Original Design and Manufacturing (ODM) providers which have more recently experienced hyper-growth. While the former are large-scale companies nearly exclusively specialized in cost-effective manufacturing and assembling of a broad array of electronic components and systems for OEM customers, the latter also

possess design capabilities and have established lead-positions in a few areas (e.g. notebooks).[14]

So far, the outsourcing wave underlying the hyper-growth of the EMS and ODM providers has been much weaker in consumer electronics than in other electronic sectors. Only an estimated 0-3% of Japanese consumer electronics OEMs' production, accounting for approximately a quarter of the world's total electronics production, has been outsourced to EMS providers.[15] A few Japanese OEMs in the AV industry, especially Matsushita and Sony, have some experience using EMS companies, but even for these firms outsourcing has to date also been in single digits.[16] Rather than outsourcing, these OEMs have established their own manufacturing facilities, often in China, Malaysia, Thailand, Indonesia and Vietnam. Philips, the world's third largest AV-consumer electronics company, has also tended to maintain ownership control over most manufacturing of its product and component portfolio, though substantial relocation to China and other low-wage countries has taken place in recent years. Contrasting the AV industry, the semiconductor industry, the telecom industry and the communication and network industries are all characterized by much higher levels of outsourcing.

From a historical context, there are good reasons for the reluctance of the large AV OEMs to embark on a major change towards vertical disintegration. The Japanese OEMs (and Philips) still regard manufacturing as a core competency, maintaining large internal component production bases. A combination of path-dependency and the comparatively higher profitability in parts of the component markets (e.g. semiconductors and LCD displays)[17] than in most of the end-user markets, seems to explain the slow move towards vertical disintegration. However, if recent announcements from companies such as Philips and Sony are to be taken seriously, this is likely to change in the coming years.

While much of the literature on outsourcing in the electronics sector has dealt with outsourcing of manufacturing operations, limited attention has been directed at the strategic issues of the organization of innovation in new digital components. In the following sections we shall address one such case of a radical component innovation for

AV products - the digital amplifier. This case illustrates the particular role of small specialized component or technology suppliers (see Figure 1) and their strategic interfacing with large-scale component providers and OEMs. We shall describe how this new amplification technology has evolved and is penetrating the AV industry, hence gradually replacing the traditional sound amplification technology. Not only is price-competition and flat demand driving profits out of the large OEMs, but specialized and broad-scaled component suppliers (e.g. Texas Instruments and Intel) are now providing critical innovations to the AV business, and seem well positioned to appropriate the major shares of the rents from these innovations. We posit that these dynamics reflect the end of the "Japanese Model" of vertically integrated control over consumer electronics.

3. Digitization of AV consumer electronics and the case of sound amplification

Over the last 20 years most sectors of the economy have been experiencing a process of digitization involving a comprehensive influx of technologies and components originally developed by and for the semiconductor and computer industries.[18] In AV consumer electronics significant technological transformations include:

- The replacement of traditional analog formats of TV, radio, VCR and cassettes with formats that record and restore signal sources in digital form, including CD (1983), MiniDisc (1991), DVD (1995), and more recently digital radio and TV, and MP3/Internet audio.
- The replacement of various removable media for storing sound and picture (records, tapes, CDs and videos) by "on board" or embedded storage technologies like flash memory cards and hard disks - devices traditionally used for computers.
- The change in the form in which audio content (music) is embodied and accessed, from tangible products (tapes and CDs) to 'streamed media' downloaded through the MP3 format from the Internet (for instance in Internet radio) – yet another import from the computer industry – and the probability of visual content (film) presently embodied in videos and DVDs becoming increasingly "streamed" as sufficient bandwidth is more broadly implemented (e.g. in on-line video).

- The transition of display technology in visual products from Cathode Ray Tubes (CRT) to Liquid Crystal Displays (LCD) or plasma-based displays.
- The incorporation of networking and wireless networking technologies into AV products for facilitating interaction and connection to the Internet - largely enabled by the influx of technologies from the computer and communication industry.
- The replacement of the hitherto predominant form of audio signaling and power processing, the linear mode associated with conventional class A/B transistor-based amplifiers, by a switched amplification mode (Class D or digital amplifiers) and the increasing use of digital signal processing.

The rest of this section gives an account of the technological trajectories of sound amplification.

In audio equipment the amplifier amplifies the audio signal, for example from a CD player, and sends the amplified signal to the speakers. Historically analog sound amplification can be differentiated into two generations: valve-based and transistor-based amplification. Originally amplifiers employed vacuum tubes or valves to boost the analog signal. This technology dates back to the early twentieth century and Lee de Forest's invention in 1906 of the 'audion' as the first purely electronic component that could amplify a signal[19]. This invention paved the way for sound amplification in telephones, radios, phonographs, motion pictures, and later televisions. Through the licensing and maturation of the technology by major corporations such as General Electric, it became a practical and reliable commercial device.[20] Still, vacuum tubes had the drawbacks of being large and clumsy, consuming much power, creating much heat, and incurring high maintenance costs by burning out rapidly.

The transistor, invented in 1947 by Shockley and his colleagues at Bell Laboratories, replaced valve-based amplification in most audio applications over the subsequent decades.[21] In the late 1950s and early 1960s manufacturing technologies were developed by companies such as Western Electric and Texas Instruments, making scale-intensive

and low-cost production of transistors feasible - first materializing commercially in the "transistor radio" market.[22] Over the years improvements in transistor technology made transistor-based amplifiers superior in several ways to tube-based amplifiers. However, the energy-efficiency of transistor-based amplifiers remained quite low implying, on the one hand, a need for large power supplies and, on the other hand, bulky heat sinks to absorb the waste electricity and prevent over-heating. In addition, the inherent and unavoidable noise and distortion from transistor-based amplifiers results in limitations in the resolution and precision of audio signal processing. The introduction of digital audio to CDs removed a weak link in the audio signal chain, but since no digital amplifiers existed the CD player still needed a so-called Digital to Analog Converter (DAC) to feed the audio signal into an analog amplifier to be heard.

Since the mid-1990s Class D or switched amplification technology has been subject to a major breakthrough and has proven to be the way ahead. This mode of amplification, while known for more than 40 years, had never before been successfully applied in an audio context. The switched amplifier exists in two basic forms, one with an analog input and one with a digital input - only the latter case can be termed a purely digital amplification process.[23] Both forms apply a set of technological principles termed Pulse Width Modulation (PWM). In switched amplification with analog audio signals PWM transforms these signals into pulses enabling the amplifier to synthesize the desired output signal directly onto the speaker terminal. In purely digital amplifiers the Pulse Code Modulated (PCM) input signal is transformed into the PWM format, which then amplifies it in the digital domain. The PWM amplification stage, a type of switching circuit, is not influenced by nonlinearity and transistor noise, enhancing sound quality greatly. In the final stage of audio production in the signal path, a simple passive low-pass filter transforms the PWM signal into an analog power signal that can directly drive a speaker. Being far more energy-efficient than analog amplifiers, they do not need any heat sinks and can be equipped with smaller power supplies, drastically reducing the size of switched as compared to conventional amplifiers. Furthermore, switched amplification technology can now be reduced to just one or two chips, creating possibilities for dramatically lowered manufacturing costs.

Class D amplifiers can be embedded in either discrete modules (based on discrete standard components) or in chips-based modules (based on integrated components). The former are high cost/performance amplifiers and they have since the late 1990s been penetrating parts of the high-end niche markets, while the latter have since 2000 begun to penetrate the mid- to low-end mass markets. Especially the latter markets, however, are still strongly dominated by conventional technology. Rodman & Renshaw Equity Research estimates the size of the analog amplifier market between $2.1 billion to 3.0 billion as of 2003 and the size of the digital amplifier market between $80 to $100 million, or 2-3% of the total amplifier market.[24] This level is expected to increase to $515 million, or 15% of the total amplifier market by 2006.

The subsequent two sections tell the story of the emergence of the new business of digital amplification from the pioneering phase of university research and business venturing into the maturing phase of strategic positioning and alliance formations across different categories of players. We shall specifically address the pioneering role of Technical University of Denmark and two Danish ventures, each reflecting highly different strategies.

4. The pioneering phase: Out of research and into business venturing

Early attempts to build a switched amplifier in the mid-1970s had disappointing results. However, by the early to mid-1990s basic scientific research in audio power conversion had matured, thus making both switched, and ultimately purely digital, amplification within practical reach. At the very frontier was a research community lead by professor Michael A.E. Anderson at the Institute of Electric Power Engineering at Technical University of Denmark, where the research culminated in two spin-off ventures: Toccata Technology initiated by Lars Risbo, and ICEpower initiated by Karsten Nielsen. [25]

In the early 1990s, Michael A. E. Andersen, with both a personal and scientific interest in HIFI sound, was investigating the opportunities for audio processing from Class D amplifiers. Meanwhile, Lars Risbo completed a PhD (1992-94) on audio converters – the

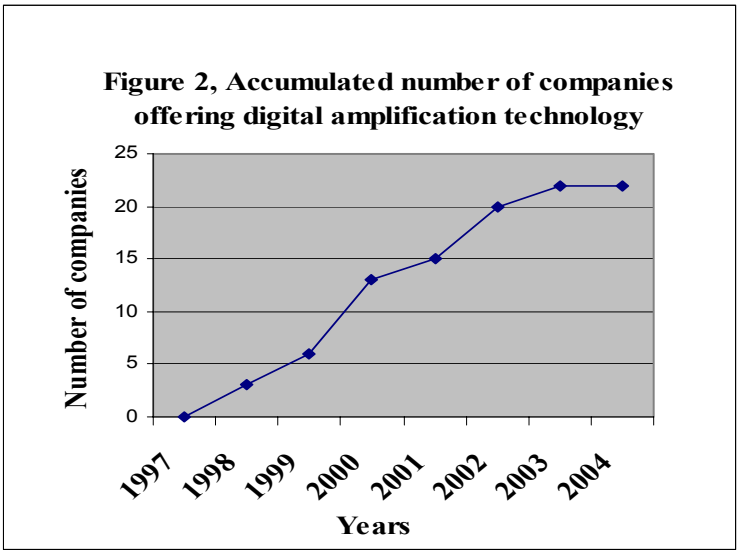
two works offered promising synergies, leading Lars Risbo to turn his interest towards the principles of PWM. Karsten Nielsen, who had done his masters project on digital signal processing algorithms, began a PhD-project in 1995 addressing the opportunities for increasing energy-efficiency in amplification. The project was carried out in close collaboration with Bang & Olufsen. Both Lars Risbo and Karsten Nielsen's research resulted in a number of patents that provided a sound intellectual property (IP) base for their respective ventures.

Lars Risbo's venture, Toccata Technology (henceforth Toccata), was established in 1997 and supported by a development contract with the Danish Audio Nord Corporation, a company with a strong market position in HIFI products in Scandinavia. Already in 1998, Audio Nord launched the world's first fully digital amplifier under the brand Tact Millennium. This high-end-market product created huge international attention in HIFI circles and eventually sold 500 of $10,000 units – a great commercial success for a small HIFI company.

Upon defending his PhD in 1998, Karsten Nielsen was immediately hired by Bang & Olufsen and charged with integrating the new amplification technology into Bang & Olufsen's speaker systems. The subsequent year Bang & Olufsen successfully launched the first speaker, Beolab 1, integrating a switched amplifier. Moreover, to expand and mature the broader opportunities of switched amplification technology, Karsten Nielsen's team was spun out as a separate firm, Bang & Olufsen ICEpower (henceforth ICEpower) with ownership shared between Bang & Olufsen (75%) and Karsten Nielsen (25%). While Karsten Nielsen brought the patents and innovative know-how on switched amplification, Bang & Olufsen provided important complementary assets such as a strong global brand, manufacturing facilities and probably the world's largest and most sophisticated R&D community in acoustics and speaker technology. This community came to constitute a highly important lead-user role in the efforts to develop switched amplifier modules from Beolab 1 through to the much more ambitious high-end speaker, Beolab 5 (launched in 2003).

ICEpower and Toccata were not the only firms to explore the opportunities of Class D amplifiers. By 2003 we have identified 24 firms with at least some activity in the area (see Figure 2 and Table 1). They can be divided into three groups. First, a number of small start-up ventures like the Danish ones, including Apogee (USA), JAM Technologies (USA), NeoFidelity (Korea), and Tripath (USA). Secondly, a group of large vendors of semiconductors and digital signal processing chips, for example National Semiconductor and Texas Instruments. Thirdly, a small group of AV OEMs, including Philips, Sony and Sharp.

A little over half of these firms are based in the U.S. and the great majority is associated with the semiconductor industry rather than the AV industry. Several of the start-ups



were based on close cooperation with universities prior to their founding (besides the two Danish ventures Mueta, Powerphysics and Pulsus). The very first pioneers of digital amplifiers were Toccata and Tripath launching products in 1998. In 1999 ICEpower and Texas Instruments joined in (the latter with an early version of a Class D amplifier prior to acquiring Toccata). In the following four years numerous semiconductor incumbents as well as start-ups dominated the wave of new products.

The large AV systems integrators have been comparatively slow-moving with respect to developing and adopting digital amplification. Even if Philips, Sharp and Sony have developed their own systems, they have, according to unanimous judgments from our interviewees, neither been setting the international agenda at the frontier of the

Table 1. Companies with in-house digital amplifier products in 2003.

Company name	Country	Products/Services*	Introduction of first product	turnover in 2002 (US$ million)
Start-up companies				
Apogee (1995)**	USA	Chips	2000	5
Bang and Olufsen ICEpower (1999)***	Denmark	Modules	1999	4
Champion Microelectronics (1998)	Taiwan	Modules	2002	N/A
D2Audio Corporation (2002)	USA	Modules	2002	N/A
JAM Technologies, Inc. (1999)	USA	IP	2003	0.5
Monolithic Power Systems (1997)	USA	Chips	2002	N/A
Mueta (2001)	Netherlands	IP	-	N/A
NeoFidelity Inc. (2000)	Korea	Chips	2001	N/A
Powerphysics (1998)	USA	Chips/Modules	2000	N/A
Pulsus (1999)	Korea	Chips/modules	2000	N/A
Toccata Technology (1997-2000)****	Denmark	IP	Early 1998	-
Tripath (1995)	USA	Chips	End of 1998	16.2
Semiconductor incumbents				
Analog Devices	USA	Chip	2003	1.700
Crystal Semiconductors/Cirrus Logic	USA	Chips	2003	411
Maxim	USA	Chips	2000	1.153
Microsemi	USA	Chips	2000	212
Motorola Semiconductor	USA	Chips	2000	26.700
National Semiconductor	USA	Chips	End of 2002	1.670
STMicroelectronics**	Switzerland	Chips	2002	6.318
Texas Instruments****	USA	Chips	1999	8.380
Zetex	UK	Chips	2000	N/A
AV incumbents				
Philips Electronics	Netherlands	Chips	1998	36.549
Sharp	Japan	Chip	End of 1999	17.000
Sony*****	Japan	Module	2001	62.280

* We roughly distinguish between three products/services: chip-based products (termed chips), amplifier modules based on discrete components (termed modules) and technological knowledge or intellectual property (termed IP). The latter is an element of most of the firms' offerings, but IP is only mentioned where tangible products could not be identified on the firm Website.

** Apogee made speakers since 1987, but chose to discontinue this business in 1995 to exclusively focus on its digital amplification technology, DDX. STMicroelectronics and Apogee began collaborating on the DDX development in early 2001 under the terms of a technology licensing agreement, later expanded to a joint development agreement in March, 2002.

*** Even if Bang and Olufsen has a majority stake in ICEpower it has here been registered as a start-up because it has largely operated as an autonomous module supplier with a strong entrepreneurial leadership and an R&D team based in the digital amplifier research community at Technical University of Denmark.

**** Toccata was in 2000 acquired by Texas Instruments.

***** Previously in cooperation with Mitsubishi Semiconductor. Now with Texas Instruments

Source: Website of the individual companies, **www.classd.com**, **www.puredigitalaudio.org**.

technology nor been aggressively pursuing commercialization of digital amplification (for an extended discussion see section 6).

5. The maturing phase: The evolving strategic game

In 1999, with a small group of specialized technology suppliers having demonstrated the potential of digital amplification, the strategic game proliferated in different directions. It was clear that the small technology specialists on their own neither would be able to fully mature the new technology nor penetrate the larger audio market segments. The questions regarding which technical design approach to follow, which AV products to adapt to (speakers, DVD receivers etc), which market segments to pursue (high-end versus mid- or low-end), whether to focus on discrete amplifiers or chips-based amplifiers, and which partners to align with, remained open. This section shall trace the evolving strategies of Bang & Olufsen ICEpower and Toccata/Texas Instruments. These strategies illustrate the two dominant routes for maturing and commercializing digital amplification technology, through integrated or chip-based solutions, or through discrete module solutions.

Despite the successful launching of the high-end TACT amplifier, Toccata required more than the small royalties this amplifier generated for its survival. While seeking potential partners in the semiconductor world, Toccata was approached by Texas Instruments (TI), who indicated a strong commitment to exploring the opportunities in digital amplification, and possessed several of the components and knowledge assets necessary for transferring switched amplification technology into chip design.[26] Furthermore, TI was recognized as one of the world's most cost-efficient chips producers.

Initially, a licensing contract was signed, providing TI rights to use Toccata's technological knowledge (1 year exclusivity and to IC manufacturing only) and supplying Toccata with down payments. In March 2000, following a mutual recognition that the technology transfer from Toccata to TI and the chip design project was proving more complex than expected, TI acquired Toccata. TI moved quickly to integrate R&D activities in digital amplification in order to ensure a more effective design process. Through the acquisition TI reduced the vulnerability and uncertainty of being dependent

on critical core capabilities located in an independent firm, and eliminated further contracting issues (as well as future royalty outlays). Later in 2000, following this successful integration, TI launched its first generation digital amplifier chip. By late 2003 TI was producing its fourth generation chip in the millions. The main challenges in the chips design were on the hardware side which is difficult to model particularly with regards to semiconductors, while the software side was well defined. TI's digital amplification chips consist of a modulator and an output stage, made in two separate silicon processes. Total integration, though technically possible, is still considered too costly. TI is thus focused on developing new processes that will lower production costs and facilitate such integration in the future.

TI has in particular focused on penetrating the attractive DVD-receiver segment. The DVD segment stands out as perhaps the only AV segment experiencing consistently high annual growth rates (around 30-40%), as the DVD receiver aspires to become the core unit of the 'home-theatre entertainment system' - and one of the core units for integrating amplifier chips. By early 2004, the high-end DVD-receiver market was experiencing nearly full penetration of digital amplification, while analog technology remained cost-competitive in the low-end mass market. For the aggregated AV market the penetration rate of digital amplification still remains very low (according to different judgments between 1 and 3%).

The second Danish technology supplier, ICEpower, pursued an entirely different strategy directed at discrete (rather than chip-based) modules and with an initial focus on application in high-end speakers. This strategy was strongly influenced by ICEpower's close ties to Bang & Olufsen, the world's fourth largest speaker specialist with great emphasis on sound quality and aesthetic design. ICEpower was encouraged to develop nearly complete switched amplifier modules, not only the core components, for integration into Bang & Olufsen's speakers. The small size of these modules relative to conventional amplifiers offers Bang & Olufsen much greater freedom when addressing aesthetic and functional concerns in speaker design. Thus, ICEpower was exposed to a tough and extremely professional lead-user environment[27] in Bang & Olufsen. Technical

development was strongly focused on improving the quality features of the amplifier modules based on discrete standard components (in contrast to integrated components), and on obtaining frictionless plug 'n play with speaker systems. While most of the other specialized suppliers of digital amplification technology provide amplifier chips or aspects of the technology underlying chips design (especially the front-end modulator part), ICEpower was among the first suppliers of switched amplifiers to develop a full amplifier module. Besides addressing the same high-end AV consumer segments that Bang & Olufsen serves, ICEpower has also targeted another high-end audio area, namely professional audio (e.g. equipment for concerts and sound recording studios). The company has established market relations with speaker producers such as Acoustic Reality and Foster Electric as well as with semiconductor companies and large AV OEMS (e.g. supplying amplifier modules for Sony's subwoofers) to whom ICEpower either sells standard modules or develops customized amplification solutions.

However, since 2002 ICEpower has also developed a chip-oriented strategic arm through a licensing contract with Sanyo - who is one of the absolute leaders in analog amplifier hybrid modules for many AV markets and possesses core competencies in cost-efficient mass-production, distribution and sales. The contract allows Sanyo to use ICEpower technology in its design of amplifier chips for both analog and digital platforms, and assures ICEpower a per unit sold royalty rate. The process of transforming the technological know-how from ICEpower into Sanyo's chip design and production processes has proven highly resource demanding and complex, with the first mass-produced chips scheduled for launch in 2004.

ICEpower is currently expanding its scope of focus from the amplifier per se to the entire audio power conversion chain. This reflects the belief in huge efficiency gains and the potential to create a more simple and integrated "black box" solution for audio conversion that OEMS could easily integrate into their products. In this respect, ICEpower is attempting to become a more broad-based technology provider.

Whether OEMs opt for digital amplifiers based on integrated or discrete components they will still need to design (or let others design) the circuitry around the core components of the amplifier in order to obtain full amplification functionalities and compatibility with the AV systems in which they are integrated. To design a full amplifier module rather than just the amplifier components requires capabilities in fields such as signal modulation, electro magnetic compatibility (EMC), error correction and electric power engineering, and competencies in optimizing and integrating the components associated with the new technology. These fairly complex system integration capabilities are very different from and complementary to the capabilities underlying the digital amplifier. ICEpower was early on pioneering full modules based on discrete components. These modules are especially targeted at smaller OEMs in the high-end markets, firms with no incentives or capabilities for providing such system integration themselves. What may be more surprising in this context is that large AV customers operating in the mid- to low-end markets are also increasingly expecting their chip-based amplifier suppliers to be *system providers*, not simply chips providers.[28] This has significantly raised the level of knowledge and system integration capabilities needed for chip-based players to leverage their positions in the market. Several of the providers of amplifier chips (e.g. TI, Tripath and STMicroelectronics) have responded by moving towards designing and offering modules (reference designs), or in other words, by offering their customers systems knowledge and IP in order to make them buy their chips.

In conclusion, after the early breakthrough years in the mid to late 1990s, two very different product-market strategies have proliferated among specialized suppliers of digital amplification technology: chip-based solutions for the mid- to low-end mass markets and discrete component-based solutions for the high-end small-volume markets. Both categories of suppliers have witnessed increased requirements from their OEM customers for integrated module solutions. By implication, OEMs opting for such solutions in reality choose to outsource not only the amplifier component but also parts of their system integration tasks. For the specialized suppliers this has the added advantage that OEMs will experience significantly higher costs should they wish to revert back to in-house amplifier development.[29] On the other hand, the OEM customers seem to have

been able to obtain module solutions from their suppliers that minimize their costs of switching between different suppliers. But let us now take a more systematic look at the incumbents' response to the challenges of digital amplification.

6. The incumbents' response

In the late 1990s, when the technological breakthrough in digital amplification became evident in both university research and business venturing, there were good reasons to expect that the large AV incumbents would aggressively try to take control over this new technology. Basically the mental model of these incumbents was one of vertical integration and control over new critical technologies. The conventional amplifier represented a critical module in any AV product,[30] hence to give up on the new amplifier paradigm would not only imply the loss of control over a critical technology module, but also the loss of a potentially large source of revenue and profits.

However, when explaining the generally slow response by AV incumbents to this new challenge, we will have to acknowledge the role of forces nullifying or modifying such strategic and economic incentives. Below we shall consider the relative significance of four lock-in mechanisms for explaining the response patterns among different categories of incumbents to the challenges of digital amplification. These mechanisms are associated with cognitive gaps, with internal stakeholder dispositions, with corporate customer demand, and finally with established systems architectures and consumer preferences.

Many innovation studies have found that new entrants are more likely to introduce radical or disruptive innovations than incumbents and often explanations revolve around difficulties of bridging the cognitive gaps between the old and the new technology.[31] Digital sound amplification builds on a set of technological disciplines in which A/B amplifier incumbents in the AV industry have no or little prior knowledge. Despite the fact that A/B and Class D amplifiers share some components, such as power supplies, filters and semiconductors, the knowledge underlying their respective core components and systemic interdependencies differ in fundamental ways. Thus, all incumbents were, at

least to some extent, locked into an engineering skill base specialized in the conventional amplification technology. So, in spite of some technological heredity[32] in peripheral parts of the amplifier, this new technology reflects a radical competence-destroying discontinuity signifying a substantial cognitive barrier.[33]

Even if this cognitive gap per se has not proven to be an insurmountable barrier for large incumbents, it is likely to have been further reinforced by a second lock-in mechanism associated with internal stakeholder interests. Thus, agents representing R&D and production engineering related to the 'old paradigm' are inclined to resist a new paradigm that threatens to erode their power base. This stakeholder position may be perfectly rational at the shorter term if the old technology is still competitive vis-à-vis the new, but in their judgments for the longer term such stakeholders will tend to overestimate the performance prospects for the old technology and underestimate the prospects for the new, due to a combination of vested stakeholder interest and asymmetric information. Combined, these lock-in mechanisms can explain why incumbents generally were slow-movers as compared to the pioneers not suffering from these lock-in mechanisms. Furthermore, when these mechanisms operate in large and dominant companies they may be reflected in the well-known NIH (Not Invented Here) syndrome and the excessive belief that "our engineers" are superior in any respect. Jim Shanahan, founder and VP of Marketing in Jam Technologies, a small IP digital amplifier entrant, told us that according to his experience with the OEMs their attitude is "if you can do it, we can do it better, because we are (fill in company name here.)"

While the first two lock-in mechanisms apply to any corporate context, the third and the fourth lock-in mechanism only apply to vertically integrated companies such as Philips, Matsushita and Sony with distinctive component and end-product divisions. In such a context component divisions tend to be constrained by the captive markets of the product divisions who in turn are more or less free to decide whether or not to buy new components offered by the component division. The third lock-in mechanism reflects the situation where a product division chose not to adopt a new component offered by the component division, either because the corporate customer considers the old technology

still to be competitive or because it prefers other solutions available in the market place. In such a situation the internal corporate customer may block the dynamic learning processes with respect to the new technology in the component division. In contrast, "pure play" component providers are open to pursue any market potentials they may find, for instance in the exclusive high-end niches, and thereby gain invaluable learning experience on which to base further improvements of the technology, and eventually move down into the high-volume markets.

The fourth lock-in mechanism may sometimes be difficult to distinguish from the third. It relates to the inertia mechanisms associated with the "perfect match" between the old technology and ingrained system architectures and their underlying organizational routines[34], a lock-in that is reinforced by major consumer segments being unwilling to adopt new and unfamiliar architectures.[35] Thus, in for instance home stereo markets large consumer segments have for long remained faithful to the familiar architectures that include a heavy A/B amplifier box that signals solid quality and is perceived as the natural heart of home AV products.

Figure 3 shows the major providers of analog A/B amplifiers and their strategic response to the challenges of digital amplification. These are the companies with both the strongest incentives to jump unto the new paradigm and the most powerful internal stakeholders in favor of the old paradigm.

Figure 3. The responses of the dominant players in conventional A/B amplification technology to the challenge of switched amplification technology.

Dominant firms in A/B amplifier technology	**Strategic response to Digital amplification technology**
Specialized semiconductor companies	
National Semiconductor	→ Slow response – few products
STMicroelectronics	→ - Licensee agreement and cooperation with Apogee - Production contract with Tripath
Texas Instruments	→ Acquisition of Toccata/production of chips
AV OEMs	
Philips	→ Early development of internal technology – few products
Sanyo	→ Slow response - licensing agreement with ICEpower
Toshiba	→ No digital amplification technology

Source: The information is provided by the companies' Web sites supplemented by the judgments of our interviewees (see Appendix).

Three of the companies are specialized semiconductor companies, and two of these, STMicroelectronics and Texas Instruments, have today, through engagements with small specialized suppliers of digital amplification technology, established powerful positions in the chip-based digital amplification market. STMicroelectronics, especially through a technology licensing agreement signed in 2001 with Apogee, and Texas Instruments - as previously mentioned - through the acquisition in 2000 of Toccata. National Semiconductor has been very slow moving and has only been out with Class D solutions at the lower power levels (e.g. for earphones).

The other three companies in Figure 3 are consumer electronics giants with large in-house component portfolios. Philips quite early on developed its own digital amplification technology, but has not so far demonstrated a strong commitment to integrate the new technology in its products. Philips has clearly demonstrated its R&D capacities in the field and possesses the competencies in both power and front-end technologies needed to become an important player in the digital amplifier market, but lock-in problems associated both with the alignment between the component provider and its corporate customers in the product divisions, and with the conservative bias associated with well-established product architectures and their loyal consumers, may explain the less successful implementation hitherto.

Sanyo combines a strong position in traditional analog amplifier and chip production with a position as large AV OEM. In its amplifier business Sanyo has shown a dedicated commitment to ongoing optimization of its conventional module technology and manufacturing capabilities. Thus, when the paradigmatic shift in sound amplification emerged, Sanyo was ill prepared from both a cognitive and stakeholder perspective. However, the previously mentioned licensing agreement from 2002 with ICEpower gives Sanyo the opportunity to combine ICEpower's technology with Sanyo’s chip manufacturing and miniaturization capabilities and distribution network. The downside for Sanyo is that ICEpower (at least so far) controls the new technology and that Sanyo will have to pay a royalty for each amplifier chip sold. Sanyo combines a slow response with an active catch-up effort based on external technology. The slow response seems to

stem from the cost-efficient and well-established product architecture and market preferences rather than to the particular captive market constraints.

Toshiba, which is operating in the low-price end of the AV markets, has not yet faced any competitive threat from digital amplification technology, and has also not demonstrated an active stance in the transition from traditional A/B technology to digital technology. Also in this case the lock-in mechanisms associated with both corporate customer demand and conservative consumer preferences seem to explain the path-dependency of a major incumbent.

Figure 4 shows how large AV OEMs without a particularly strong position in A/B amplification have responded to the digital amplifier. On the one hand, these players have no strong stakeholder interests embedded in conventional amplification assets. On the other hand, their incentives to engage in strong in-house development are likely to be lower than those of the players with strong positions in A/B technology. This is also reflected in the dominant pattern of Figure 3. Only Sony has successfully developed its own proprietary digital amplifier module, the so-called S-master technology, which seems more or less dedicated to its captive product markets in order to seek differentiation gains. However, the core component of this module, the amplifier chips, was from the early start provided by Mitsubishi and more recently by Texas Instruments. Sharp has been less successful with its 1-bit technology which has so far been implemented in few products and small volumes. The other three companies, Matsushita, Samsung and LG Electronics have adopted external solutions from specialized suppliers.

Figure 4. The response of AV OEMs without a dominant position in A/B amplification technology to the challenge of switched amplification technology

Large AV OEMs without a dominant position in A/B amplifier technology	Strategic response to switched amplification technology
LG Electronics →	External technology – e.g. Pulsus, Neofidelity
Matsushita →	External technology – e.g. Texas Instruments, Tripath
Samsung →	External technology – e.g. Texas Instruments, ICEpower
Sharp →	Internal 1-bit technology –few products
Sony →	Internal module – external chips

Source: The information is provided by the companies' Web sites supplemented by the judgments of our interviewees (see Appendix).

It seems clear from the analysis above that the two "universal" lock-in mechanisms (cognitive gaps and vested stakeholder dispositions) fail to explain the differential response to the new technology from different categories of incumbents. The fact that vertically integrated AV incumbents have been slower and less successful in pursuing the opportunities from digital amplification than the "pure play" semiconductor incumbents (STMicroelectronics and TI) points to the particular importance of the lock-in mechanisms pertinent to the vertically integrated AV companies, one associated with short-term corporate customer (or product divisional) preferences and the other with ingrained organizational routines and consumer preferences for well-established product architectures.

Lifting the level of analysis from the particular case at hand to the overall contextual dynamics of consumer electronics, yet another factor becomes visible. The vast expansion of the AV consumer electronic product domain and technological opportunity set in recent years has created a new agenda increasingly forcing the AV giants to carefully *prioritize* which new technologies and components to invest in and which to leave to others. In contrast to the situation ten years ago, consumer electronic incumbents

can no longer afford to develop all technologies internally. In this new competitive context AV OEMs seem to have bet their money on high growth products/technologies with possibilities for pushing performance and adding extra functions valued by their mass market consumers. Products such as flat screen TVs, DVDs, MP3 players, home theatre systems and the rapidly emerging group of digital convergence products, not the more mature products and components categories. Despite the new technology the amplifier is still considered a mature component or module that cannot provide the AV OEMs large new growth opportunities nor a clear competitive edge.

7. Conclusion

In contrast to other parts of the electronics sector (as well as many other industries) the AV industry has up till now remained remarkably reluctant to jump onto the wave of vertical disintegration involving outsourcing of the systems assembling, R&D and manufacturing of components and modules. This reluctance may to a large extent be ascribed to path-dependencies of the 'vertical integration' model successfully pursued by the Japanese companies such as Sony and Matsushita in the 1970s, 1980s and into the 1990s.

The path-dependency factor can be translated into some difficult strategic trade-off dilemmas. First, the trade-off between the perhaps decreasing advantages of maintaining control over manufacturing in order to assure optimal coordination between product and process development versus the increasing cost advantages that dedicated manufacturers (ODMs and EMS providers) have demonstrated in large-scale production. The increasingly tough price-competition in most AV mass markets seems currently to drive AV OEMS towards short-term return-on-asset considerations and into more comprehensive outsourcing of assembling and manufacturing processes. Secondly, the dilemma between the advantages of maintaining technological lead positions based on in-house R&D associated with a large component portfolio, versus acknowledging that specialized suppliers of technology and components in many areas tend to conquer the cutting-edge of technological innovation in consumer electronics.

However, it is likely more than path dependency that has made the large AV OEMs reluctant to disintegrate and outsource. Companies like Philips and Sony have better profitability on their semiconductors and other critical components than on most of their AV end-products, giving them an incentive to try to maintain strong positions in these component markets. However, the problem for the leading AV OEMs is that the AV product markets have witnessed cascading penetration of new technologies primarily originating in the neighboring information and computer industries. This means that the "natural" initiative has tended increasingly to slide from inside to outside the AV OEMs' domain, leaving them with the difficult choice of either embarking on the risky task of trying to catch up with little hope of being able to leapfrog, or to choose the "low-cost" and/or best performing solution and outsource. This "outside-in" invasion of technologies and components has furthermore been associated with a tendency, also originating from the information and computer industries, towards using modular systems based on standard interfaces giving the AV OEMs decreasing scope for building proprietary components and systems that can keep competitors at bay.

The case presented in this paper on the transition from conventional to digital amplification clearly illustrates this broader pattern. It points to the critical role that pioneering small specialized component or technology suppliers can play in interaction with small medium- and high-end AV OEMs (like Bang & Olufsen and Kiss Technology) and large-scale component providers (like STMicroelectronics and TI) in setting the agenda for the next generation AV amplification technology. We do not try to argue that the large AV OEMs are not able to integrate this technology - they clearly are. What we do maintain, however, is that increasing shares of the unique technological competencies underlying the current transformation of AV product markets are located outside the natural domains of most of the AV incumbents and that the Japanese Model of the 1970s and 1980s is being replaced by a much more globally integrated network model in which in particular European and American firms (specialized suppliers, large-scale component providers, and EMS providers) and new Chinese/Asian players (ODMs) have demonstrated increasingly strong positions. To what extent and for how long the Japanese Model can live on within the AV product markets on the basis of a) powerful

competencies in system integration and the building of product and technology standards b) strong branding and marketing competencies added c) cutting-edge positions in a decreasing number of critical component areas, will be left to be seen. One thing, however, seems quite sure: the heydays of the classical Japanese Model, based on vertical control and powerful integration of product development and flexible production systems, are long gone. The current strong strategic focus of the large AV OEMs on convergence products may not only reflect new technological opportunities for interlinking user functionalities from different industries and product markets (e.g. telecom, computer and networking), but also the struggle to find new business opportunities outside the hard-pressured traditional core areas of AV consumer electronics. But it is a tough struggle dominated by two previously thriving industries, the PC and the consumer electronics industry, whose leading players are now desperate to make inroads into the other party's backyard.

Appendix: List of interviewees

- Michael A.E. Andersen, Professor, Technical University of Denmark (interviewed 28/10-2003).
- Niels Anderskouv, Vice President of Digital Audio & Video, Texas Instruments (interviewed 19/12-2003).
- Lars Michael Fenger, Research and Technology Access Engineer, Bang & Olufsen ICEpower (interviewed 9/9-2003).
- Karsten Nielsen, founder and Chief Technical Officer, Bang & Olufsen ICEpower (interviewed 12/11-2003).
- Steen Klint Pedersen, Global Sales Manager, Bang & Olufsen ICE power (interviewed 9/4-2002).
- Poul Præstgaard, Senior Technology and Innovation Manager, Bang & Olufsen (interviewed 21/10-2003).
- Lars Risbo, founder of Toccata and Strategic Research Manager, Digital Audio & Video, Texas Instruments (interviewed 6/10-2003).
- Jim Shanahan, founder of and VP of Marketing in Jam Technologies (correspondence via e-mail, April 2004).

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[3] *Dieter Ernst, Digital Information Systems and Global Flagship Networks: How Mobile is Knowledge in the Global Network Economy, in: Jens Frøslev Christensen and Peter Maskell (eds.): The Industrial Dynamics of the New Digital Economy, Cheltenham, (UK: Edward Elgar, 2003)*

[4] *Page 1 in Michael Hobday, Andrea Prencipe, and Andrew Davies, Introduction, in: Andrea Prencipe, Andrew Davies, and Mike Hobday (Eds.): The Business of Systems Integration (Oxford: Oxford University Press, 2003)*

[5] *Wintelism is a code word created by linking the names of Microsoft Windows and Intel that are the two main symbols of this shift in competitive strategy. See Michael Borrus and John. Zysman, "Globalization with Borders: The Rise of Wintelism as the Future of Global Competition," Industry and Innovation, 4, (1997): 141-67*

[6] *Susan W. Sanderson, The Consumer Electronics Industry And the Future Of American Manufacturing (Washington, DC: Economic Policy Institute, 1989)*

[7] *See for instance David B. Yoffie (ed.), Competing in the Age of Digital Convergence (Boston: Harvard Business School Press, 1997); Nils Stieglitz, Digital Dynamics and Types of Industry Convergence: The Evolution of the Handheld Computer Market, in: Jens Frøslev Christensen and Peter Maskell (eds.): The Industrial Dynamics of the New Digital Economy, (Cheltenham, UK: Edward Elgar, 2003)*

[8] *Recently American players, e.g. Dell, HP and Gateway, have entered the consumer electronics industry. As the leading PC vendor, Dell's entrance reflects the convergence between the two industries. Broadly*

stated, Dell's success in computers reflects its ability in sales and marketing to conceive the computer as a consumer electronics product.

[9] American companies are, however, represented in certain niches in the high-end markets, for example Jeff Rowland Design Groups. Moreover, American computer peripherals providers such as Logitech and Creative have launched increasingly advanced sound systems (both soundcards and loudspeakers) for PCs and DVD players. Even if the market share of these products is still very small as compared to the traditional AV OEMs' surround sound equipment, the digital convergence dynamics that these products reflect, may very well signal a revival of American business in the AV industry. See Michael Borrus and John. Zysman, op. cit.; Susan W. Sanderson, op. cit.; Steven Klepper and Kenneth L. Simons, "Dominance by Birthright: Entry of Prior Radio Producers and Competitive Ramfications in the U.S. Television Receiver Industry," Strategic Management Journal, 21/10-11, (October – November, 2000): 997-1016; Alfred D. Chandler Jr., Inventing the Electronic Century. The Epic Story of the Consumer Electronics and Computer Industries (New York, NY: The Free Press, 2001)

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[17] Philips' full year net income for 2003 of EUR 695 millions was primarily due to cost saving and higher income from semiconductors and LCD panels, see Philips, Philips annual rapport 2003, Philips 2004; WestLB Panmure, "Koninklijeke Philips Electronics N.V. / Thomson SA," WestLB Panmure, 2004

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[19] http://www.wikipedia.org/wiki/Vaccuum_tube and http://www.ieee.org/organizations/history_center/legacies/deforest.html

[20] http://uv201.com/Tube_Pages/deforest_audion.htm

[21] Ernst Braun and Stuart MacDonald, Revolution in Miniature. The history and impact of semiconductor electronics, Second edition (Cambridge: Cambridge University Press, 1982)

[22] http://www.vac-amps.com/page0030.html

[23] However, to simplify the presentation we shall henceforth use the terms switched and digital amplification interchangeably for both forms of Class D amplification.

[24] Rodman & Renshaw, "Tripath Technology, Media Technology, Market Outperform/Speculative Risk, New Coverage, 2003

[25] This and the following section is primarily based on interviews with the central agents involved in the Danish cluster of innovation within digital amplification. Se Appendix for a list of interviewees.

[26] Just prior to TI's early contacts with Toccata Technology, TI had build a strong position in catalog analog semiconductors for power management through the acquisitions of Unitrode, a major supplier of power management components, and Power Trends, a leading supplier in the fast-growing market for

point-of-use power solutions. (http://www.ti.com/corp/docs/press/company/1999/c99041.shtml, http://www.ti.com/corp/docs/press/company/1999/c99055.shtml).

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[28] Delivering fully designed systems to the customers, and not simply chips, is a general trend in the semiconductor industry – a consequence of the emergence of the ODMs (see figure 1) and the overall need for lowering time-to-market.

[29] This is a highly dynamic technological field that is most likely subject to 'time compression diseconomies' implying that a company cannot quickly replenish its knowledge pool on how to develop and produce for example amplifiers if this knowledge has once been outsourced and lost, see Ingemar Dierick and Karel Cool, "Asset Stock Accumulation and Sustainability of Competitive Advantages, " Management Science, 35/12, (December 1989): 1504-11

[30] The amplifier module would typically account for about 20-30% of the total sales price of a traditional home stereo system.

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