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The decision to make or buy a critical technology: semiconductors at Ericsson, 1980–2010

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This article considers the decisions to outsource and re-integrate the development of critical and innovative technologies. It documents a historical sequence of choices made by strategists within a high-tech company, Ericsson. The evidence discussed indicates that a broad range of different factors were taken into consideration and that the influential people made a point of running different kinds approaches to outsourcing in parallel. Re-integration occurred when the structures put in place by collaborating firms did not sustain innovation.

1. Introduction

Influential students of the rise of the modern corporation such as Edith Penrose (Penrose, 1959) and Alfred Chandler (1962, 1990) have attributed the growth of industrial corporations to the organized pursuit of innovation within the firm, including synergies across corporate divisions. Mainly drawing on the experience of the large US manufacturing corporations, Chandler viewed this growth as a process of creating new lines of business from the corporations existing resources. Chandler (1962) characterized this type of growth in terms of economies of scope derived from multidivisional organizational structures of the large vertically integrated corporation. Economies of scope and scale were interrelated: the economies of scope built on scale achieved through vertical integration of production and distribution. Penrose conceptualized this process as teams that engage in collective

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exploration of how to make new use of the corporation's resources (Penrose, 1959). As they expanded, the multidivisional firms diversified into new lines of business, requiring investments in organizational capabilities to generate and gain from innovation. Chandler's insight was that innovation is collective and, hence, organizational (Lazonick 1991, and in this volume; Jones 2008).

Business strategy scholars have, since the mid 1970s, followed this lead by emphasizing the links between related diversification and industrial growth (Rumelt, 1974; Rumelt, 1982; Montgomery, 1994; Teece *et al.*, 1997). In attempting at providing a more general explanation, Kogut and Zander (1992) argued that it is difficult to succeed in conducting certain activities involving mainly un-codified knowledge without shared language, norms, and routines within a business organization. Indeed, the searchlight was directed towards innovative capabilities of the integrated firm.

This view differs radically from the widespread idea that vertical integration can, by and large, be seen as a strategic response by mass-manufacturing firms to avoid the threat of being exposed to opportunistic behaviors and outright hold-ups inherent in co-specialization of the lead-manufacturer's and supplier's production investments. According to Oliver Williamson's well-known ideas, mass-manufacturers become exposed to the risk of hold-up because their *continued operations* build on a steady flow of specific inputs from unique suppliers. Once the mass-manufacturer invests in product-specific production tools, and tries to induce a particular supplier to make matching specific investments, the relationships shift in favor of the supplier. To get out of this type asymmetric relationship, Williamson argues, mass-manufacturers favor vertical integration because it places all critical assets under the control of a single corporation. (Williamson, 1975, 1979, 1998)

Since the late 1970s, there has been considerable debate about how and to what extent industrialists have developed alternative strategies to grow business enterprise. Producers, it is argued, cannot be self-reliant autocrats presupposing that they can maintain their innovative capacity in all the different areas of expertise and new emerging technologies required to compete successfully in multi-technology competition. Firms have to be open and inclusive, building strategic alliances along the lines of what has been called 'open innovation' (Chesbrough, 2006, 2006). Seeking innovative partnerships, firms are developing new and innovative forms of organizational solutions for decentralized innovation (Piore and Sabel, 1984; Borrus and Zysman, 1997; Helper *et al.*, 2000; Lamoreaux *et al.*, 2001; Sturgeon, 2002; Gawer and Cusumano, 2002; Zeitlin and Whitford, 2004).

From this perspective, the new firms will be different from the 'Chandlerian firm' along several dimensions. Contemporary observers see the new economy as a shift away from coordination by managerial hierarchies in vertically integrated firms toward coordination through long-term relationships. Corporations are increasingly electing to acquire by contract components that in the past they would have made themselves. Put differently, instead of vertical integration, we observe vertical specialization in a significant number of industries. The fear of hold-up seems now to be overshadowed by the fear of not having access to the broadest possible array of new technologies through external suppliers.

While there has been a focus on collaborative learning across the boundary of the firms in decentralized supplier networks (Helper *et al.*, 2000), an extensive literature links the withering of the vertically integrated firm to the introduction of modularization—that is, through the separation of learning tasks as opposed the integration of learning (Baldwin and Clark, 2000; Simon, 1962; Langlois and Robertson, 1995; Henderson and Clark, 1990; Garud and Kumaraswamy, 1995). In his recent examination of the "post-Chandler" corporation, Richard Langlois (2003) argues that break-through advances in communications and information technologies along with the creation of stable technical interfaces and more "modular" product and process technologies have laid the groundwork for the "vanishing" of Chandler's "visible hand" in several industries.

The basic claim is that the break-up of corporations occurs because technologies can be developed in well-defined units that can be seamlessly combined with each other at practically zero-cost into novel product offerings. The hypothesis is that innovation becomes like a Lego-toy system, consisting of defined parts, or modules, that fit together through highly specified interfaces. As such, interfaces (or standards) specify how the parts interact technologically with a given product architecture: "The key unit of analysis is...," as Christensen *et al.* (2002) put it "...the interface at which a supplier of a added-value and a customer of that added-value interact—whether or not that interface is within or between organizations. It is within that interface that structured or unstructured dialogue occurs" (p. 958). Because coordination is by markets, new terms of competition have distributed the power to direct the course of innovation across firms to the extent that modularity has become leaderless.

1.1 Understanding re-integration

As demonstrated by recent developments, the world of industry may behave differently. There is no denial in the trend towards organizational decentralization through outsourcing of innovation as well as manufacturing into global value chains (e.g. Gereffi and Korzeniewicz, 1994; Gereffi *et al.*, 2005), but there is also evidence that firms are re-integrating previously outsourced activities. There is evidence of re-integration. A widely discussed case is, of course IBM, which famously tried, after having created the conditions for the rise of specialized component manufacturing by introducing the open PC system architecture, to vertically re-integrate operations by taking control of the development of the operating PC/2. By 2005, Sony Ericsson re-integrated manufacturing operations that were put out to contract manufacturers (Glimstedt and Lindoff, 2007). Apple Computer agreed in 2008 to purchase P.A. Semi, the fables chip firm, for $278 million. PA Semi provided Apple with a skill base in sophisticated, low-power chips for future models, such as the internally developed A4–chip for Apple's much discussed iPad. These were just three quick examples.

Why do firms re-integrate in the midst of the general trends towards organizational decentralization? Is it because they have re-discovered the risk of hold-up, or is it because the various organizational solutions for decentralized engineering do not work at all times? This is the general question addressed in this article. The work of both Christensen (2002) and Chesbrough (2006) demonstrate that modular production has only been feasible in the presence of quite stable technologies. From this perspective, re-integration of operations may be caused by what Chesbrough has described as a "modularity trap". Specialized firms are too 'paranoid' to stick to a singular product architecture because they do not want to be stuck with a low-performing standard when competitors introduce a superior standard. Glimstedt (2001) shows that telecom equipment vendors firms, rather than locking themselves into a single standard, promote family of standards relatively open long term evolutionary technology paths. Sabel and Zeitlin (2004) extends this argument by pointing out the technological and organizational limits to modularity.

Cacciatori and Jacobides (2005) provide a different perspective. Drawing on institutional sociological perspectives (e.g. Whitley, 1992, 1999), they investigate the rise and institutionalization of integrated one-stop-shopping solutions in the previously vertically specialized construction business. Re-integration was driven by different firms seeking to establish a stronger position in the value chain at a point when the existing institutional framework was breaking up. Attempts to protect their professional domain from commoditization and to leverage their craft/knowledge bases, construction firms take the lead in bundling previously separate activities into an integrated construction offer. The ability to integrate then becomes a higher value-added activity.

In a similar vein, Macher and Mowery (2004) deploy the concept of commoditization within the value chain to account for re-integration in high-tech industries (semiconductors, biotech and computers). Impulses for re-integration, they argue, occur when vertical specialization has commoditized specific activities within the value chain and entry increases. Motivated by the fear of being commoditized by other actors within the same value chain, the most capable firms shift strategy towards complex system integration services. Like IBM in the 1990s, these firms start to exploit their previously vertically specialized structure by expanding their activities in the area of custom software and system integration solutions (p. 346).

A common theme for these writers is the notion of a plausible cyclical relationship between vertical specialization and re-integration. In the case of Chesbrough, the relationship is cyclical; Producers specialize re-integrate to re-define architecture and explore new technologies when the existing architecture matures and new architectures building on vastly improved technologies appear on the horizon (Chesbrough, 2006). Macher and Mowery share with Cacciatore and Jacobides the notion that the relationship between vertical specialization and re-integration is primarily a matter of maturing business models; firms re-integrate not so much to create conditions for exploring new skill bases as to protect their existing skill bases and their positions in the value chain relative to other professions and actors within the same value chain.

These ideas are moving quite distinctly in a direction away from transaction cost theory, which is seen as too static and, furthermore, being built on "... textbook images of products, whereby vertical integration is a simple choice of one of the producers which can select to integrate..." and thereby also lacking a understanding of informal, or formal and contractual, arrangements designed to support decentralized collaboration between firms (Cacciatori and Jacobides, 2005).

1.2 Outline of the argument and theoretical contribution

While this article extends the criticism of transaction cost theory as the sole explanation of how the boundaries between manufacturers and suppliers are drawn, it paints an alternative view concerning the drivers of re-integration: rather than being associated with older and soon to be phased out products, integration may also be closely linked to the need to exercise control over the innovation in new products, particularly at the point when the products are complex and there are uncertainties also in the area of infrastructure put in place to sustain decentralized innovation. When that organizational and technical infrastructure provides insufficient support for the decentralized innovation process, then there is a case for re-integration. Put differently: firms re-integrate not only to control the development of old products, but also to control innovation in new products. A second related, and equally important, finding is that corporations within rapidly changing high-tech industries tend to keep their outsourcing arrangements flexible in order to be able to adapt to new challenges in terms of changing technologies and markets. Whether high-tech firms make or buy is a complex issue that cannot be resolved by only looking at one dimension. When technologies and markets are uncertain, there is little consensus about what constitutes an ideal outsourcing relationship (Glimstedt and Zander, 2003; Herrigel, 2004).

For the reasons cited above, our hypothesis is that outsourcing arrangements within the context of high-tech innovative enterprise are characterized by changes regarding:

(i) the depth (i.e. the degree to which the design and manufacturing processes are outsourced),
(ii) the nature of the collaboration (i.e. the degree of modularization with respect to the handover between internal and external processes), and
(iii) the complexity (i.e. the degree to which the corporation implements different kinds of co-existing outsourcing arrangements in parallel).

Particularly, innovative corporations in rapidly developing multi-technology product markets cannot be too certain about the merits of a particular kind of outsourcing arrangement for the simple reason that they cannot be certain about either the technological mix of the *next* product, or the design problems and the need exercise to control over the learning process. Therefore, multi-technology firms are known to hedge rather than make definitive choices between types of collaborative supplier relationships.

On this view, different organizational paradigms may co-exist not just due to different forms of "organizational inertia" (Hannan and Freeman, 1984), but also because of strategic actors fear of losing the dynamic capabilities associated with a certain practice. Rather than being regarded as old or new routines, different organizational solutions become, in this view, co-existing options on a menu from which to select.

To test this hypothesis, and to refine the underlying ideas, this article introduces a historical analysis of outsourcing and re-integration of innovation in semiconductor technologies between 1980 and 2010 at L.M Ericsson, Sweden's global competitor in communication technologies. Semiconductor technology is an important empirical case for the simple reason that it developed rapidly through the entire period, posing constantly new challenges for the implementation in high-tech products. In addition, the demand for finding high-performance solutions is relatively high (compared to, say, personal computers), resulting in need to adapt semiconductor technologies to telecom system requirements.

1.3 A brief overview of the case

The telecommunications company L.M. Ericsson (Ericsson hereafter) belongs to the cohort of Swedish engineering-based corporations that successfully internationalized their operations already around the late 19th century. By the 1920s, Ericsson was established as one of the leading actors in telecom switching systems. In the post-1945 period, the company grew by diversifying into a series of related technologies. Among those were wireless and defence products. From the mid-1960s and onwards, the company made efforts to innovate in digital and computerized switch systems as well as in wireless mobile phone systems, including mobile phones.

From the early 1970s Ericsson allied strategically with mainly US-based semiconductor vendors, such as Advanced Micro Devices (AMD) and Texas Instruments (TI), for the purpose of building internal semiconductor design and manufacturing capabilities through technology transfer. In exchange, the strategic outsourcing partner received orders for the semiconductors that Ericsson did not choose to develop and/or manufacture internally. By the early 1990s, Ericsson had provided itself, through the alliance external partners/suppliers, with the capabilities to both develop and manufacture the most sophisticated chips needed.

One could say that Ericsson, by the mid-1990s, was running an internal "fabless" semiconductor design house with a somewhat limited integrated manufacturing arm for early prototype and small batch production runs. In addition, Ericsson had implemented a structured design and manufacturing flow, which implied certain cut-off points between the main tasks within the design flow, i.e. between what is called chip conceptualization, front-end, and back-end design. Having implemented this type of structured flow, which in turn built pre-defined interfaces and computerized design tools, Ericsson was in the position to differentiate and experiment its approaches to outsourcing of semiconductor design.

For its mobile phones, Ericsson mostly was responsible mostly for conceptualization and parts of the front-end design for so-called main processors, leaving the rest of design and manufacturing to TI, and other secondary outsourcing partners such as Philips. Yet, the company decided to develop both front-end design and back-end design for a particular mobile baseband chip to be manufactured by regular contract chip manufacturers in Taiwan.

On what grounds and to what extent, then, did Ericsson choose to outsource chip design and/or chip manufacturing of internally designed chips?

By analyzing outsourcing decisions for an array of different kinds of semiconductors, we find that there was no singular formula applied. Rather, outsourcing was tied to different kinds of risks, such the risk of not being able to match system requirements with chip design closely enough, risk associated with the technical inadequacy of interfaces, risk of not differentiating products enough, and risk of leaking valuable algorithms to competitors via the supplier.

These risks were seen as considerable, resulting in a restrictive, if not a negative, view on outsourcing of semiconductor design throughout the 1990s. Hence, going against the general trends towards increasing outsourcing, Ericsson developed advanced modular design techniques to be able to integrate pre-defined functional blocks (or IP-blocks). In addition, Ericsson sought to find ways to de-couple the construction of IP-blocks from specific semiconductor architectures. These investments in modular technologies were at the outset not made to facilitate outsourcing. Rather, they aimed at creating efficient alternatives to outsourcing.

As a consequence of the crises in the early 2000s, Ericsson moved to restructure its semiconductor operations. The manufacturing facilities were sold to Infineon (Siemens). This deal also implied that Ericsson stripped the major part of its resources in back-end design, which were closely integrated with the manufacturing operations. Ericsson nevertheless kept some minor back-end design teams located within the product design units. For the future, Ericsson aimed at maintaining close ties between front-end design and product designers by embedding front-end design units within the product divisions.

Was this a move in preparation for a more general downgrading the design capabilities, shifting out also the bulk of the design activities to suppliers like ST-Microelectronics and TI? Despite the financial pressures during the 2002–2004 period, Ericsson kept the control of development of vital semiconductor constructions internal to be able to differentiate their design from the competition. The company's semiconductor experts nevertheless kept reviewing external alternatives and used external design resources as "hedging bets" when there were uncertainties.

Further adding to vertical integration in the period 2000–2009, technical outsourcing became a perennial problem in mobile chip design, leading to the decision to vertically re-integrate mobile semiconductor design. The final section of the article thus analyses Ericsson's current move to integrate its mobile platforms operations (EMP) with Europe's leading semiconductor vendors (ST-Microelectronics and NXP) into a vertically integrated player. The main finding of this section is that Ericsson, after having experienced serious technical troubles with outsourcing of chip manufacture, saw no alternative but a rushed re-integration to gain control over the design process.

2. Ericsson's experience in semiconductors, 1980–2009

Within the world of telecommunications equipment, digital switching gained in importance with Alcatel's revolutionary digital switch (E 100), introduced in 1964. Even if conventional electromechanical switching technology continued to dominate the market until well into the 1970s, the technological landscape of telecommunications was in transformation. All actors in the market—that is, both national monopolies and private telecom equipment vendors—started to dedicate more resources to the building of new capabilities in computer system design, hardware based on semi-conductors and software programming.

The change from conventional electro-mechanical switches to digital switches was driven by engineering. From the 1980s and onwards, the deregulation and privatization of the telecom sector kicked-in. From that point and onwards, competition in both cost and new value-added services underpinned the technological change in the telecommunication sector.

The development of semiconductors became critical to the development of telecommunications technology. In sharp contrast to many computer manufacturers, who relied on chip vendors like TI for their semiconductor components, practically all major competitors in telecommunications equipment invested in the capability to both design and manufacture semiconductor components.

There were particular reasons for making investments in integrated circuits (ICs). The ICs developed by the chips vendors, such as Intel, were general devices and not well adapted to the specific needs of telecommunications. They worked well for computers, but did not meet the much higher system requirements of telecom systems. Also, designing ICs required close cooperation between system design, IC design and manufacturing. Hence, telecom equipment manufacturers needed to build internal competence in IC design as well as in IC manufacturing (Steinmuller and Langlois, 1999).

What was the significance of these investments? In the longer term, the wireless revolution created a demand for stronger "engines" in both wireless systems and mobile phones. So to forego investment in semiconductor capabilities was originally not an option for global competitors in the telecommunications industry. Nevertheless, there are two especially interesting points which merit our attention.

First, designing and manufacturing *custom* IC was a rapidly changing practice. Two of Bell Lab's hardware experts, Ashoka Mody and David Wheeler (1986), reported in 1986 on the six major trends in the semiconductor industry:

1. Powerful 32-bit mainframe processors were widely available.
2. Both Japanese and American manufacturers were now mastering advanced programmable digital signal processors, which promised to be more suitable for real times systems (e.g. telecommunications) than mainframe microprocessors
3. New processes, such as C-MOS, were put to use for fast static RAM memory chips.
4. The rapidly increasing complexity of semiconductor design (e.g. more tightly integrated transistors) has led to the introduction of high-level design software and automated design automation environments.
5. The advances in software tools have made it possible for semiconductor vendors to create regional service centers where customers can design their chips with support of experienced staff.
6. Further advances in software tools for structured and computerized design environments indicated that standard off-the shelf components could be programmed by the customer –not the manufacturer–to perform a certain array of functions.

These rapidly changing technological implementation and design strategies presented themselves to telecom equipment manufacturers as a wide array of untried paths and choices, all with highly uncertain outcomes. Only one thing was certain for competitors in the communication technology industry: failures were costly.

3. Building capabilities through strategic paertnerships, 1980–1999

Ericsson's capability in semiconductor technologies came through the transformation of Ericsson's wholly-owned component manufacturing subsidiary Radioindustrins Fabriksaktiebolag (RIFA). Originally, RIFA's manufacturing was focused on the production of various traditional analog radio and telecommunications components. Ericsson's investments in semiconductor capabilities built on a string of strategic alliances with the specialized semiconductor vendors, including: National Semiconductor (NSC) in the 1970s and GEC-Plessey and AMD in the 1980s. In 1987, Ericsson forged a long-term strategic alliance with TI, which would last until the end of the 1990s.

These alliances built on a business model for strategic partnering in digital components that Ericsson had already developed in the early 1970s. While the external partner transferred know-how in semiconductor design and manufacturing to Ericsson, Ericsson promised in return to give future orders for components to the strategic partner. In practice, the deal implied that Ericsson sent engineers to NSC and AMD and, later on, TI to study design and manufacturing techniques. In the next phase, Ericsson used the know-how to build silicon centric design centers and silicon fabs in Kista, just north of Stockholm, with the support of the strategic partners.

The cooperation with NSC was crucial to Ericsson's capabilities in semiconductors. Through this collaboration, Ericsson gained basic insights in semiconductor design and manufacturing issues. In 1977, Ericsson struck a long-term know-how deal with AMD that enabled it to start making integrated circuits in Kista—initially a pilot run of 4k static RAMs. In 1983, the AMD agreement was extended to give Ericsson a CMOS process and establish a Large Scale Integration design centre in Kista. Ericsson's mobile systems and mobile phone arm, Ericsson Radio Aktiebolaget (ERA), accumulated considerable experience in designing ASICs in partnership with GEC-Plessey during the 1980s while building its own semiconductor capabilities.

3.1 The Ericsson–TI alliance

Ericsson's partnership with AMD was generally seen as successful, but in 1986 AMD was in the process of re-orienting itself strategically. Being impressed by the rise of Japanese electronics, AMD shifted customer focus from large and complex systems to consumer electronics. Hence, the company decided to leave the alliance with Ericsson for a new partner, Sony.

From the early 1980s, TI had emerged as a strong specialist in silicon-centric ICs, so-called Complementary Metal Oxide Semiconductor (CMOS), which offered huge advantages in size, performance, and manufacturing characteristics. No doubt, CMOS looked particularly attractive to any engineering team seeking to miniaturize. For practically all telecom applications, and particularly mobile phones, these features were attractive; not least for a company that was eyeing the global mobile phone market. Therefore, it is hardly surprising that the Ericsson's technology strategists identified TI as the new preferred partner.

For its part, TI responded positively. TI was already in the process of re-thinking its position in the industry. In an interview with the trade magazine, *Electronics* (February 3, 1986), Jerry R. Jenkins, the President of TI, is reported to have said that he is "asking TI divisions to develop 'much closer customer relationships.' Service dominates our thinking now . . . It is no longer sufficient for a company to have a corner on the technology and the cost" (p. 18).

Jenkins' effort to re-position TI strategically through customer-cooperation entailed (i) improved customer-relations aimed at securing just-in-time sourcing of standard components within exclusive single-sourcing agreements, and (ii) a more advanced support structure for customization, which was to be promoted by opening a network of "service centers" where customers could design their products with support of TI experts. These designs could then be transmitted into TI's prototype manufacturing for testing. Once tested (and, if necessary troubleshooted at the TI service center), the design would be sent off to a TI's central fabs.

Once initiated in 1987, TI's partnership with Ericsson's went well beyond the plan that Jenkins discussed in public. In effect, the relationship between Ericsson and TI grew into a framework for long-term mutual technology transfer between the companies. At the core of the alliance was a cross-patenting agreement. In short, this agreement gave Ericsson access to cutting-edge hardware technologies while TI got access to Ericsson's advanced signal processing algorithms which could be used for TI's commercial hardware.

The agreement had several dimensions:

- transfer of advanced manufacturing technology, enhancing Ericsson's in-house manufacturing
- joint studies of new semiconductor technologies in the context of advanced telecom applications
- joint studies design strategies in the context of advanced telecom applications
- joint studies of software (algorithms) in the context of advanced telecom applications
- integrated routines for outsourcing of manufacturing of devices designed by Ericsson
- integrated routines for efficient outsourcing of design and manufacturing from Ericsson to TI

Initially, TI helped Ericsson to implement the latest generation of CMOS technology, resulting in the new "Submy-Fab" in Kista. Under the agreement, TI installed its 0.5-µm process technology in the plant in exchange for a greater share of Ericsson's semiconductor business. At a later stage, the parties aimed at installing TI's 0.35 µm technology in Kista. The new fab was originally designed as a small volume facility for complex and strategically important designs (such as, for example, RF power devices and the main processor of AXE switches). The partners extended their alliance in 1992 when they announced plans to construct Ericsson's pilot production fab in Kista.

The agreement also included the cross-licensing of certain technologies and joint development of advanced ICs for telecommunications applications, known as *digital signal processors* (DSP), which TI started to develop in the late 1970s. Signal processing algorithms typically require a large number of mathematical operations to be performed quickly on a set of data. In the 1980s, most general-purpose microprocessors executed signal processing algorithms successfully, but the new 'heavy' signal processing algorithms linked to the coming GSM standard required even greater processing power. The general microprocessors were not suitable for application of mobile telephone and systems. Simply put: the microprocessors were too slow, large, power hungry and generated too much heat to work well in mobile communication systems.

Compared to general digital microprocessors, DSPs offer several advantages, particularly in the trade-off between efficiency (computing power) and energy consumption. More generally, digital processor technologies offer several performance advantages over analog systems. Many speech applications have constraints on latency; that is, for the system to work, the DSP operation must be completed within some time constraint. An important 'fit' between the DSP technology and the realities of the telecommunication market was "the real time requirement"—that is that telecommunication services are constantly on-line in *realtime* that the signal represents physical or "real" events.[1] The DSP is faster, because it has a dedicated and reduced instruction set compared to a general micro processor, thus being able to operate in "real time".

3.2 The structured design flow

Transfer of DSP technology and design and manufacturing technology also implied that Ericsson turned chip design into a structured process, building on the use of specific software tools and routines across a structured work-flow in accordance with TI's design environment (Table 1).

While the integrated environment could be seen as internal to the company, it also provided the infrastructure for the re-allocation of tasks between Ericsson and TI (or any other supplier with matching pre-defined processes). Using the analogy of electronic interfaces, the interfaces between the stages in the design and manufacturing processes were defined with respect to (i) data to be exchanged, (ii) formats and protocols that govern the data transfer, and (iii) performance requirements to ensure that the interface can keep up with the project schedule.

Ericsson thus invested in an integrated approach to semiconductor development. A simplified graphic representation is shown above. The entire set of activities required to develop and manufacture ICs was hence internal to the company. These included specification, definition, design implementation (front-end and back-end design), verification and prototyping and manufacturing. Given that these rules of the development process are clearly defined and implemented, each stage ends with a hand-over item that can be logically interpreted at the next stage. Each interface represents a potential cut-off point, which allows the functional

[1]Real time means that the signal represents physical or "real" events. In real time environments, adding significant delay, or latency can be disastrous. A hospital room heart monitor doesn't need to be fast, but does need to be real time; it would be disastrous if the processing of a sample took so long that after a few hours, the monitor was displaying five-minute-old data. DSPs are designed to process real-time signals and must therefore be able to process the samples at the rate they are generated and arrive.

Table 1 The digital hardware design flow by phases and interfaces for handover to next stage

Direction of Design Flow					
DESIGN PHASE (i.e. the *fabless* phase)				CHIP IMPLEMENTATION	
Conceptual technology study	Definition /Structuring	Design Implementation		Mask making	Volume Manufacturing
Demand Functional and performance goals Investigate tech alternatives: –Standards –Prod cost –Life-cycle cost –Reliability High-level description of architecture (text and graphic)	HW/SW partitioning HW/SW interfaces Definition of functional blocks and the chip level block diagram Create behavioral models and first functional modeling (MathLab, C, C++, VDHL) Select re-use of IP and memory Select ASIC technology (full custom, standard cell, gate array) or FPGA	FRONT-END: (non-dependent on target technology) Design in Verilog or VHDL Logical synthesis: RTL-description Pre silicon verification Bench test of design	BACK-END: (target technology dependent) Floor-planning: place and route blocks, gates, etc Design rule checks (DRC) Layout versus Schematic (LVS) checks	Validate database at mask shop and foundry	Prototype production for customer evaluation Validation of yield and cost Capacity planning Production test Yield enhancement
Deliverable: High-level description of architecture (text and graphic)	Deliverable: first sketch of micro-architecture	Deliverable: 'Verilog netlist'	Deliverable:Physical implementation in GSD database, earlier 'tapeout'	Validated mask	Full volume manufacturing of chips

separation of the tasks from each other in accordance with the principle of modular development.

3.3 Buy or make? Matching design and outsourcing decisions to component requirements

In the 1980s and the early 1990s, as we discussed above, Ericsson tooled up in semiconductor capabilities. In addition, the alliance with TI provided Ericsson with a powerful outsourcing partner with particular strengths in some of the areas of critical importance to telecom applications, such as DSP-technology. But at the core of the strategic alliance between the two partners was the idea of differentiated outsourcing: the two companies agreed to transfer technologies to build Ericsson's internal design and manufacturing capabilities at the same time as the agreement called for certain chips to be outsourced from Ericsson to TI.

Which ideas guided the decisions to buy or make? To reconstruct the logic that guided design choices and sub-division of tasks, we have gathered data on design choices and decisions on outsourcing in connection with a wide range of semiconductors with particular importance to telecom systems (Table 2).

Table 2 Sub-division of tasks in semiconductor design and manufacturing by type of chip, ca 1980–1999

Example chip type	Mid-1980s to early 1990s		Mid- to late 1990s	
	Activity		Activity	
	Design	Manufacturing	Design	Manufacturing
SLIC	In-house	In-house	In-house	In-house
SLAC	External	External	External	External
AXE control processor (APZ)	In-house	External	External	External
RBS control processor	In-house	In-house	In-house	External
Digital baseband (mobile phone)	External	External	External	External
Digital baseband (RBS)	External	External	Often but not always In-house	External
RF chips	In-house	External	In-house	External
CODEC (programable DSP)	Programmed In-house	External	Programmed In-house	External

First, the decision to buy from external sources or make internally was according to Gösta Lemne, a DSP specialist and director of technology sourcing at Ericsson at the time, based on the specific product's market share and the potential differentiating impact of the chip. For products with large market shares, there was a solid ground for investing in internally designed chips because it allowed Ericsson to differentiate the product from the competition (Lemne, 2009).

The radio base station (RBS) chip is a case in point. As the GSM standard developed into GSM 2.5 through the implementation of GPRS and EDGE, the RBS needed to compute the more complex algorithms. In addition, the 3 G algorithms developed in the late 1990s took the complexity to yet another level. As a result, the radio base stations needed more computing power. Yet RBS developers needed to put a lid on the power consumption and cooling needs of the new RBS-unit, since these two factors were important variables in the mobile operator's calculations.

For the purpose of making DSPs more powerful, TI came up with an innovative so-called parallel DSP architecture which can run eight sequences in parallel. Ericsson found, however, that this architecture was not particularly well fitted to the RBS's main functions. By developing unique RBS chip designs internally, Ericsson adapted the hardware to specific task of the RBS. A cluster of simplified DSPs on a chip were found to be more efficient to the extent that it was less costly to manufacture compared to the comparable DSP solution from, say, TI. More importantly however, the internal design differentiated Ericsson's RBSs positively from the competition through low power consumption.

By contrast, the design of chips for Ericsson products with lower market shares, such as the mobile phones, was outsourced to a much larger degree. Hence, Ericsson left the development of the main application processor chip of mobile phones, the digital baseband, to TI. TI thus came to play a major role in mobile phones, and especially in the design of digital base band chips. According to Mats Lindoff, an Ericsson mobile phone veteran and later CTO of Sony Ericsson, "we [Ericsson's mobile arm] did not have enough designers to do the digital base bands quickly enough, which is why TI made the design for us" as one well-placed informer told us in the interviews.

In addition, the supply of standardized commercial chips fitted better with the technological profile of the mobile phones than with radio base stations. By comparison, the mobile phones were more general devices in which the main processor was running a larger array of tasks (such as software applications, control of camera etc.). Therefore, Ericsson's mobile phone hardware designers based in Lund found that TI's DSPs, which were based on the complex parallel architecture fitted well with the technological requirements of the advanced mobile phones. For its part, TI was more inclined to adapt their hardware for mobile phones because this market was ultimately much larger in terms of manufacturing volumes compared with the RBS market.

In the area of relatively less complex design, such as codec chips, Ericsson expected to gain low differentiation from investing in its own design. Ericsson hence relied on TI's supply of standard programmable DSPs for the codec function.

Secondly, technological maturity was another important variable. When technology was advancing quickly, Ericsson tried to use programmable off-the-shelf chips as far as possible because of their flexibility. When system requirements and technologies were more stable over time, and Ericsson's technologists were more certain about what the market expected from the systems, Ericsson moved to internally developed ASIC chips with a higher differentiating factor (Gösta Lemne, quoted in *Elektroniktidningen* 13/12 2002).

Thirdly, the need to keep differentiation design secret influenced the decision to buy or make. In differentiating chips "we have to do it ourselves [internally] because the typical DSPs on the external markets are like an estate wagon with a powerful engine—it is good for all purposes . . . But if we know the algorithm well enough, we may very well be able to come up with more optimized task-specific designs. We do not want to make those designs available to our customers by sharing the knowledge through the suppliers." (Gösta Lemne, quoted in *Elektroniktidningen* 13/12 2002). Need for secrecy thus determined how much of the design and manufacturing processes Ericsson revealed to the suppliers. Cases in point were the subscriber line integrated circuits (SLICs) and subscriber line audio processing circuits (SLACs) for AXE systems. Originally, Ericsson asked its partner, AMD, to co-develop the ICs with RIFA/Ericsson Components on the basis of technological exchange within the strategic alliance. Once the first attempts were ready in 1982, Ericsson allocated the main responsibility for the design of SLIC to RIFA/Ericsson Components. Within RIFA, research resulted in an innovative design and several patents. (Of particular importance was Ericsson's US Patent 4,908,854). After further internal development of the SLIC technology in the late 1980s, RIFA's SLIC was cutting-edge patented technology that would reinforce the position of the AXE-system in the world markets.

These SLIC-chips were relatively standardized and manufactured in large volumes, making them suitable for outsourcing from an economic point of view. But to keep the design principles and algorithms secret, Ericsson decided to manufacture in-house. Ericsson also applied this rule of secrecy in the area of RBS processors. "Many suppliers would like to be involved in the design and manufacturing of most important chips to get a glimpse of our algorithms for radio base stations, but we do want to risk sharing our crown jewels with our competitors through the suppliers." (Gösta Lemne, quoted in *Elektroniktidningen* 13/12 2002).

In the 1990s, the company however became more confident that it could outsource manufacturing without risking "leakages" between the external manufacturer and Ericsson's competitors. When secrecy was regarded to be a critical issue, however, Ericsson still maintained both front-end design and back-end design in-house (Lemne, 2010).

3.4 Technical limits to outsourcing

Thus far, we have examined the business reasons why Ericsson chose to outsource or produce internally. It should be recognized, however, that outsourcing depends on the technical ability to separate different tasks from each other.

In digital semiconductor design, the high-tech tools for computerized semiconductor design (or Electronic Design Automation, EDA tools) became more advanced from the late 1980s. In particular, the main part of front-end design, *the logical synthesis*, was greatly simplified by so called high-level hardware description languages, such as VHDL or Verilog. (By nature, this software-based automation of synthesis is akin to the advantages of using high-level software languages, such as, C and C++, and related compliers for translation of high-level code to the low-level assembly language). The EDA tools provided a framework for the design flow, making outsourcing feasible. In particular, the EDA tools defined certain cut-off points and interfaces between front-end and back-end processes as well as between back-end design and manufacturing.

As pointed out by the semiconductor designers we have interviewed as well as in the in the basic standard literature on chip design (e.g. Martin et al., 1999; Martin and Chang, 2003), the process of establishing interfaces is just as complex and can often "constitute quite a challenge in itself" (Martin and Chang, 2003:53). EDA tools were applied however with some degree of success in the design of digital microprocessors. Chip designers found the tools less relevant in the design of analog chips. Contrary to the development within digital design environments, analog design interfaces are notoriously difficult to master. In fact, analog design has often been regarded as a *black art*. Analog modeling very often depends on parameters that can vary dramatically, such as temperature. It is very difficult to represent the dynamic characteristics of such parameters by the use of generic parameters contained in high level hardware description languages (Lindoff, 2009).[2] Characteristically, the main type user-request for improvements of hardware description languages (HDL) called out for increased coverage of the analog domain. The same report also indicated that the most sophisticated efforts to tweak existing compilers yielded very poor results in terms of code quality (Meersmann, 1993).

Thus, the lack of efficient EDA-tools for analog design environments implied also that there were greater technical barriers to outsourcing in analog chips, precisely

[2]All groups involved working on different hardware and software design elements need to access a behavioral model of the chip. It is however a fact of life in chip design that the models are likely to be in different formats. *Changes* in design may then constitute problems to the extent that the models tend not to be absolutely logically equivalent. There are a number of solutions to the problem of lacking logical equivalency, including manual translation into a RTL model. All solutions are nevertheless making the different design tasks more interdependent because, as put by Martin and Chang (2003): "the change has not really made it through the interface until it is in a form that can be used by the group on the other side of the interface." (p. 53)

because the lack of a well-defined and fully logical interface between front-end design and back-end design in the analog design environment made the hand-over between the two stages of the design process highly uncertain and problem ridden. Analog design of mobile phone chips is a good case in point: as long as there was no stable logic interface separating front-end from back-end, the design remained connected through non-modular systemic interdependencies. Simply put: it was difficult to separate front-end design from back-end design without major disruptive consequences (Lindoff, 2009).

4. Towards full re-intergration in mobile chips

During the 1990s, Ericsson's effort in mobile phones needs to be seen in the context of the tight connection between mobile phones and wireless systems. While Ericsson's main competitor, Nokia, had already recognized the consumer product dynamics in mobile phones in the early 1990s, Ericsson kept perceiving mobile phones as an extension of wireless systems, or more precisely as being essential market drivers in its wireless system business. On this view, the purpose of mobile phones was to secure the system sales by making certain that the end-users would have access to the newest generation of "handies". In the early 1990s, Ericsson learned that its GSM system business hinged on reliable access to GSM phones. Mobile operators would postpone their investments in GSM networks if they were not sure that they could live up to their promises to the end-customers by having GSM phones in stock.

Within Ericsson, the mobile phones were regarded as technological extension of the mobile system and not a consumer good. Only too late did Ericsson realize the full consequence of this notion. Around 1999 and 2000 the financial situation of Ericsson's handset business became alarming. In 2000, some SEK 20 billion were lost in the mobile phone business—a loss that should be added to the weak financial results of the preceding years. And more bad years were foreseeable. Something had to be done. And at the Millennium, the Ericsson market share famously collapsed.

To save what remained of its mobile phone division, Ericsson entered into negotiations with Sony about merging the mobile phone divisions of the two companies into a joint venture, later to be named Sony Ericsson (SEMC). After having failed to compete with Nokia in consumer-oriented phones, Ericsson lacks both the financial muscle and the self-confidence to turn-around its mobile phone operations. It was generally understood that Ericsson's expertise in "deep" technology could be combined successfully with Sony's grasp of consumer electronics.

When plotting the new future for Ericsson's mobile arm, the company also realized that there was a growing need for one-stop-shopping particularly among Asian firms aiming at strong positions in the 3 G mobile phone business. Among those OEM entrants, Korea's Samsung and LG were looking for platform-solutions for customization. (This idea was not new. Philips, who made a less successful attempt to carve out a position in the GSM phone market in the early 1990s, announced in the late 1990s a new business model introducing its Telecom Platform as a solution of reusable hardware and software building blocks. The first announcement of Philips Semiconductors' system-level platform-based design methodology was made at the IFA show in Berlin at the end of August 1999. Qualcomm—Ericsson's main adversary in the 3G standards war—was developing a hardware centric business model following its decision to withdraw from the OEM equipment market.

In 2001, Ericsson announced that its reformed mobile technology arm, Ericsson Mobile Platform (EMP) based in Lund, was starting to license the core technology to a number of companies. Sony Ericsson was the obvious first licensee. In addition, Sharp of Japan as well as South Korea's Samsung and LG Electronics have signed up for EMP's platforms. The agreements with the Asian mobile phone OEMs push EMP platforms into the low-end of the Chinese market, a market not addressed by SEMC.

EMP's platform products consisted of several entities, the main ones being the reference design—that is, a tried-and-tested blueprint for making a mobile phone; the EMP integrated circuits, which comprise the key hardware components in the phone [mainly Radio Frequency ICs as well as analog and digital base band ICs (ABB and DBB)]. Using this platform as a starting point, the mobile phone vendors could define a variety of phones by developing and mixing applications (e.g. imaging,

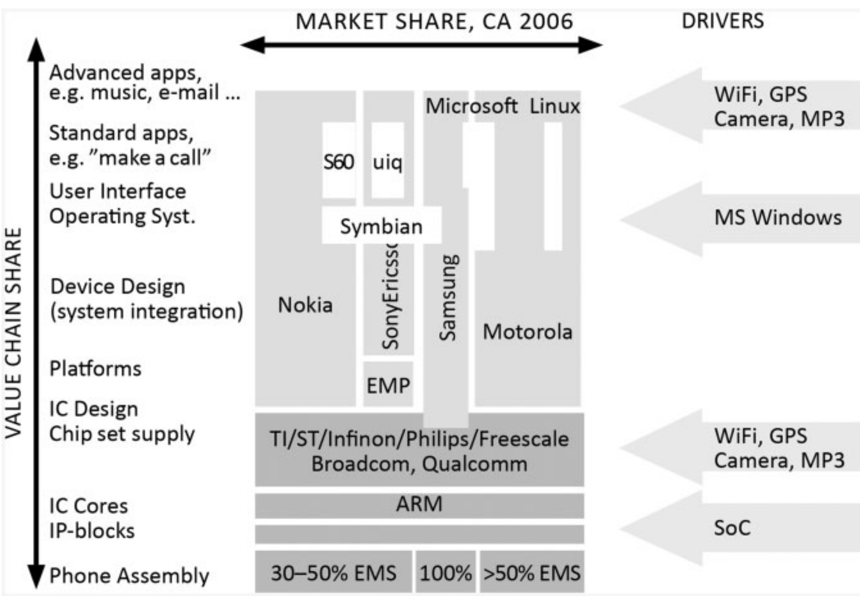

Figure 1 Mobile industrial ecology by market share and value chain share, ca. 2005
Source: Adapted from (Glimstedt and Lindoff 2007).

video, simultaneous streaming and voice call, local and multi-player games, synchronization, secure access, and banking).

In fact, EMP picked this opportunity to make a far more solid offer to Samsung and other entrant OEMs by re-packaging the services offered to SEMC as a licensable mobile platform. According to Jan Wäreby, SEMC's Corporate Executive Vice President and Head of Sales and Marketing 2001–2006, the mobile phone business was becoming just as competitive as the personal computer industry. In such environments, Wäreby concluded, "...you need a lean organization to focus on key things—like product designs, applications and software components." (quoted in EE Times 2002-03-15). Another Ericsson spokesman took the argument even further, stating that "A whole new race has begun for the mobile handset vendors. The industry is making a dramatic shift from a few complete suppliers to an open chain of specialized companies, similar to the PC industry." (quoted in EE Times 2002-03-15).

Clearly, EMP emerged at a point in time when the established business model was about to change. Rather than keeping their ASICs, homegrown operating systems and software stacks to themselves as corporate crown jewels, leading handset vendors had already transformed their business models to open their architectures and make them available for licensing.

The Symbian operating system, which Ericsson, Nokia, and Motorola developed jointly in the OS joint venture, was offered on the basis of license. Nokia was about to make the source code for its internally grown smart-phone software stack, called Series 60, open. Already established chipset manufacturers, such as TI and Broadcom, used a processor core IP from ARM, a British IP firm.

By the way of summary, Ericsson re-shaped its mobile phone business not as a response to a more general break-up of the value chain but by taking the lead in a general move towards efforts to establish horizontal leadership. In doing so, the basic mobile phone technologies were more clearly than before conceptualized as a modular mobile phone platform.

The questions are, however, how these concepts were realized and what the impact was on the organization and sub-division of tasks in semiconductor design.

4.1 EMP's choices in semiconductors

Mobile phones were significantly more complex affairs compared with the phones designed even in the late 1990 s. A typical Ericsson GSM phone contained a number of processors. An 8-bit processor might take care of the user interface, games, etc., while a 16-bit DSP provides the processing power necessary for digital voice encoding and decoding. More features imply a need for more computing power. Hence more powerful 32-bit main processors were becoming necessary.

Already in 2001, Sony Ericsson set its course towards industrial leadership in the higher end of the mobile phone market. By 2003, there was a wider consensus within the industry what the smart phone was about. According to a leading veteran in the mobiles phones, Ericsson's Nils Rydbeck (2005), the initial definition of the high-end mobile phone involved several features as reflected in Ericsson's mobile technology roadmap for 2001–2005:

- *High-tech camera*
- *Color displays are a must*
- *Bluetooth for personal area network*
- *Beginning music players*
- *High-tech industrial design*
- *3G is finally taking off*

To meet the demand, EMP designed its first 3G platform (U100). It was launched—after no less than 1500 man years of development work—in May 2003. The solution was based on significant internal design around TI's digital base band technology.

Rather than trying to maximize efficiency, designers sought the safest possible solution. In essence, U100 built on no less than seven different chips by EMP designers. Commenting on the number of ICs, Björn Ekelund, EMP's head of product planning, indicated that breaking up the design into several components facilitated the process greatly (Ekelund, quoted in *Electroniktidningen*, 30/8 2006). Instead of developing one integrated DSP chip, the designers divided the functions into two linked chips, giving the designers a greater degree of control over chip behavior. One observer described the design as a "realistic," hinting that getting to with a functional platform was the chief concern, rather than being somewhat late to the market with more optimized product (Lindoff, 2009). The U100 project was crowned with success. It enabled EMP's customers to launch true 3G phones in the global markets.

Nevertheless, the U100 was not without flaws. Generally, customers leveled two types of criticism at the early 3G phones. First, end-users complained about the computing power. Simply put, most people experienced the 3G phones as "slow". A second type of reaction came from the phone vendors. This criticism was mainly related to its "safe" design and low level of system integration with many chips. From the point of view of manufacturing costs, the low level of integration was far from ideal. Since manufacturing cost was a chief concern for the mobile phone vendors, they urged EMP to work towards higher level of platform integration—that is, fewer chips.

EMP's plans for the second generation of platforms addressed both types of criticism. The new platforms released in 2005, were 20% smaller and offered twice the multimedia performance of their predecessors. Equally important, the second generation of EMP platforms were more integrated, reducing the number of main semiconductors from seven to three (RF-device, analog baseband and digital baseband). This was, in many respects "more of the same" but with a simpler chipset

Table 3 Sub-division of tasks in the design flow in by type of chip 2003–06

	RF	DBB	ABB
System requirement	Internal	Internal	Internal
Chip definition	Internal	Internal	Internal
Front-end	Internal	Internal	External
Back-end	Mostly internal	External	External
Prototype verification	External	External	External
Manufacturing	External	External	External

structure and more economic design. Characteristically, the second generation used one single integrated DSP for base band functions. External analysis indicated that this kind of simplification reduced manufacturing cost—a chief concern for EMP's customers—by around 70 USD from ca 230 to 160 USD. (Portelligent, cited in EE Times 10/18/2004).

Under considerable time pressure from operators and customers, the hardware design teams engaged in upgrading the hardware components for the new platforms. In hardware design, as our interview with Jörgen Lannto (presently the CTO of ST-Ericsson) shows, the division of labor between EMP and its suppliers differed across the different kinds of hardware. Generally, for RF hardware EMP internalized front-end and outsourced most of the back-end design tasks. For the digital base band, EMP kept front-end design in-house and trusted chip suppliers with the back-end design. Finally, in the analog base band chips, EMP only specified the system requirements and the conceptualization and structuring of the chip. Front-end design as well as back-end design was externalized. Compared to the first generation of 3G platforms, which were internal design, outsourcing increased after 2003.

4.2 Responding to demands on computing power and new service

By the mid-2000s, there was a significant drive for product up-grading and innovation in the 3G phone market. Sony Ericsson as well as its competitors were all in the process of differentiating their phones by offering distinctly different features, leaving the "Swiss army knife" concept behind.

The Sony Ericsson service roadmap for 2005–2008 was driving the development in the high-end of the market, emphasizing an escalation of connectivity, service levels and differentiated features (Rydbeck, 2005; Glimstedt and Lindoff, 2007)

- Advanced camera technology: Resolution, light, color, zoom and vibration reduction
- Advanced music player: Multiple audio codecs, noise and sound quality
- Broadcast TV Microchip technology

- Full featured web browsing
- Small screen rendering, proxy servers, picture
- More and faster data (EDGE, UMTS, WCDMA, HSDPA) on the same phone

Hence, Sony Ericsson introduced two of Sony's brands—Cybershot and Walkman—for camera phones and music phones, respectively. It was the first time Sony Ericsson utilized such a broad platform-sharing strategy. At the drawing board, the differences between the W800 and the K800 were, apart from the exterior design, Walkman-branded hardware (including a "Walkman button"), a dedicated "Walkman player" (software), a stereo headset and a larger memory card.

To EMP's platform designers, it seemed impossible to achieve the desired increase in computing power and service level associated with the new phones solely through software. Hardware design was greatly impacted by the market demands: application processors were being added for multimedia functions. Secondly, hardware design was also impacted by the demand for implementing parallel support of GSM, EDGE and WCDMA, HSDPA data protocols. Third, there were major challenges associated with power consumption.

The conclusion was that the new platforms needed to be based on new technologies:

1. New advanced energy efficient technologies (from 130 nm and 90 nm to 65 nm and 45 nm)
2. New DSP architecture
3. More complex and powerful main application processors
4. Higher clock speeds on all chips
5. Higher level system integration to keep costs low for customer (i.e. fewer but more complex chips)

Competition was heating up, and EMP's strategists drew up the plans for two new cohorts of mobile platforms to replace the U100 and U200 cohorts. EMP's challenge was to improve on all fronts, and to do it quickly.

For the first new platform, the U300, EMP used the same "safe" approach to design as in the U100. EMP's technology strategists conceived the U300 cohort with the new camera and music phones in mind. EMP added to the older platform's computing power, but the company re-used the proven radio technology from U100 and the U200 platforms (see Figure 2). Clearly, Sony Ericsson's decision to differentiate the high-end phones into defined feature phones played a major role in the definition of the "specs".

Sony Ericsson derived several success phones from the U300 platform, including the K810 Cybershot camera phone, and the W810 Walkman music phone. Both the Cybershot and the Walkman phones were important to Sony Ericsson's market position.

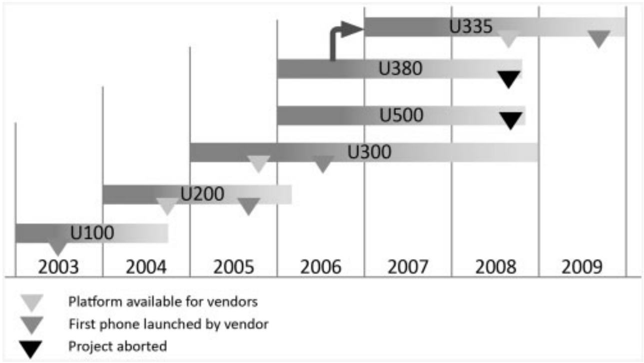

Figure 2 EMP's mobile platform road map 2003–2009.
Comment: Table 1 reflects the development of the advanced feature phone and business phone platforms. It does not reflect less advanced EDGE and GPRS platforms.

In 2006, EMP hammered out the plans for the U380 high-end platform for the future, aiming in particular at adding supporting mobile TV to the list of advanced features. The U380 should be built on a 65 nm implementation of EMP's three chip design, using one digital baseband chip with an integrated application processor and Ericsson's modem, an analog baseband (see Appendix) TI's OMAP platform combined with an EMP-designed modem, resulting in one of the smallest multimedia mobile platforms in the high-end market category (EE Times 02/08/08). According to Robert Puskaric, General Manager and VP at Ericsson Mobile Platforms, the U380 "was a truly open mobile platform for the rapidly growing Open OS market, e.g. Microsoft CE, Linux, and Symbian.

In addition, EMP started drafting the U500 platform based on EMP's basic three chip-design with a DBB (incl fat modem), ABB and RF chip, The U500 platform was even more future-oriented and advance, providing support to 12MP cameras, large touch-screen, high-definition video camcorder technology and all other possible thrills. To keep size and energy demand to the minimum, the U500 was designed the latest 45 nm chip technologies. For the U500 platform, EMP envisioned a series of fully fledged high-tech "business phone", complementing the camera and music feature phones.

However, the U360 and U500 became problem ridden and never made it to the market in time for different reasons we will discuss in detail in what follows.

4.3 Focusing on the fat modem solution

When conceptualizing the architecture of the U380 and U500 platforms, EMP's designers took aim at a high level of chip integration (Appendix 1). In particular, the designers worked towards integrating the modem function with the application processing units into what in industry jargon is called a "fat modem". This solution calls for the integration of a microprocessor for running the operating system and the user-applications with an advanced DSP-core for the low-level the modem functions. The chip designers could, in principle, have arrived at a less integrated solution: namely using a separate DSP chip for the modem function in combination with a separate microprocessor. Simply put: the digital baseband could serve as a "slave processor" to the analog chips. In industry jargon, this solution is called a "thin modem" solution.

The new fat modem DBB-design required subsequent changes in other major components too.

Even if EMP was known to strive for re-using of older and modularized "carry over" components for its new platforms, it decided to move forward with the level high-level of integration despite it demanded the company to re-design analog circuits (RF devices and ABB) as well. Indeed, the U380 and the U500 put EMP's design abilities to a test.

So far, the design of the two platforms followed the same path. They differed however in to what extent the design teams would rely on external partners for the design process as well as the choice of outsourcing partner. First, for the U500 chip EMP choose ST-Microelectronics as its partner and supplier. Much of the semiconductor design was done internally. For all three main chips, EMP's design teams were responsible for both the first stage conceptualization and the front-end design. The digital baseband (internally called *Miranda*) was based on a very advanced design, which integrated three so-called ARM microprocessor cores for applications and graphic acceleration with a homegrown modem function (internally called *Eva*). ST-Microelectronics was responsible for back-end design and manufacturing of the Miranda DBB-chip. The ABB and RF chips were to be designed internally by EMP itself. With respect to the U380, EMP used a different approach. EMP aimed at integrating a homegrown HSDPA modem technology with TI's OPMAP processor into a single digital baseband chip. This choice implied that EMP would be co-operating closely with TI on the conceptualization as well as on the front-end design of the U380 baseband chip. From back-end design and onwards, the work was left to TI. (The ABB and RF chips were to be designed internally by EMP itself.)

Thus both chips used the so called "fat" modem approach on EMP's, although they differed with respect to the outsourcing of design.

4.4 Design challenges in digital baseband technologies

As already stated, the challenges in digital baseband were increasingly shaped by market demands: end-users expected new hot multimedia functions and, yet, they expected faster and smaller phones with improved battery time. Secondly, Radio Frequency chip design was impacted by the problems in implementing parallel support of GSM, EDGE and WCDMA, HSDPA data protocols.

In digital basebands, EMP's design team responsible for the U500 and U380 concentrated on the three first steps of the design flow. The starting point for the U380 was the OMAP architecture, which EMP's designers sought to enhance in close collaboration with a team of TI's OMAP engineers. One might characterize this development work as tweaking of a microprocessor that TI "packaged" for EMP. One of the major concerns was to move from 130 and 90 nm chip technologies down to more energy efficient implementations in 65 nm. The team responsible for the U500 faced an even greater design-challenge. In the early specifications of the U500 team outlined an industry-leading power house with three high-end ARM cores supporting advanced multimedia functions. To economize on size and battery time, the U500 was to be implemented in 45 nm technology.

Developing a highly integrated digital baseband chip with both application processing microprocessor cores and the modem DSP core proved to be difficult for both design teams. Two problems appeared to be particularly thorny: power consumption and "cross talk". (Cross talk appears when the connection lines between the different functions on chip become very thin and come very close to each other. Information from one connection line will leak into another).

The CTO of SEMC and senior technologist within the Ericsson group, Mats Lindoff, had deep insights into these problems. His view was that EMP's hardware design expertise was mainly in the area of analog RF devices. After all, Ericsson had been supplying TI with pioneering algorithms for telecommunication applications since the late 1980s. Digital baseband, however, required different skills. "Even if development of digital baseband microprocessors never was our strongest point, we [SEMC] and EMP were pretty good as long as the baseband implementations were done in 130 nm technology. But the step from 130 and 90 nm down to 65 and 45 nm proved to be really difficult. At these low levels, we hit the wall." (Lindoff, 2008)

When designing at the level of 130 or 90 nm technology, the chips design followed a strict digital logic. This means that the design concepts developed in the early stages of the design flow (i.e. definition, structuring and front-end design) could be logically implemented in back-end design. When moving to 65 nm technology, that logic was not all that strict any more. In chip designer speak, the chips crossed the line between "digital and analog". By this expression, chip designers imply increased unpredictability throughout the design flow—what was clearly defined at one stage of the design did not translate logically in the next step.

At the heart of the problem was a mismatch between the exact implementation of the design flow at Ericsson and the set of EDA tools used for designing at 65 nm. While EMP moved very quickly towards 65 and 45 nm technologies, the existing tools lagged behind to the extent that they did not fully support digital design below 130 and 90 nm. Hence there were major problems with the implementation of the small geometry basebands for the new EMP platforms. The problems derived from the previously mentioned cross talk and the insertion of clock trees. A clock tree is a derivative of an oscillation crystal feeding a clock signal into the base band chip.

The main clock signal is divided into different sub clock signals, which are used in different parts of the chip. These different clocks must, of course, be synchronized over time. Otherwise the complete chip will malfunction. Unfortunately, some of these problems will disappear, if the power consumption is allowed to increase—an almost impossible equation for the designer to solve. In addition, the EDA tools available are not that good in supporting the designer, as the phenomena are, as previously mentioned, close to analog.

At an EDA tool industry conference held in 2006, Mats Lindoff made an unusual public statement about the problems he experienced as the industry was shifting to less power hungry platforms. Addressing the *nature* of these problems, Lindoff concluded that they were closely related to how the EDA tools were used within the design flow. "We will have to get the energy consumption [of our phones] down. We have partly succeeded in getting down from 305 to 210 mA, but it is not enough. Sony Ericsson and EMP need support from you [the EDA tool industry] to succeed." (Lindoff, quoted in *Elektroniktidningen* 3/10 2006).

One key problem was the absence of an integrated tool set that supported EMP's sub-division of tasks in chip design. Developers found themselves experimenting with several tools and standards, a practice that evidently demanded more experience in baseband design than was at hand at EMP. Again, the separation between front-end and back-end design became tricky.

In particular, there were problems, within this highly fragmented development environment, in getting a clean hand-over between front-end design and back-end design, which made it difficult to find solutions to the power management problems (Lindoff 2009). Therefore, both the U500 and the U380 projects were running late. Delayed sub-tasks became too common. By late 2007 and early 2008 there were clear signs that the platforms would not be ready in time to follow up on the success of the Cybershot K800 and Walkman W810 phones. Ideally, Sony Ericsson and other EMP-customers would show feature phones to the market at the industry fairs, such as Barcelona Mobile World Congress, in early 2008. Compared to the original road map (see above), the platforms were running late.

For EMP and its customers, the consequences of the failed platform projects were noticeable. EMP's main customer, Sony Ericsson, was left without a competitive platform at the point when the competition was heating up in 2007 and 2008. Therefore, Sony Ericsson stood without the latest technology for its planned business phone series—the X1. Sony Ericsson was also hurt badly by the lack of advanced platform technology for entertainment phones. The delays were well known within the Ericsson Group, and Sony Ericsson did something unusual in 2007: the top executives of Sony Ericsson turned to the owners—Ericsson and Sony—with a request for using alternatives to EMP-technology for the high-end business phone (called Sony Ericsson X1). Rather than using the U500 as a starting point, Sony Ericsson thus turned to one of EMP's competitors—Qualcomm—to buy the American company's platform called Snapdragon.

In addition, EMP initiated a closer collaboration with STMicroelectronics which was one of the leading European suppliers of mobile semiconductor components and Nokia's closest collaborator, in order to create alternatives to the delayed U380 (i.e. U335 in Figure 2). Thus STMicroelectronics and EMP started in 2008 joint development of 3G and 3.5 digital baseband processors as well as joint development in the area of analog baseband. But the U335 started too late.

In essence, none of the two approaches to outsourcing tried in the two platform projects discussed here yielded strong results. Both ways of outsourcing various parts of the semiconductor design delayed the projects severely. EMP found itself between a hard place and a rock. Its incapability to deliver new advanced platforms for 2007 and 2008 put EMP in a very difficult position. How bad was the situation? As the gap between the market introduction of U300 platform and the planned introductions of U380 and U500 increased, due to the inability of EMP and its outsourcing partners to deliver, the people within the community of technology strategists at Ericsson realized that something drastic had to be done. In the search forf alternatives to the now defunct development model, key people at EMP suggested that the company should consider moving towards re-integration of front-end and back-end design to gain control of the design process. Lars Tilly, a technology strategist with EMP, discussed these matters in public (Tilly 2007). His address contained a clear statement. To solve the present problems in <65 nm technology, Ericsson needed to re-think its "role as fab-less company. Lars Tilly put forward two interconnected reasons why Ericsson and EMP should go against the current trends towards increasing outsourcing in semiconductors. First, EMP "... strategic competence in hardware is a competitive advantage and should be retained within the company". Secondly, Tilly made a reference to the technological problems of outsourcing just being experienced by EMP. "Many projects... Tilly writes. "... have complex inter-dependencies which will lead to focus on interfaces rather than on solutions and content". Another key player, Mats Lindoff, had by then arrived at the same conclusion: "In semiconductor design, there was a need...", Lindoff said, "... to be in charge of the whole process" (Lindoff, 2009).

4.5 Up-date: towards re-integration

Besides forging closer ties with the suppliers to integrate system and semiconductor design, EMP, the leading technology strategists within the Ericsson group, were contemplating a more radical solution.

As recalled by Mats Lindoff (2009):

> Sony Ericsson was really hurt by not having access to new competitive platforms throughout 2008. One year is an eternity in the mobile phone business. Within the broader context Ericsson, we needed to do something radical to deal with EMP's problems .Taking full control of the value chain in semiconductor design, it seemed to many of us, should be

our first priority. The top-level executives were listening as we outlined a case suggesting that there was a strong business case for backwards integrating EMP with its main suppliers.

Together with Joakim Westh, Lindoff developed a business case for merging EMP with ST-Microelectronics. (In short, the case started from the idea that the market for mobile platforms was limited to 500 million euro on the yearly basis. Nokia owned 50% of the market. Hence, there was an additional 250 million euro market to fight for. But the costs of the development of new mobile platforms were soaring, due to accelerating hardware and software costs. Sooner or later there would only be enough space for a handful of players in the market, if the end-customers did not agree to pay more for the phones. And there was no evidence pointing in that direction.

This move towards full re-integration of the design flow would turn the company into a full-fledged and fully integrated European contender in mobile platforms. Buying Europe's strongest player in the semiconductor business still seemed a bit unrealistic. But Ericsson's CEO, Carl Henric Svanberg, had the background, reputation and the appetite for mergers and acquisitions.

Two unexpected developments in the mobile and semiconductor industries in 2007 facilitated the realization the merger:

- Nokia sold parts of its internal semiconductor unit, the so called "A-Team", to STMicroelectronics.
- ST moved ahead and merged its now enhanced mobile semiconductor operations with Philips semiconductor arm, NXP.

Table 4 STEricsson by products and customers

Product offering	Key customers
High-end multimedia mobile platforms	SEMC, HTC, LG, and several ODMs.
Low-end platform	SEMC, HTC, LG, and several ODMs
EMP single-chip platform	SEMC, HTC, LG, and several ODMs.
Baseband chipset (Nomadic): high-end video and TV focused phones	Nokia
Baseband chipset (ex-Nokia)	Nokia and other vendors with internal platform capabilities
RF-devices and power management chips	Nokia and other vendors with internal platform capabilities
General competence in platform design, ASIC's, and IP-block design	Nokia and other vendors with internal platform capabilities
3G and 4G USB-modem for laptops	Mobile operators

These two developments clearly made the idea to create a strong and integrated European player in mobile platform technologies more attractive. In essence, the concentration of skilled semiconductor designers to ST Microelectronics through its take-over of Nokia's so called "A-Team" and Philips semiconductor arm both created a stronger semiconductor specialist for EMP to partner with. In addition, Nokia's sudden decision to outsource larger parts of semiconductor design activities clearly created a potential market for the joint venture between ST and EMP.

In early in 2008 the industry gossip had it that EMP and ST/NXP were the process of discussing closer relationships. The new joint venture would be called STEricsson. According to what the parent companies expressed publicly, the move gives ST the chance to expand its market position to future technology generations. EMP in turn gets access to a complete and consistent hardware platform as a basis for future applications and services.

The new structure represents almost full re-integration of platform and semiconductor design. ST did not however bring manufacturing into the new organization. The fabs will be controlled by the remaining part ST, which still exists as an independent operation and 50% owner of the Joint venture. What the long-term effects of this new joint venture will be on the development of mobile platform in the new company will be is, of course, too early to tell.

5. Conclusions

This article considers the decisions to outsource and re-integrate the development of critical and innovative technologies. It documents a historical sequence of choices made by strategists within a high-tech company. Rather than being dominated by simplified economic models guiding the decision "what to buy and what to make" when it came to advanced semiconductor design, the actors shaping the development were careful not to make hard choices. The evidence discussed indicates that a broad range of different factors were taken into consideration and that the influential people made a point of running different kinds approaches to outsourcing in parallel. Being active in a rapidly evolving and very competitive industry with few certainties, it seems to us, technology strategists hedged their bets. Re-integration, finally, was a matter of increasing control of innovation. On this view, re-integration was neither just a cyclic matter of old stable technologies nor a matter of inertia—that is when old habits shape the behavior in an un-reflective way. On the contrary, re-integration became a progressive move at a point when the structures put in place by collaborating firms did not sustain innovation.

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Appendix: What integrated circuits are inside a mobile phone?

The core technology inside a mobile phone is typically based on a chipset existing of three or more main components (Integrated Circuits) designed to collectively provide a complete functionality for communication and running applications.

The Radio Frequency Circuit (RF) sends and receives modulated voice or data signals to the mobile phone through the antenna(s). The RF circuit also transforms the signals into base band signal's, for further processing in the Digital Baseband.

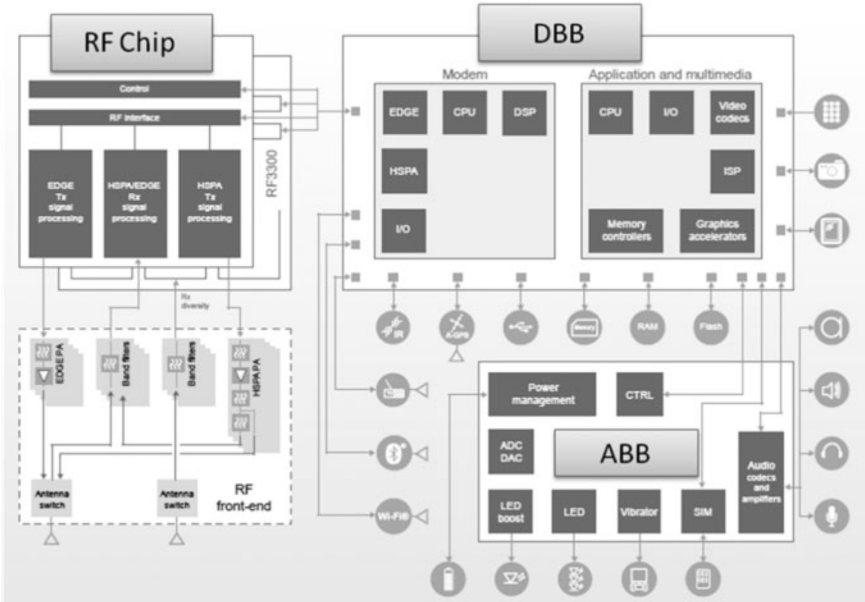

Figure A1 An example of the architecture of an EMP feature phone.

The Digital Base band (DBB), as an example in an EMP feature phone platform, can be seen as the phone processor where both the application software and the communication software are managed. It contains two sub-block's: the signal processing modem and the digital application processor. The modem deals primarily with communication processing in real time, which means that it is live and functioning constantly. The digital application is running the user-applications (e.g. the high user-interface: making a call, take a photo), which is not real time critical. The combination of application processor and the modem on a single chip is often referred to as a *fat modem*. In a more complex Smart phone platform application, the DBB could be split into two separate chips—a modem chip and an application processor chip. The separate modem will then be referred to as a *thin modem*.

The Analog BaseBand (ABB or Mixed Signal Circuit) is connected to the microphone and speaker and manages human voice, which is an analog signal. The ABB converts (voice) signals from analog to digital and vice versa so that the information can be managed and processed by the Digital Baseband (DBB). It includes the power management functions and connects to the SIM-card, which identifies the individual phone in the communication system.