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Title: The Case study of Sony transistor radio: Understanding the technological dimension of Disruptive Innovation

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1 Introduction

A new research topic of the Division of Engineering and Technology Management is “Understanding the Technological Dimension of Disruptive Innovation”. Specifically the research focus is on how to design the mechanism to create disruptive technology candidates in advance. Because of the nature of this research topic, qualitative research method using case studies, particularly multiple case studies has been selected as the most appropriate method to address our questions. Before extensive studies, we shall spend some effort first looking at one single case: The transistor radio developed by Sony in the 1950s. The single case is used as a revelatory case, which hopes to provide in-depth and stimulating insights. The case in point was the story of Sony in the 1950s. Although most of the key persons have retired or passed away, a substantial amount of archive was freely available in public websites as well as company publications. Documented over 50 years, they were objective and provided the details of the story from various angles, thus forming archival data which serve as the primary data that are complemented by interviews. The data collected in this case are presented in Table 1.

Table 1 Sources of the case study

TYPE	SOURCE NAME	DATE OF COLLECTION	SOURCE INFORMATION
Document	Sony history	April to July, 2007	http://www.sony.net/Fun/S/H/1-1/h2.html , http://www.sony.net/Fun/S/H/1-2/h5.html , http://www.sony.net/Fun/S/H/1-5/h6.html , http://www.sony.net/Fun/S/H/1-4/h1.html , http://www.sony.net/Fun/S/H/1-6/h3.html , http://www.sony.net/Fun/S/H/1-6/h2.html ,
	Sony Challenges 1940-1968	April, 2007	Genryu, published by Sony Corporation, 1988
	The Sony Vision	July, 2007	Author Nick Lyons, Published by Crown Publishers Inc., New York, 1976
	Made in Japan	February, 2007	Author Akio Morita, Published by Harper Collins, London, 1994
	How Europe missed the transistor	July, 2007	Written by Michael Riordan, on IEEE Spectrum, November 2005, p46-50
	Sony Radio	June, 2007	Sony transistor Radio 35 th Anniversary 1955—1990, house booklet published in 1990
	First Commercial Transistor Radio	June, 2007	TI Information Bulletin, http://www.ti.com/corp/docs/company/history/radio.shtml
	The TR-1's Golden Anniversary, 1954--2004	June, 2007	http://people.msoe.edu/~reyer/regency/ Website about the first transistor radio by Dr. Steven Reyer, a Professor in the Electrical Engineering and Computer Science Department at the Milwaukee School of Engineering

	Sony Service Note on Transistor Radio	July, 2007	Published by Sony Corporation, 1960
	Sony Servicing Guide	May, 2007	Published by Sony Corporation, c.1962
	Japan Electronics Buyer's Guide	May, 2007	Published by Denpa Shinbun Inc, Tokyo, 1962
	Japan Electric Industry	May, 2007	Magazine of various numbers from 1961-1964, published by Dempa Publications Inc, Tokyo.
	Sony turns small things into big profits	May, 2007	Article published in the Readers' Digest magazine, Great Britain, June 1964
	Sony succeeds like success	May, 2007	Article published in the Readers' Digest magazine, Great Britain, February, 1985
	The portable Radio in American Life	July, 2007	Written by Michael Brian Schiffer, published by The university of Arizona Press, 1991
	Transistor Radios: 1954-1968	July, 2007	Schiffer Book for Collectors by Norman R.Smith
	The Regency TR-1 story	June, 2007	http://www.regencytr1.com/Regency_Early_years.html
	The Japan Project: Made in Japan	July, 2007	A documentary film about Sony's early history in the US by Terry Sanders
	Transistor radios	May, 2007	Published on "TRANSISORIZED" in 1999, http://www.pbs.org/transistor/background1/events/tradio.html
	Sony: electronics ordered 'to go'	May, 2007	Written by Yoshiko Hara, on EETIMES, http://www.eetimes.com/special/special_issues/millennium/companies/sony.html
	Sony's RADNY RADIO	May, 2007	Published by Sony Corporation

	booklet		
Interview	Interview with Dr Yoshiyuki Kaneda ¹	April, 2007	Please see the appendix for the interview transcript.

2 Objective of the case study

Without explicit market demands and technologies available at hand, Sony determined to launch the transistor radio project and made the classic success of disruptive technology by intuition. Disruptive Technology has become a very important topic of research and practice because it could eventually topple a big incumbent although it was initially inferior in performance. However, this “initial inferior” characteristic has also given rise to the misperception that it was not technologically challenging. The data collected for this case are devoted to understand how shirt-portable transistor radios were created by Sony with great determination to overcome overwhelming technological challenges. We hope to extract some insights on how a company may create disruptive technologies by purpose rather than by chance.

3 Transistor as a disruptive technology

Christensen has clarified that disruptive technology is a relative term². Transistor was disruptive compared to vacuum tube in many applications such as portable radios. Hence, vacuum tube technology and tube based radios should receive certain coverage in our research before demonstrating the disruption by transistor via the theoretical framework of Disruptive Innovation in terms of trajectory diagram, key constructs and value networks.

3.1 The rise and fall of vacuum tube technology in the electronics industry

In electronics, a *vacuum tube* is a device used to amplify, switch or modify a signal by controlling the movement of electrons in an evacuated space. Vacuum tubes were critical

¹ Dr Yoshiyuki Kaneda joined Sony early in 1957 and he was a former Executive Deputy President and Representative Director of Sony Corporation.

² Christensen and Raynor, “*The Innovator’s dilemma*”, 2003

devices in electronics technology, leading to the development and commercialization of such technologies as radio broadcasting, television, radar, high fidelity sound reproduction, telephone, analog and digital computers, and industrial process control. It was the dominating technology in electronics industry from 1920 to 1960 before its replacement by transistors.

Nowadays, for most purposes, the vacuum tube has been replaced by the much smaller, less power-hungry, and less expensive transistor, either as a discrete device or in an integrated circuit. However, tubes are still used in specialized applications, such as in ultra-high-end audio systems, musical instrument amplifiers, some microwave ovens and some radar systems. For example, vacuum tubes inherently have higher resistance to the electromagnetic pulse effect of nuclear explosions. This property kept them in use for certain military applications long after transistors had replaced them elsewhere.

RCA, GE and Westinghouse were the key players in the vacuum-tube based radio industry as shown in Table 2.

Table 2 Main players in the vacuum-based radio industry

Cartel Arrangement for the U.S. Radio Industry		
Company	Field	Share of RCA
AT&T	Radio-telephone systems broadcasting transmission equipment	10.3%
<i>General Electric</i>	<i>manufacturing radio receivers</i>	30.1%
<i>Westinghouse</i>	<i>manufacturing radio receivers</i>	20.6%
United Fruit		4.1%
American Marconi	wireless spark technology	34.9%
Miscellaneous inventors		

RCA	Marketing Radio receivers	
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Source: Watkins, <http://www.sjsu.edu/faculty/watkins/radio.htm>

3.2 Demonstration of transistor developed in Sony as a disruptive technology

A *transistor* is a semiconductor device, commonly used as an amplifier or an electrically controlled switch. The transistor has replaced vacuum tube as the fundamental building block of the circuitry that governs the operation of computers, cellular phones, and all other modern electronics. Initially, the performance of the transistor was inferior to vacuum tube on the main attributes such as sound quality and reliability. However, it subsequently reduced the performance gap and enhanced its advantages, which allowed transistors to replace their vacuum tube predecessors, in the following ways:

- (1) Small size and minimum weight, allowing the development of miniaturized electronic devices;
- (2) Highly automated manufacturing processes, resulting in low per-unit cost;
- (3) Lower possible operating voltages, making transistors suitable for small, battery-powered mobile applications.

The first practical point-contact transistor was invented by William Shockley, John Bardeen and Walter Brattain at Bell Labs on 16 December 1947 (Emmerson, 2002) . Bell Telephone Laboratories coined a generic name for the new invention as “transistor” (Technical Memorandum of Bell Telephone Laboratories, 1948). Early transistors were chemically unstable and only suitable for low-power, low-frequency applications, but as transistor design improved, these problems were slowly overcome. Its importance as a scientific breakthrough which could have profound impacts to science and technology earned these 3 inventors the Nobel Prize in Physics in 1956.

The first workable transistor radio TR-1 was produced and commercialized by Texas Instruments and Regency in 1954. Due to the low frequency of transistors at that time, it

incurred high cost to get adequate radio frequency and this made TR-1 very expensive. Furthermore its size was large and the product was not commercially successful³ (Genryu, 1988). In 1955 and 1956, Sony had several early testing of transistor radio such as TR-52, TR-55, TR-72 and TR-6 that lacked the attraction and the appeal of the real miniature sets, and somehow failed to reach great sales numbers. In March 1957, Sony released the world's first real miniaturized shirt-portable transistor radio TR-63 with all miniature components, which went on to become the dominant design for the next two decades (Genryu, 1988; Morita, 1994).

After basic understanding of transistor and vacuum tube, the next question would be in what way or ways did it constitute a disruptive technology?

According to the dominant metrics of radio performance in the mainstream market, these early transistor radios were really bad, offering far lower fidelity and much more static than the vacuum tube-based tabletop radios that were the dominant design of the time (Christensen, 1997, p201). These transistors could not handle the power required to be used in the mainstream market such as application in tabletop radios and big floor-standing televisions. But if these deficiencies could be overcome, the transistors could be the successors to vacuum tubes which had the problem of being bulky, creating lots of heat, etc. Most of the leading electronics companies such as RCA, GE, and Westinghouse regarded transistors as potentially new radical technology which would help them to sustain their main electronics business (Christensen, 2004). They focused their R&D on improving the sound quality and fidelity of transistors. They invested as a group, in today's US dollars, between 1 and 2 billion trying to make the transistor good enough to be used in mainstream market but did not achieve influential commercial success after 10 years of intensive R&D effort.

Especially noteworthy were their responses to the successful Japanese imports during the late 1950s. An optimistic Westinghouse executive, C.J. Urban put it like this: "*We can meet*

³ Source also from: The Regency TR-1 story, based on an interview with Regency co-founder, John Pies. http://www.regencytr1.com/Regency_Early_Years.html. ; Sony history, <http://www.sony.net/Fun/SH/1-5/h6.html>, both accessed in July 2007.

foreign competition with innovation and creativity.” Benjamin Abrams, Emerson’s founder and president, was even more upbeat, predicting in mid-1959 that “*the Japanese import will kill itself off and disappear—within the next 12 months we will see a material decline in Japanese imports.*” They ignored the great impacts of Japanese miniaturized portables and continued to make larger transistor portables with premium sound quality largely for the mainstream home applications⁴.

SONY, being a small company then, did not have the same resources to pursue radical technology. But it discovered a new market composed of teenagers that valued the attributes of the pocketability of transistor radio based on much smaller transistors compared with vacuum tubes. It enabled teenagers to do something that they couldn't before—listen to rock'n'roll out of their parents' earshot, though the music quality could not compete with tabletop vacuum tube radios (Schiffer, 1991; Morita, 1994; Seeley, 2004;). According to Sony’s “Brands History”, “*in the mid 1950s, American teens had begun buying portable transistor radios in huge numbers, helping to propel the fledgling industry from an estimated 100,000 units in 1955 to 5,000,000 units by the end of 1958.*”⁵

The typical trajectories pursued by both large incumbents and Sony on how to improve and apply the transistor technology are illustrated in Figure 1.

⁴ The source of the information in this paragraph was mainly from “The Portable Radio in American Life” by Schiffer page 214-218

⁵ Source from: http://brands-history.info/?page_id=4

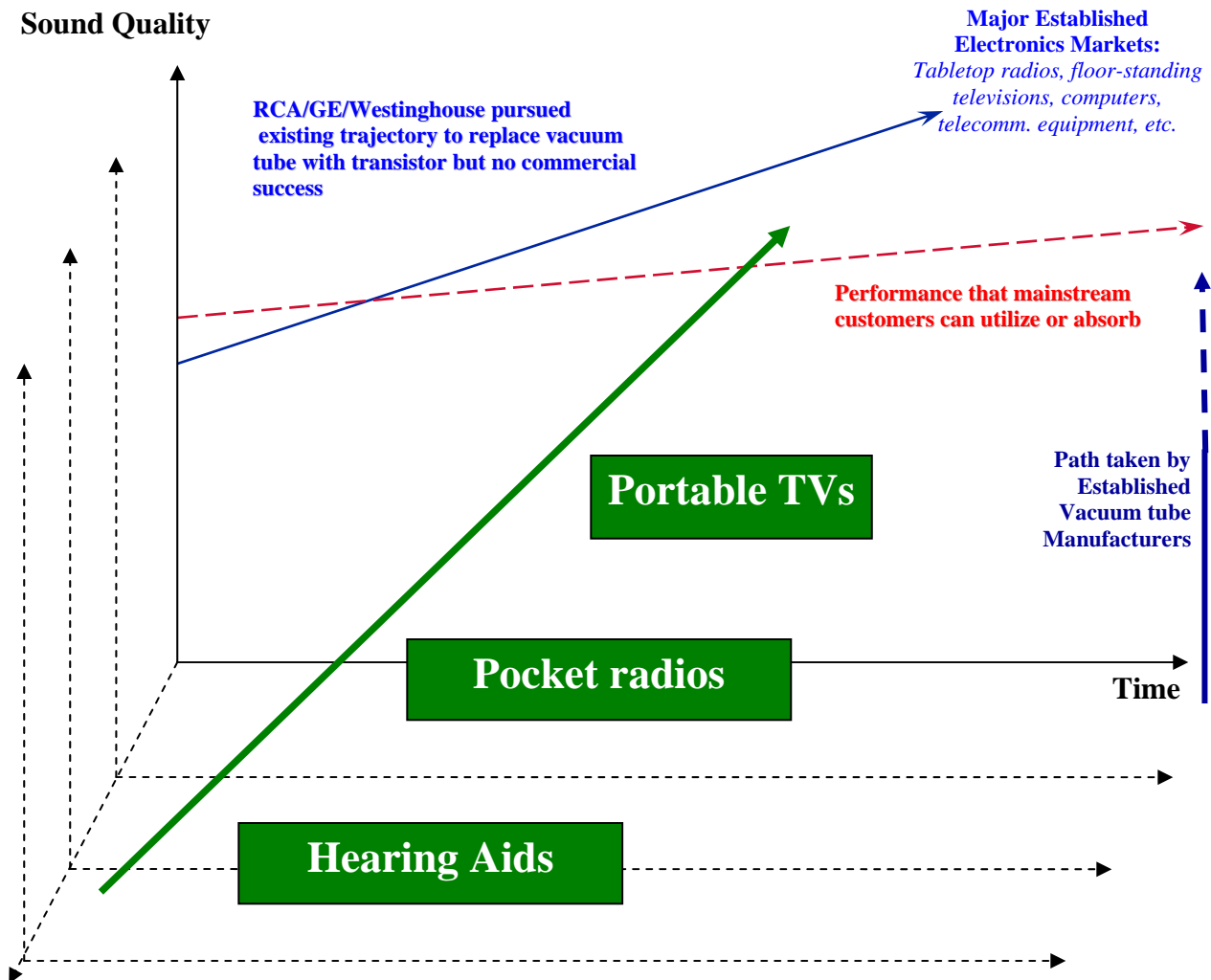


Figure 1 Sony pursued the new-market disruptive path

The first new market application of the transistor was in hearing aids around 1952, which happened to value the very low power consumption and less than one-tenth the cost of the tube models of hearing aids, but the hearing aids market was not the target of Sony⁶. The next was the Sony transistor radio introduced in 1955. Although it only had tinny sound and the batteries wore out quickly, it was miniaturized to be taken anywhere the teenagers wanted. Hence the inferior transistor radio that the mainstream customers disliked found a nonconsumption. The accumulative return from transistor radio provided strong financial support to further improve technical performance of transistors. SONY later introduced its

⁶ Source from: "The Portable Radio in American Life" by Schiffer, page174.

first portable television in 1960 thus making another successful disruption⁷. The 3 steps of disruption caused no pain to the leading electronics incumbents because they did not lose their existing customer base. As can be seen from the feedback of leaders of incumbent firms, they still aimed to meliorate transistors until it could substitute vacuum tubes in established applications which they considered as creativity and innovation, and even for the transistor based radios, they despised the miniaturization of Japanese radios as fad. However, in 1965, the transistors gradually became good enough in terms of sound quality and power requirement in big machines, so within 3 years all the customers got sucked out of the vacuum tube plane into transistor plane (Christensen, 2004)⁸. The large incumbents just vaporized overnight. The disruption process can be summarized in Table 3.

Table 3 The major elements in the disruptive innovation of transistor radio

COMPANIES	Disruptee: RCA/GE/Westinghouse	Disruptor: Sony
TECHNOLOGIES	Existing technology: Vacuum tube based radio	Emerging technology: Transistor based portable radio
ADVANTAGES IN TECHNICAL ATTRIBUTES (when transistor introduced in 1950s)	Primary/key attributes that mainstream historically valued: Sound Quality; Fidelity	Secondary/new attributes that mainstream ignored: miniaturized; low-cost; less power hungry.
MARKET	Existing market: Customers of Tabletop radios, floor-standing televisions etc, adults	New market: Teenagers who like to listen to rock 'n' roll
TIME OF DISRUPTION	1965—1968	

⁷ Source from: Corporate history of Sony Corporation, <http://www.sony.net/SonyInfo/CorporateInfo/History/history.html>, accessed in July 2007

⁸ Source also from: IT Conversations, Christensen, Capturing the Upside, March 17th, 2004. <http://www.itconversations.com/transcripts/135/transcript-print135-1.html>, accessed in July 2007.

The value network comparison is shown in Figure 2. The market was experiencing a shift in value networks. The transistor based radios got its commercial start in emerging value network which appreciated the pocketability and the low price before invading established value network that valued sound quality and fidelity. Established incumbent firms such as RCA and GE tried every means to cope with the challenges posed by the sustaining innovation along the value network in Figure 2a, expecting transistors could excel in mainstream values and further replace vacuum tubes. The ideal pattern depicted in Figure 2b illustrates clearly the innovator’s dilemma that precipitates the failure of leading firms since entrant firms like Sony laid solid foundation in the new value network and later disrupted incumbents.

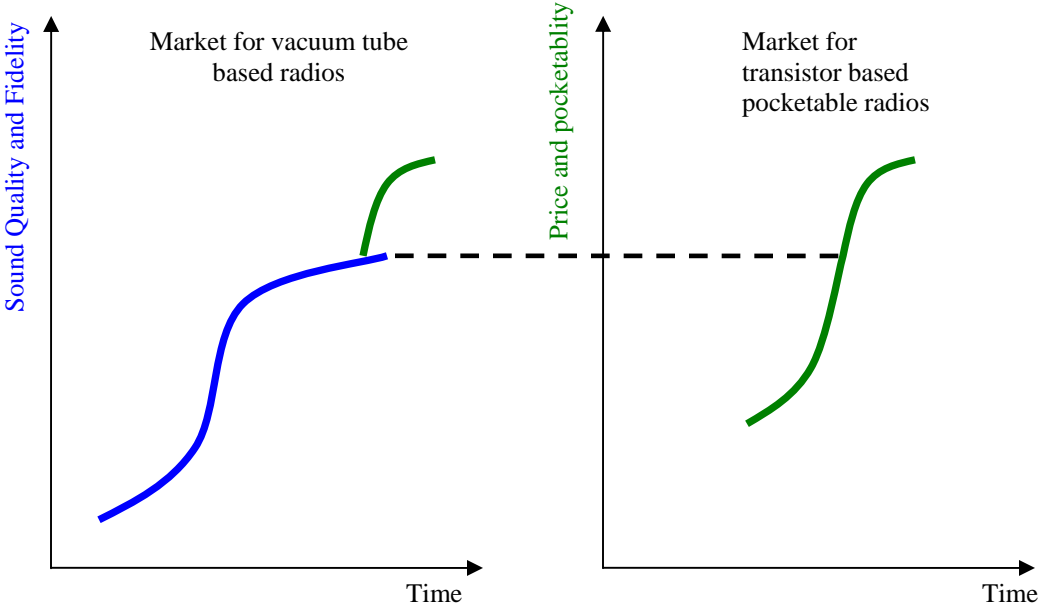


Figure 2a Value network of vacuum tube based radios

Figure 2b Value network of transistor based radios

Figure 2 Comparison of value networks

4 Findings on how Sony overcame technical obstacles

4.1 Background of Sony

In 1945, after World War II, Masaru Ibuka started a radio repair shop in a bombed-out building in Tokyo. The next year he was joined by his colleague Akio Morita and they founded a company called Tokyo Tsushin Kogyo in May, 7th, 1946, which translates in English to Tokyo Telecommunications Engineering Corporation. The name was changed to Sony Corporation in 1958⁹ (Morita, 1994). Before the businesses of transistor-based radio, Sony was just a small startup¹⁰ focusing on tape recorder production¹¹ (Morita, 1994).

Sony's greatest success in transistor radio was the pocket-sized TR-63 released in 1957. It was the first transistor radio to utilize all miniature components and was the first Japanese radio to be imported into the USA¹² (Genryu, 1988; Morita, 1994).

4.2 Sony overcame tremendous technical challenges to create transistor radios

(1) There was not even transistor technology available in the US

In the early 1952, Ibuka traveled in the United States and heard about Bell Labs' invention of transistor. He convinced Bell to license the transistor patent to his Japanese company. However, the patent did not cover technology, but only the rights to manufacturing the transistor¹³. While most American companies were researching the transistor for high-end

⁹ The source of Sony history was from: <http://www.sony.net/SonyInfo/CorporateInfo/History/history.html>,

¹⁰ In 1945-1946, Sony was a small startup beginning with 7 employees in one room. The initial business was electric rice cookers.

¹¹ Source also from: Corporate history, <http://www.sony.net/SonyInfo/CorporateInfo/History/sonyhistory-a.html> and Yoshiko Hara, "Sony: electronics ordered 'to go'" at

http://www.eetimes.com/special/special_issues/millennium/companies/sony.html, both accessed in July 2007

¹² Source also from Sony history, "Rest assured we can make it!" at <http://www.sony.net/Fun/SH/1-4/h6.html>, accessed in July 2007.

¹³ The source of the information in this paragraph was mainly from Genryu, 1988.

military applications¹⁴, Ibuka envisioned applying it to communications. When consensus was reached in the company, Ibuka went to the Ministry of International Trade and Industry¹⁵ (MITI) of Japan to obtain a license for manufacturing the transistor in Japan. MITI gave a point-blank refusal: “*Transistor cannot be produced so easily*” and they questioned how such a small factory could produce such a complex thing as the transistor (Morita, 1994; Genryu, 1988; Interview with Dr. Kaneda, 2007). Furthermore, in the harsh economy after World War II, when Japan was just beginning to accelerate its recovery from the war, foreign currency was so scarce in Japan that the bureaucrats at MITI could not see the use for such a device as transistor and were not eager to grant permission. Ibuka was eloquent on the possible uses of this little-known device, and it took him six months to convince the bureaucrats. At the end, in August 1953, Morita visited Western Electric and signed a provisional agreement contingent upon MITI’s approval. In the Genryu publication, this Totsuko-WE agreement did not cover technology, but only the rights to manufacture the transistor. Similarly, as Akio Morita said: “*This solid-state device was something completely new to our experience*”, “*it occurred to Ibuka that our company now had about one hundred and twenty employees, about a third of them graduate engineers and developing the transistor for our use would be a job that would challenge the skills of all of them.*” (Morita, 1994).¹⁶ According to Akio Morita, “*I must make it clear that the transistor being made at that time was not something that we could license and produce and use right off the shelf. This miraculous device was a breakthrough in electronic technology, but it could only handle audio frequencies.*”¹⁷

Not only MITI, even Ibuka’s old friend Shigeo Shima of Japan Broadcasting Corporation felt the same way. When Ibuka told Shima they would produce transistors and make radios with them, Shima replied: “*Transistor radio? Are you sure? Even in the U.S. transistors are used*

¹⁴ As introduced in vacuum tube application in 4.3.1, even today, vacuum tubes are still used in military applications long after transistors had replaced them elsewhere. It echoes the clarification in the literature review chapter that disruptive innovation does not necessarily lead to the extinction of the old technology being disrupted.

¹⁵ In post war Japan, the real power resides in two government agencies: The Ministry of Finance and the Ministry of International Trade and Industry (MITI). MITI decides which industries will be targeted for future growth, which companies will have access to foreign currency and technology, and which goods will be protected by tariffs’ and red tape from imports.

¹⁶ There were 40 engineers in 1948 when Sony started to research on transistor (Morita, 1994).

¹⁷ The source of the information in this paragraph was mainly from Genryu, 1988; Morita, 1994 and interview with Dr Kaneda in April, 2007.

*only for defense purposes where money is not object. Even if you come out with a consumer product using transistors, who can afford to buy a machine with such expensive devices?”*¹⁸

The transistor was not available to be applied in any market except hearing aids at that time and Sony did not have the technological know-how in transistors. Bearing the skeptical eyes of MITI and the warning from old friends, Ibuka set a firm R&D goal to pursue the project of developing an affordable and portable transistor radio.

(2) Material science challenge

The inventors of transistor were from the Bell Lab. The early transistor used a slab of germanium, the negative part, to which indium, the positive part, was alloyed on each side. After a period of intensive analysis, the Sony team reasoned that since negative electrons moved faster than positive ones, they could get higher frequency by reversing the polarity. That meant replacing the positive-negative-positive configuration to negative-positive-negative, but they could not find the right material. Indium had too low a melting point for their purpose, so they began experiments using gallium and antimony, but it didn't work well either. At one point, everyone seemed stumped and they thought of using phosphorus to replace antimony. Unfortunately, they found that Bell labs had already tried this approach and failed. As Morita said, *“It was very complicated work, and our project team went through a long period of painstaking trial and error, using new, or at least different, materials to get the increased frequency we needed.”* They even had to rebuild and virtually reinvented the transistor. Nevertheless, one team kept trying what was called phosphorus doping method, using more and more phosphorus in the process and finally succeeded at the end that greatly shocked the Bell labs scientists who gave up prematurely.¹⁹

¹⁸ Source from Sony history, *“Rest assured we can make it!”* at <http://www.sony.net/Fun/SH/1-4/h6.html>, accessed in July 2007 and Genryu. 1996.

¹⁹ The source of the information in this paragraph was mainly from Genryu, 1988; Morita, 1994 and interview with Dr Kaneda in April, 2007.

(3) Miniaturization challenge

In order to fit the transistor and other electronics components into their small radio, they needed to miniaturize almost everything such as the capacitor, the loudspeaker, the inductor, the transformer, the condensers, the micro-speakers and even the batteries. At that time, most of the components for the radio were produced by subcontractors. Sony could not purchase the components readily from the market and then directly assemble them in the box because most Japanese manufacturers produced capacitors, inductors, and other radio components that copied both the design and size of similar products made in Europe and the United States. Finding or designing other parts small enough to fit together was not easy at all. Ibuka went around to every individual component manufacturer and persuaded them to start to miniaturize every component from scratch and that was the major driver for a prosperous electronic industry in Japan since then. Ibuka managed to convince the industry to go with them and had created great impacts in history. Therefore, the French daily paper, *Le Figaro* described Mr. Ibuka as the father of the Japanese post war industrialization. The government of Sweden decorated him with Commander First Class of the Royal Order of the Polar Star in 1986.²⁰ Meanwhile, they designed and made the Printed Circuit Board (PCB) by themselves and eventually it became SONY Chemical Engineering Company that is very profitable subsequently.²¹

In pursuit of miniaturization and compactness, the world's first real shirt-pocket transistor radio was introduced by SONY in March 1957, by the model name of TR-63. It was the first properly designed miniature radio. This was what, at the time, marrying technology with glamour was really about. It was an amazing achievement of miniaturization and design that took the world by storm. It was not like any other product on the market at the time. It was the smallest (112*71*32mm) six transistor set in regular production in the world. Instead of the mixture of old and new technology which could be found in the previous models, the TR-63 was made with an all new imaginative design with many purpose-built miniature components (for example its microscopic solid dielectric variable capacitor).

²⁰ The source of the information in this paragraph was mainly from Morita, 1994, the interview with Dr Kaneda in April, 2007 and Nick Lyons, "*The Sony vision*", 1976.

²¹ Source: Interview with Dr Kaneda in April, 2007.

(4) Cost reduction challenge

In the nascent stage of commercial transistors, they were very expensive, with an average price in late 1953 of around US\$ 8 each, whereas an ordinary vacuum tube for radios was less than US\$ 1²². Hence, how to develop the mass-produced capability of transistor to make low cost but better yield production were questions very tough to address.

At that time, Japanese were not rich and they wanted to make transistor radio a product that anyone could afford. Hence, they had to set very aggressive pricing targets to keep the price as low as possible. If they planned to do cost reduction, they could not overlook the transistor itself which was a major part of the total cost of radio. The targeted cost of the transistor radio was 13000 yen. However, the cost of each transistor was 3000 yen and there should be 6 transistors in one radio. Hence, the cost reduction was an extremely challenging undertaking. With an attempt to meet the challenge, first of all, Sony employed cheap labor instead of high-tech manufacturing operations. For example, they made their own Printed circuit board. The PCB required labor-intensive fixes, including the use of wires and the soldering of a half dozen components on the board's underside. In addition, all connections were soldered individually by hand. Luckily, the Japanese labor costs in the late fifties were about one-seventh of those in the United States. Hence, the portable transistor radios of Sony could be cheaper than their counterparts of US competitors. Secondly, Sony not only tried every means to reduce the cost of manufacturing, they also strategically set the American market as their first target, because for a nation such as Japan, still recovering from its war wounds, the success in selling a high-tech consumer product to people in the world's mightiest industrial nation would be a significant coup²³.

4.3 The key roles played by core team members to overcome the impossible mission

A glance at the key members of the transistor development project could also help us to identify the key managerial characteristics underpin their ability to create disruptive innovation.

²² Source: The Portable Radio in American Life, by Schiffer, page 175

²³ The source of the information in this paragraph was mainly from the Interview with Dr Kaneda and the book "The Portable Radio in American Life", Schiffer, page 208

Dr. Leo Esaki had a Physics PhD degree from the University of Tokyo²⁴. He received various awards for his outstanding pioneering work and contributions to many areas in Physics; he also served on numerous international scientific advisory boards and committees. He joined Sony in 1956 to participate in transistor research, particularly the heavy use of phosphorus. Esaki and his colleagues discovered and described the diode tunneling effect on how subatomic particles could move in waves through a seemingly impenetrable barrier. He was awarded a Nobel Prize for this work in 1973²⁵ as we all know. However, few people might notice that the process using more phosphorus was sentenced to death by Bell Labs before their intensive experiments at Sony. As the head of Sony research laboratories, Makoto Kikuchi recalled in those days the level of research and engineering in the US was so high that “*the voice of Bell Labs was like the voice of God.*”²⁶ Esaki, one representative of Sony engineers, dared to challenge the authority and tried to think out of the box.

Akio Morita, another physicist, was the co-founder of Sony Corporation together with Masaru Ibuka. With a deep technical background, he could understand and support the technical R&D needed to improve the transistor. He also played a critical role in financing the project. Although he agreed with Ibuka to go into this unknown field, SONY as a small company did not have sufficient credit finance²⁷. He spent a very hard time selling and marketing the new product. He was the marketing champion in Sony’s serial disruptive innovations from transistor radio to Walkman.

Masaru Ibuka graduated in 1933 from Waseda University where he was nicknamed “genius inventor”. He co-founded the forerunner of Sony with Morita in 1946. He was instrumental in securing the licensing of transistor patent to Sony from Bell labs in the 1950s, thus making Sony one of the first companies to use transistor in non-military areas. Morita told the public, “*I always trusted him (Ibuka) absolutely—even when there was little more than a dream to*

²⁴ Source: Nobel Lectures, Physics 1971-1980, Editor Stig Lundqvist, World Scientific Publishing Co., Singapore, 1992

²⁵ The source of the information in this paragraph was mainly from the Interview with Dr Kaneda and the book “Made in Japan”, by Morita, page 69.

²⁶ Source: “Made in Japan” by Morita, page 68

²⁷ Source: The interview with Dr Kaneda, April, 2007

*build on. He has a great genius for innovation.*²⁸ ” Without explicit market demands in miniaturized shirt-portable radios, without straightforward method of manufacturing of transistor radios, without support from MITI and old friends, Ibuka dared to set a visionary R&D goal to aim for low cost while maintaining adequate performance at the very early stage of a science/engineering breakthrough.

Kazuo Iwama greatly contributed to the development of transistors. He was the general manager of tape recorder production and volunteered to head the transistor team. At the beginning of January, 1954, Iwama went to the US for transistor research which gave Sony the foundation it needed to work on the transistor. Iwama’s knowledge of transistors was limited to the little he had acquired on manufacturing basics from the text book called Transistor Technology. Western Electric would not provide specifications for the manufacturing equipments. He learnt everything from the plant tours. Based on his prodigious reports and Transistor Technology, the team managed to start making transistors and later in June 1954, they had begun to build a transistor radio prototype using both point-contact and junction-type transistors²⁹. Iwama was a scientist who knew the scientific mind; so he encouraged the research team to add more phosphorus to see further results when they reported to him. “*Well, if it looks to you as though you are getting interesting results, why don’t you just keep working and see what happens*³⁰?” The phosphorus method eventually worked, and expanding on it Sony developed the high-frequency device they needed.

Much of the credit of the TR-55 must go to the sterling efforts of Junichi Yasuda, the electric engineer and his circuit designers. The early transistors’ yield still left much room for improvement, and their characteristics remained uneven. They would never be commercially viable while the manufactures were still forced to select the good transistors and discard the defective ones. This was where Yasuda’s team came into play. At that time radio circuits were of the superheterodyne type. The team made as many as twelve different varieties of these local oscillator coils in an attempt to reduce the spread of characteristics. Apart from the circuits, TR-55 was ahead of its time in that it used a Printed Circuit Board (PCB).

²⁸ Quoted from Nick Lyons, “*The Sony vision*”, 1976.

²⁹ Source: Genryu, 1988, page 77.

³⁰ Source: “Made in Japan” by Morita, 1986, page 68.

Although today we take PCB for granted, a large amount of research and improvement went into its design. Yasuda's pioneering team had to do everything on its own. Team members searched for a wide range of adhesives and tried them out on copper foil, and what they needed was an adhesive that could withstand the temperatures (230~250°C) at which solder begins to melt. Also, instead of rolled copper foil, they had to use electrolytic foil— Morita lost no time to import it from US³¹.

Led by the above capable men with exceptional vision and courage, Sony did manage to bring shirt-portable radios into reality and later became one of the most powerful and respected multinational corporations in the world. Should the project be put into a group of more ordinary engineers without these outstanding scientists/engineers/leaders, as well as market champions, we might not be able to see a commercially successful portable radio developed so soon after the invention of transistor—a record of less than 10 years after a Nobel Prize breakthrough invention. The contributions of the core team members are summarized in Table 4.

Table 4 Major contributions by core team members of transistor project in Sony

NAME	POSITION	CONTRIBUTION	IMPLICATIONS
Leo Esaki	Physicist	Discover and describe diode tunneling effect, Nobel Prize winner	Technical talent, dared to challenge authority and think out of box
Akio Morita	Founder	Finance the project, marketing champion	Companies are in urgent needs of marketing champions such as Morita who has the tacit wisdom on how to create disruptive technologies in advance.
Masaru Ibuka	President	Obtain the license, set up the mission	Set counter-intuitive R&D goal to aim for low cost while maintaining adequate

³¹ The source of the information in this paragraph was mainly from Sony History on <http://www.sony.net/Fun/SH/1-5/h6.html>, accessed on July, 2007.

			performance at the very early stage of a science/engineering breakthrough.
Kazuo Iwama	Project leader	Responsible for R&D of this project, send prodigious reports and principles of transistor technology back to Sony	inter-disciplinary talent, good manager who knew the scientific mind.
Junichi Yasuda	Electric engineer	Design twelve different varieties of local oscillator coils. Design PCB all by themselves.	Technical talent, very creative and innovative.

5 Discussion

The revisit of the transistor radio R&D has provided an excellent insight into how disruptive technologies were created in Sony in the past. Several important lessons are discussed as follows:

(1) The low cost was obviously the critical factor in Sony's conquest of transistor based portable radios. Ibuka once said to Morita "*Let's make transistors for a radio which anyone can afford to buy*³²." From the beginning, they already had a vision to minimize the cost and consider the low-end segment of customers and they have put it into reality through overcoming cost reduction challenges. As a result, even the leading companies in U.S. such as Zenith mounted an aggressive all-American campaign, targeting two shirt-pocket models at teenagers in 1960s³³; their prices were still uncompetitive and by the end of 1963, no all-American sets survived. The low cost strategy from the starting day significantly contributed to Sony's success against not only incumbents of vacuum tube based radios, but also competitors in transistor radios.

³² Quoted from Genryu, 1988.

³³ The two shirt-portable radios marketed by Zenith were Royal 50 at US \$ 30 and Royal 100 at US \$ 40. At that time, the Japanese models sold at US \$ 20 on average, and the price of Japanese radios was still plummeting.

(2) We have also found that a clear and compelling vision to propose new values, relentlessly communicated by a company's senior team, is crucial in developing disruptive innovation of this nature. From mainstream customers' perspective, *Consumer Reports* remarked on the early transistor radios' poor tone quality, unpleasant distortion at high volume, low power output, and excessive background noise³⁴. If Sony attempted to improve their radios in above performances, it would have no difference from other U.S. producers. In fact, on October 18, 1954, the Regency TR-1, the world's first transistor radio was put on the market³⁵. At that time, Sony was close to manufacturing its first radios when it heard that an American company had beaten them to the punch. But they kept up the hard work and eventually produced a radio they named TR-55. However, TR-1, earliest models of Sony such as TR-55 and TR-72 had failed to create considerable success.³⁶ Buried in meditation for some time, Sony decided to speed up the miniaturization process and their work finally paid off with the world's first pocket transistor radio TR-63 1 year later. Because of the new value proposition in miniaturization, although it was static and coarse in terms of sound quality, it successfully marched into the teenagers market³⁷.

(3) Another impressive finding is that Sony was very smart to make R&D efforts in technologies which can support them to compete against nonconsumption. Ibuka clearly stated the vision of the new company: "*We shall maintain our business operations small, advance technologically and grow in areas where large enterprises cannot enter due to their size*"³⁸." Had Sony targeted consumers in established markets, the pocket radio would have failed as mainstream customers would have been disgusted with the crummy product because they had a better alternative (Christensen, 2004). But for teenagers, the alternative to a Sony pocket radio was no radio at all. By competing against nonconsumption, Sony set a more practical technical hurdle for itself: The product just had to be good enough in order to find

³⁴ Source: "The Portable Radio in American Life" by Schiffer page 177.

³⁵ Recall the introduction of the first transistor radio in 4.3.2

³⁶ The source of the information in this paragraph was mainly from: The Regency TR-1 story, based on an interview with Regency co-founder, John Pies. www.regencytr1.com/Regency_Early_Years.html, and Norman R. Smith, *Transistor Radios: 1954-1968* (Schiffer Book for Collectors)

³⁷ The source of the information in this paragraph was mainly from Genryu, *Sony Challenges 1940—1968*, Sony Corporation 1988 and *Early Sony transistor radios Mini-history* on <http://engforum.pravda.ru/showthread.php?postid=2272589>, accessed in July 2007.

³⁸ Source: "Sony, electronics ordered 'to go' ", written by Yoshiko Hara, published on EETIMES

delighted consumers. Another consideration to lock in teenagers as new customers is that in the late fifties, adults in America have strong loyalties to American-made products while teenagers had little loyalty to American brands and preferred to choose the cheapest portable radios³⁹. This also contributed to Sony's success in the American market.

(4) Because of the initial inferior performance and emergence in relatively insignificant markets, technologies in disruptive innovation could be disregarded as not very challenging. However, the above case study has given strong evidence that they might not be as simple as incremental R&D as they were indeed discontinuous. In this specific case, it was even challenging enough for a future Nobel Prize winner. Generally speaking, the R&D leading to the creation of disruptive technologies could indeed be extremely challenging and suitable as agenda for use-inspired upstream research in companies as well as universities, especially if they are based on new scientific discoveries. Companies are therefore advised to pay attention to the significant technological challenges in disruptive innovation, in addition to dimensions of business model and leadership.

(5) Starting with Japan's first tape recorder, Sony has established the unique competencies in transistor-related technologies and miniaturization. In the following years, they produced a steady miniaturization of today's typical range of consumer electronic products: transistor radio, transistor TV, videotape recorder, home-use video cassette recorder, 3.5-inch floppy disk, CD player, 8-mm video, Mavica, MiniDisk, digital VCR and flat-screen TV. The epitome of Sony's miniaturization effort is the Walkman, a product that has simply changed the way the world listens to music. From Sony's case, we could be aware of the possibility and necessity to mark technologies in disruptive innovation as part of the core competences for the company. The more novel the disruptive technology, the more promising and longer future the disruptive innovation could be expected, and thus it makes more sense to keep it as core competence. By creating disruptive technologies ahead of competitors, the company could command a substantial lead in exploiting them for subsequent disruptive innovations and building unique core competences.

³⁹ Source: "The Portable Radios in American Life" by Schiffer, 1991, page 218.

(6) The case in point tallies closely with the literature that disruptive innovation should be separated from the mainstream businesses whose resources, processes and values were the worst impediments to disruptive innovation. From the beginning, Sony has separated transistor research project from their mainstream businesses. Before the license of transistor patent from West Electric, Sony was simply too deeply committed to the tape recorder, which was just beginning to sell quite well⁴⁰. Kihara⁴¹ recalled the past: “*To develop magnetic-recording devices, a magnet tape laboratory was established. Then when we started transistor-related product development, a central laboratory was established to include transistor research.*” In contrast, the electronic giants recognized the threat of the coming transistor, they all took a license to it, invested hundreds of millions of dollars, and tried to cram it into the existing market and finally failed.

(7) We could not overemphasize that disruptive technological innovation may require an international perspective. Sony, as a Japanese brand locating their battlefield of shirt-portable transistor radios in U.S. has its own wisdom. Even they have tried their best to minimize the cost; the price could be very expensive in the eyes of post-war Japanese. However, compared with US equivalents, the Japanese transistor radios were very competitive in terms of price that enabled the dominance of a new disruptive innovation.

(8) A problem of great concern to incumbent firms is the cognitive frames of senior managers and engineers, which also corresponded with literature. In this case, the executives in U.S. electronics companies did not view the loss of the shirt-pocket portable radios to the Japanese as a calamity or as an omen of worse things to come. The best engineers in these companies wanted to ensure that they were the first to replace vacuum tubes by the new transistors and thus sustained their mainstream businesses. After all, it was a low-profit child’s radio. However, they eventually had to abandon the R&D venture after over 10 years of intensive efforts without producing commercially successful transistor radios. On the contrary, Sony focused their energy on miniaturization of the radio and the teenagers market that large enterprises ignored, thus became the eventual disruptor to the large incumbents.

⁴⁰ Source: Nick Lyons, “*The Sony vision*”, 1976.

⁴¹ Nobutoshi Kihara, the key engineer who best know for his work on the original Walkman cassette-tape player in the 1970s. He also worked on Japan’s first magnetic tape recorders.

(10) As a whole, the above analysis indicates that creating R&D strategies to promote disruptive technology is of great importance, not only to fill the gap in theory, but also could satisfy the industrial needs to sustain competitive advantages, to create new growth, or only to avoid awaiting their dooms as disruptees. Sony has unconsciously pursued the disruptive path and with appropriate creations of new technologies for disruptive innovation, Sony made a series of successful disruption and became one of the world's largest electronics conglomerates.

6 Conclusion

The case study has shown that Sony has set a visionary R&D goal to pursue new values and low cost in new markets and produced an affordable, reliable and portable radio with great determination regardless of overwhelming technological challenges. It is usually counter-intuitive to have an R&D goal which does not aim to achieve high-performance in a mainstream market, especially at the early stage of a science/engineering breakthrough. It is often very challenging at this early stage to aim for low cost while maintaining an adequate performance. The disruptive innovation began with a disruptive vision that was not consistent with the common wisdom of large incumbents. The setting of this vision has to be purposeful with the strongest support of the top management as disruptive technologies, in some cases, could demand significant efforts and skills. Indeed, creation of disruptive technologies is suitable to be set as an agenda for upstream research in industrial labs as well as in universities. Furthermore, companies could command a substantial lead in exploiting them for subsequent disruptive innovations and building unique core competences by creating disruptive technologies ahead of competitors.

The above case also indicates that creating R&D strategies to promote disruptive technology in advance is a worthwhile research direction not only in theory but also in practice which could provide another lens for managers to create opportunity for sustaining growth.

Appendix ---- Interview Transcript

Title: Interview on SONY's challenge in inventing the 1st major transistor application commercial product

Time: 12:30-13:30, April 18th, 2007,

Venue: SONY HQ, Tokyo, Japan.

Attendants: SONY : Dr. Yoshiyuki Kaneda, Mr Masao Toyama, and Mr Koji Kurata

NUS: Prof. Hang Chang Chieh, Ms. Yu Dan

Contents:

K=Yoshiyuki Kaneda

H=Hang Chang Cheih

T=Masao Toyama (Translating for Dr Yoshiyuki Kaneda when he spoke in Japanese)

Y=Yu Dan

K: As you know, the transistor was invented in 1947, 1947 to 1948. The 1st transistor radio was then invented by SONY using a transistor license from the US.

H: According to the document, in 1953, you licensed the transistor technology from Western Electric, but for 1954 to 1956, you introduced the first transistor radio.

K: I will help you understand the situation at that moment. I joined SONY in 1957, so at the initial stage, all the project leaders, researchers and engineers were senior to me. Almost all of them have passed away or have retired. Mr Masao and Mr Kurata could also help you and they quite understand the background and all the stories of SONY.

T: Background of Japan at that time: After the 2nd World war, we were defeated and we had to make a living. The engineers were available and we created a small lab. There were some establishments like major companies. So we have to make something new or different, which

was our critical need. Our first product was the tape recorder and it made a success that attracted more engineers to SONY. Ibuka tried to think of something new after the success of tape recorder, and he heard of news of transistor technology in 1948. The transistor technology was possibly the replacement of vacuum tube technology.

{Dr Kaneda subsequently showed us some introductory pictures of transistor and transistor radio for illustration. One picture: Vacuum Tube portable radio. So they are making vacuum tube portable radio. Very heavy, very big. }

T: Transistor could possibly replace the vacuum tube and had a wide application in radio and beyond. SONY has talented engineers at hand, so they should find a good project to do. As they were doing the research, the experts' suggestion for the transistor application was military application or hearing aids. So to give challenging objectives to talented engineers, transistor radio was a suitable project. Of course, we should have access to the patent. SONY was a small company at that time, so what we could do was to buy only the patent itself. SONY had to develop the transistor for radio by ourselves, because the Bell Lab did not develop transistors for radios. On top of technology problems, we had a foreign exchange limitation by the Japanese government, and we had to have a license to use dollars to buy technology from USA. Initially, the Japanese government did not give us a favorable response but finally we convinced them. So we have to start from very limited data from the research result of Bell Lab. The Project leader was Mr Iwama, who was a good engineer and good manager. He passed away in 1982. His background was science, not applied technology, and his background was Physics of the earth with expertise in earthquake. But Iwama has very good chemistry with Mr Ibuka. Mr Ibuka convinced Iwama to lead a few more experts to create the project team.

H: verify Kazuo was Iwama's first name. Kazuo Iwama

T: Iwama was a Physicist; Chemist was Imaaya; Mechanical engineer was Akanadei Kihawa; Electrical engineer was Yasuda and later Mr Kanoyi joined.

A transistor development task force was formed immediately with the most capable staff. Kazuo Iwama, general manager of tape recorder production, volunteered to head this team. Physicists Tetsuo Tsukamoto and Saburo Iwata, mechanical engineer Sukemi Akanabe, chemical expert Akio Amaya, electrical engineer Junichi Yasuda, and others from various fields joined together to work on the project with Iwama. <http://www.sony.net/Fun/SH/1-4/h6.html>

H: They were about 5 to 6 members of this core team.

T: Including the leader there were 8.

H: So you had physicist, you had chemist, you had mechanical and electronics engineers.

T: Yes, we needed good target setting and team building.

H: Is it possible to talk about the kind of challenges they have to overcome? Because from the literature, transistor was only for audio frequency, whereas you want radio frequency. You might have technical challenges like material science problem. Was there any war story which we could tell the next generation?

T: There are various kinds of frequency, high, low, and they are different. So as you mentioned, the high frequency transistor was for radio. The high frequency transistor would not only make radio possible, but also could reach out to FM and short wave radio as well as improving the quality of sound.

K: Purity needed to increase to 99.99999%, also crystal must be ideal.

T: So you could not have any contamination, as purity requirement was extremely high. For transistor, we have 3 layers, P, N, and P. To create those layers with crystal purity was indeed a challenge, and we had to make a good junction.

K: So how to create an ideal germanium crystal structure, not something easy. Especially how to improve the high frequency characteristics, that was very difficult at that time.

H: So how did SONY overcome this problem at that time? You needed very good scientists, people like Leo Esaki

K: My two bosses at that time were Dr Zikamodo, physicist and Mr Imaya. I worked so hard under these two bosses.

K: In order to improve the high frequency, it was necessary that one end layer introduced much high density electronic layer. In order to do that, it needed to add other items, introduce layer of the end.

T: In order to improve the high frequency feature of transistor, one person joined SONY one year earlier, who eventually became the Nobel Prize winner who was Dr Esaki. But at that time, he was still Mr Esaki.

H: So Esaki joined SONY in 1956.

K: Yes. So on the way of his investigation, he found the “Esaki Effect”.

T: So he firstly wanted to find why the transistor did not work on some occasions, and then finally found Esaki Effect. So... tranting pull the end, the characteristics went the other way, the effect became worse, so he wanted to know why and he found it. There were two problems, the one was wiring of transistor. Each layer had to connect to the outside, so the wire had to be mounted to the right part of the transistor; otherwise, you don't get PNP. Number 2, we had to avoid the contamination between the layers. We could not copy anybody else because on body did it before, so no benchmarking, the only choice was to do by ourselves. So Mr Esaki saw this feature of tunneling effect could have some other applications. Dr Kaneda followed up to find if any application for tunneling effect and it is not over yet. Mr Ibuka tried to miniaturize the layers so that you could fit it in the pazl. We had to limit the price low as Japanese were not rich, so we had to set very aggressive pricing targets. So we had to do cost reduction and transistor was the major part of the total cost of radio. The target cost was 13000yen, and we needed 6 transistors, and each transistor cost 3000yen, so the cost did not match. So we had created a cost reduction target. Every thing had to be miniaturized for portability. For example, printed circuit board.

H: This PC board was invented by you or you were the first one to use it?

T: We had to ask the component manufacturers/suppliers, we had to convince them to make new stuffs. Then we found out that we had to make PC board by ourselves, so eventually it became SONY Chemical Engineering Company which now exist and very profitable.

H: So this becomes your core competence?

T: Our core competence included how we influence the engineering development; we had to convince the component manufacturers, many many suppliers to make new things, small miniaturized parts. You could not put the components from the market and then put them together into the box, so miniaturization of components has to start from the scratch. So the component manufacturers started to work on the militarization, Ibuka managed to convince them, that's why there was a big electronic industry in Japan. The French government recognized and gave Mr Ibuka an award because he was the father of modern electronic industry in Japan, not only electronics, also chemical, mechanical, everything, so French government named him a large figure-- Father of post war industrialization with Ibuka. The most important challenge was how you create the influence, how you convinced the industry to come with you.

H: So in the process of meeting the challenge, he could had a very huge task to convince all the suppliers to go with you. Because a small company can not do this mass production, the challenge was not only on the engineering and so on, it included how to create the infrastructure that would support this manufacturing.

T: Mr Akio Morita played a critical role in financing the project. He agreed to Mr Ibuka to go into this unknown world/field. We do not have sufficient credit finance. He was a Physicist, a scientist. Mr Morita had a very good chemistry with Mr Ibuka because of his background in science. He had to make efforts and spend time to get money. He spent hard time selling it, marketing the new product. SONY didn't have a good recognition by the Japanese market, it was very small. The USA was a very rich country with a lot of money, strong soft power and strong curiosity for new products. We initially brought the products to USA and it became successful. Cheap price in low end market?

H: So you were initially more successful to sell it in USA rather in Japan?

K: Yes

T: Even today, Japan is a consensus community. Unless others are doing, Japanese are reluctant to do something new.

H: At that stage, you had very strong physicists, chemists, etc, you more or less reinvented the transistor. Because the original transistor was only for low frequency, you improved it to high frequency, you managed to miniaturize it and so on. But when we tried to check the patents at that time(1950-1960) , there were very few, was there any special reason prevent you or hold you back in protecting your technology?

T: We are not sure. But that belong to US patents, I believe we had patents in Japan.

T: Is it under materials science, or processes?

H: Maybe they were kept as trade secrets; for the material science, you did not want to file patent.

K: Yes.

T: You might not find the patent in transistor, you might find it under chemical or processes engineering, or materials.

K: Also the technology was changing fast and the next stage was silicon and another kind of circuits.

H: So that became obsolete by the new technology.

K: And also the diode tunneling effect.

H: May be we have to search tunneling effect also.

Y: yes, other patent classification like chemical engineering, process engineering..

H: Quite a lot of patents might be filed in Japan rather than in US, as SONY was still a small company at that time.

T: Our IP department told me that not to over-focus on this thing. They were very selective to file patents because there was cost involved and maintenance cost. If you don't use it anyway, why pay for cost? So they were highly selective. SONY is not in the TOP 10 of US patent holders, probably outside. Another point is to look how much you received in terms of royalties rather than paid. If you have useful patent, the revenue from the IP is surplus, if it's useless, you might be paying. I believe today, SONY is benefiting from patents.

H: But those data were not available in public so we could not verify it.

T: I don't know. The annual reports may give not very detail, but much of the trend.

H: Maybe you can quickly go through the pictures.

K: (Illustration on the documents and models)

H: Your education background is Physics?

K: Yes, Metallurgical Physics.