Supporting the development and commercialization of a disruptive loudspeaker network system: a case study

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1. Abstract

In the course of the last decade, an increasing number of publications have included the challenges related to disruptive or radical innovation. Many authors describe the struggles established organizations often meet, when engaging into projects involving disruptive products and services. However, most of these studies focus on a rather narrow scope, typically limited to the technology or market aspects.

Through a single-case study, this work uses a holistic framework offered by O'Connor & Rice (2013), which looks at disruptive innovation from a multitude of perspectives. Via this framework, this study analyzes a given organizations (TC Group) ability to support the development and commercialization of a digital networked loudspeaker technology aimed for professional fixed installations, implying a paradigm shift.

To estimate the above-mentioned ability, the organization has been analyzed, the market has been surveyed, and suitable technology candidates have been reviewed. Through this process, critical factors and uncertainties have been identified and a list of suggested actions is given. The aim for these suggestions is to prepare TC Group for engaging in this project involving a disruptive product.

In this case study it was found that one of the most critical factors, hindering success for disruptive innovative products, was related to the current strategy and the values buried in the organization, as being a firm that historically had been developing incremental innovative products with relaxed marked related risks.

2. Acknowledgement

I would like to express my deep gratitude to my supervisor Jacob Brix for the fruitful discussions we have had through the learning process of this master thesis. The pieces of advice given from Jacob have been very helpful in the research process, not least by pointing at relevant authors. Furthermore, I would like to thank Michael Böwadt (my manager at TC Electronic) for the sparring and support on the way. Similarly, I would like to express my gratitude to Anders Fauerskov (CEO at TC Group) and Michael Munch (VP of install) for their valuable participation in the organization analysis part. With regards to the questionnaire design and email invitation, I would like to thank Klas Dalbjörn (Product research manager at Lab.gruppen) for his great help. I would also like to thank the participants in my surveys, who have spent their precious time during the process of interviewing and filling out questionnaires. Last but not least, I would like to thank Bettina Arknaes (my wife), who has supported me throughout the entire process and accepting a mentally absent husband for a great many evenings and weekends.

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4. Introduction

Today, the typical professional audio solution for large and fixed installations in buildings is built around a centrally located “server room” that holds an *audio matrix unit* and several audio power amplifiers. These amplifiers are of the so-called constant voltage (70V/100V) type and they drive loudspeaker lines, which have many speakers attached per line. The loudspeaker lines are driven with a high voltage (and thus low current) to reduce transmission power loss from amplifier to loudspeaker, just like the mains power grid from power plant to the 115V/230V consumer. Each individual loudspeaker is paired with a transformer, which converts the high voltage audio down to a lower voltage that fits the low impedance loudspeaker. The matrix unit receives both audio and control signals from local and remote audio sources and control panels. From the matrix unit, the audio is distributed to the amplifiers and loudspeakers. This kind of star configured system has been the de facto standard in a quite conservative installation audio industry for decades.

An alternative to the above described architecture is to distribute the amplification and signal processing tasks over an intelligent network, such that network nodes (audio receivers and small local amplifiers sitting either in the loudspeaker enclosure or close by) on the network are capable of both selecting, processing and amplifying audio from any signal source found in the network.

This network based approach offers many advantages compared to the existing standard:

- Both the matrix unit and large central amplifier setup will be obsolete. This task is now handled by the network nodes. Saves cost.
- The transformer sitting in each loudspeaker today will be obsolete, since the small local amplifier can drive the low impedance loudspeaker directly. Saves cost.
- The proposed system is very easily scaled compared to the traditional system.
- System installation price is potentially lower, since power may be distributed using a lower voltage, meaning that cables can be mounted without any need for further electrical insulation (*conduit*), contrary to many 70V/100V installations. The installation can thus be carried out by IT installation companies or electricians, which compared to the very specialized audio installer charge less per working hour.
- A networked system is very easily monitored. Today audio install companies typically offer a service package for the buyer, which include system function verification on a regular basis. This technology offers an easy path to remote monitoring.
- The audio playback quality will be enhanced since the interaction between cable and loudspeaker will no longer have an influence on the transfer function from amplifier to loudspeaker. This typically degrades audio performance. Further, the bass reproduction will be enhanced since the audio power transformer is no longer a part of the system.

For an audio equipment manufacturing company like TC Group it is thus very appealing to engage in an attempt to begin a revolution in commercial audio installation with the new approach described above. The potential of being among the dominant players in this market is huge, and only a few companies embrace all competences and market channels required for developing and commercializing such as system.

TC Group (TCG) embrace the following audio equipment manufacturing daughter companies:

- TC Helicon (Canada, 20 persons, primarily engineers).
  Makes vocal processing audio processors.
- Tannoy (Scotland, 180 persons, primarily production).
  Makes loudspeakers for both residential and installation applications.
- TC Electronic (Denmark, 100 persons, administration, development, production).
  Makes equipment for install, production/broadcast studios and for guitarists/bassists.
- LabGruppen (Sweden, 80 persons, development, production).
  Makes audio power amplifiers for both install and touring.

4.1 Statement of Problem

Even though distributed and networked audio amplification for fixed installations has a huge potential and that TCG might have the required competences regarding both the issues concerning technology and business, there are still many challenges in such a process:

Organization
TCG is characterized by being a company that makes incremental innovation. Only relatively small steps are made, to reduce risk. The company is very market driven. There is a risk that TCG does not have the required mindset and ambidextrous capabilities for engaging in the development of a potential disruptive product. On top of that, you could fear that internal resistance will exist, since new skill sets are required in both development and sales. Finally, the development, marketing and sales processes will happen as cross-affiliate processes, which further complicates things and makes it harder to share goals and visions.

Market
Today, TCG sell the dominant portion of its install products to the dedicated audio installation company. With this new technology, a new market may be aimed for. This means that TCG might damage a good relation to existing customers, by offering cost effective and easy-to-use products to other markets, which may hurt the existing audio installation market. Another very important issue for TCG, is to fully understand the (latent) need of the customer (installation company). TCG has to solve existing problems and/or offer features that are more attractive and/or lower the price compared to traditional solutions, otherwise a new installation paradigm is doomed to fail. It is further assumed that it would be required (or at least be very beneficial) to join-up with an early-adopter kind of installation company to be able to enter the market.

Technology
Regarding technology there are several issues that have to be solved and decided. As a first question, should the power distribution be based on e.g. standardized *PoE* (Power over Ethernet) solutions, which would make the network nodes compatible with many of-the-shelf Ethernet switches, or should a proprietary solution be adopted that may be more cost and energy efficient? Secondly, should the audio and control mechanisms be based on analog or digital signaling and should standardized protocols be used? Thirdly, should the physical transport layer continue to be based on simple two-conductor cables (as in 70V/100V solutions today) or should multi-conductor cables like CAT5 be used? In the context of professional audio, wired connections are required for fixed installations, ruling out wireless solutions.

The above concerns make it obvious that the development and commercialization of a networked and distributed amplifier system for fixed loudspeaker installation is not a trivial task and that such a project may pose a tremendous challenge for TCG.

4.2 Aims of the study

The goal of this study is to (1) identify the critical factors and uncertainties expected to exist as a function of engaging in the development and commercialization of a potential disruptive product, and (2) make suggestions in how these factors can be handled and uncertainties be foreseen. It is the authors clear assessment that technology exists, which potentially can solve the fixed loudspeaker installation task in a better way than done by the 70V/100V traditional approach today. It is however not obvious whether the market will embrace solutions based on new technology, nor if TCG as an organization has the required capability and will, to aim for something outside the comfort zone of incremental innovation.

4.3 Research Questions

Based on the problem statement and purpose of the study, the following questions can be raised:

How can TCG support the development and commercialization of a networked and distributed amplifier system for fixed loudspeaker installation, which is potentially disruptive?

(1) Which organizational properties are required for such a project?

(2) Which market(s) should be addressed with this system and how can the system satisfy the market?

(3) Which technical solution will be applicable for the proposed system?

(4) What resources and competences are required to handle the development and commercialization of the system?

4.4 Relevance and Importance of the Study

This study has a high relevance and a high importance for TCG since they face an engagement towards a project that will differ from most other projects carried out by TCG. This project will potential be disruptive, both on the market, but also for the organization itself. Further, it is assumed that the development and commercialization of the proposed system will require resources and competences not found inside TCG today. Hopefully, this study will uncover these uncertainties and thus equipping TCG with knowledge that can be used to solve these issues.

To scholars, the study will offer insight in how an established firm may prepare itself for developing and commercializing a disruptive product, when this firm currently operates on a mainstream market, selling incremental innovative products. A vast amount of literature exist in the field of disruptive innovation, however most of this literature focus on the analysis and modelling of the disruptive innovation process seen in a retrospective perspective. This study however, makes suggestions to the measures that would make sense for a firm to do proactively in this context. Further, this study has a different perspective than a pure academic study would have, since it has been carried out inside the organization, as the author is an employee of TCG and is directly involved in the problem described in chapter 4.1 (page 6). This will potentially reveal important issues not necessarily identified when observing the organization from the outside.

4.5 Reading instructions

Following this chapter, you will find a review of the literature centered on disruptive innovation. Chapter 6 describes the research approach taken in this study and explains the methodology at a high abstraction level. From the concept of disruptive innovation, the study is partitioned into three main sub-topics (*Organization and resources*, *Market*, and *Technology*) that are investigated and elaborated in the individual chapters 7, 8 and 9. These chapters all have similar structure, containing (1) analysis, (2) methodology, (3) findings, and (4) discussion and sub-conclusion. The sub-conclusion in these chapters are all finalized with a table (Table 2, Table 6 and Table 12) listing identified critical factors derived from the findings. These tables hold three columns, (1) Critical factor, (2) Latency, and (3) Suggested action. In this context, the term Latency describes to what degree the given critical factor can be predicted or not. A high level of latency for a given factor means that it cannot be predicted. Finally, the thesis holds a closing chapter that elaborates the implications identified through this study and a conclusion is given.

4.6 Definition of Terms

Audio consultant	An individual or a firm specifying audio installations.
Audio contractor	A firm carrying out the physical task of audio installations, with mounting of equipment and cabling.
Audio matrix unit	A central element in centralized audio installations. The unit receives all audio signal and through a matrix function, it sends audio to the desired output channels.
AVL	Audio, video and lighting.
AWG	American Wire Gauge. A logarithmic scaled cabling dimension system.
BOM	Bill of material. A (price) list of the components constituting a given design.
CAT5	The standard Ethernet cable.
Conduit	A (metallic) tubing often required for loudspeaker cable shielding. In many US municipalities, electrical wires holding a voltage potential to less than 100Vpeak (70Vrms) is considered low-voltage and may be installed by non-electricians and without conduit. The local Fire Marshal decide whether conduit is required.
Crest factor	The ratio between peak value and RMS value of a given (audio) signal.
CRT	Cathode ray tube. Used for TV screens beginning in the 1930s
Daisy-chain	A chain of devices, electrically coupled in a serial manor.
dB	Decibel is a logarithmic unit used to express the ratio between two values of a physical quantity, often power or voltage.
Disruptive innovation	A successfully exploited radical new product, process, or concept that significantly transforms the demand and needs of an existing market or industry, disrupts its former key players and creates whole new business practices or markets with significant societal impact” (Assink, 2006).
EN54	A European safety standard family, covering passive loudspeakers and audio amplifiers.
Insertion loss	In this context, insertion loss is the loss introduced when transferring audio energy through an audio power transformer.
Low-end disruption	Market being overtaken by new and lower cost technology (having inferior performance).
M2M	Multipoint-to-Multipoint communication, meaning that each individual network node can receive from and transmit to every other node found on the network.
Market disruption	A new markets is created, consisting of (previously) non-consumers that now can afford and/or understand a given product and/or service. This is enabled by new technology or a new concept (the first SONY transistor radio is a good example).

Matlab	Matrix Laboratory. A mathematical software suite. Widespread tool used in natural science and engineering.
Non-consumers	See Market disruption
P2P	Point-to-Point network communication.
Plenum space	A plenum space is a part of a building that can facilitate air circulation for heating and air conditioning systems, by providing pathways for either heated/conditioned or return airflows, usually at greater than atmospheric pressure. Typically used to house cables (which require plenum rating due to increased risk of flame spreading in case of a fire). Often drop-ceiling airspaces are considered plenum space.
PoE	Power over Ethernet. A standardized (IEEE 802.3af / IEEE 802.3at) way of distribution DC power over network cables.
Radical innovation	See Disruptive innovation
RJ45	The standard Ethernet connector.
RMS	Root Mean Square. The RMS value of a sinusoidal waveform is 71% of its peak amplitude. Similarly, the nominal RMS voltage in European electrical outlets is 230V, whereas its peak voltage is 325V.
SMPS	Switch-mode power supply. A technology where the voltage frequency is increased before passing it through a transformer. The purpose of this frequency increase is to enable the use of a physical much smaller transformer.
UA	Unit of analysis. In this context, UA is the part of the organization being analyzed.
Voice coil	Together with the permanent magnet, the voice coil moves the membrane in an electrodynamic loudspeaker and thus emits sound.

5. Review of the Literature

A vast amount of literature exist about product innovation. However, this study will focus on the challenges a disruptive product may cause for a firm when developing it and bringing it to the market, when using radical innovative approaches. The aim of this literature review is thus to point at previously research in that field along with other important work carried out on innovation as a broader term.

Disruptive and radical innovation can be defined in many ways. In his article from 2014, Brix defines radical innovation as a *paradigm stretching activity*. This radical innovation activity leads to a significant positive change in business model, process or product – resulting in new performance features, significant cost reduction or a new line of business (Brix, 2014).

As illustrated in Figure 1, Assink (2006) distinguishes between incremental innovation, disruptive technologies, disruptive business concepts and breakthrough innovation. In his study, he uses (1) a flat TV monitor as a disruptive technology example, (2) the SONY Walkman as a disruptive business concepts example and finally (3) cellular mobile telecommunication as an example of breakthrough innovation. For (1), new technology is used to offer a similar product (smaller physical size, but similar features) to an existing market where existing CRT based TVs will be replaced by LCD or plasma based TVs. For (2), existing technology (cassette tape playback system) is used with a disruptive business concept, leading to a new market (young people can afford a portable music player). For (3), both ingredients are present. A new technology (radio based telephones using compact, low power electronics) enables the creation of a portable product that suddenly opens a new market with huge potential. Assink (2006) thus defines disruptive innovation as:

"A successfully exploited radical new product, process, or concept that significantly transforms the demand and needs of an existing market or industry, disrupts its former key players and creates whole new business practices or markets with significant societal impact" (Assink, 2006).

This definition will be used in this study, for the terms disruptive and radical innovation.

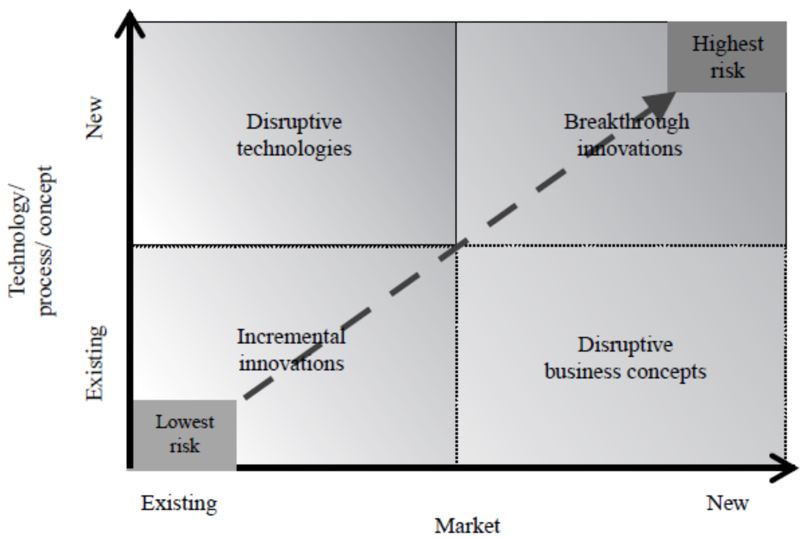


Figure 1. Innovation application space (Assink, 2006).

It is well known that the development and marketing processes comprising disruptive product or service innovations, posed a completely different set of challenges for a firm comparing to products or services having a more incremental innovation level. This difference is elaborated by many authors and will be described in the following sub-chapters.

5.1 Leadership

To foster the capability of developing products having a disruptive innovation level, the senior leaders within a company need to support it. They need to paint a clear picture of the purpose of engaging in a potentially risky venture and share the overall innovation strategy and business goal with the rest of the company:

This type of leadership offers a vision of what could be and gives a sense of purpose and meaning to those who would share that vision. It builds commitment, enthusiasm, and excitement. It creates a hope in the future and a belief that the world is knowable, understandable, and manageable. The collective energy that transforming leadership generates, empowers those who participate in the process. There is hope, there is optimism, there is energy (Van de Ven, 1986).

The senior leaders need to show their willingness in the increased risk of engaging in radical or disruptive innovation projects. Typically the short term payback of such projects are lower compared to development projects having a more incremental character, perhaps based on an existing product with the aim of a lower price and/or a richer feature set. However, seen over a longer time horizon, it may be required to engage in a risky radical innovation project, to improve the market position of the company. During this process, it is important that leaders offer their staff a safe space where they can explore ideas and praise them for using their discovery skills (Chang, 2012; Dyer, et al., 2013).

The required skillset for team members working on a project including disruptive elements may be very different from team members working on incremental innovation projects (Henderson & Clark, 1990; Herrmann, et al., 2007). The latter group has often acquired several years of expertise in effectively carrying out predictable tasks and is evaluated on that scale: being able to predict a given development phase and executing it. Often these estimates were given as a function on experiences from similar projects in the past. However, radical or disruptive projects are very different from that. It may require experiments with an uncertain outcome and the acceptance that failure rate during such a project is typically much higher. It is thus very important that the project evaluation criteria is different from the predictable, incremental innovation project. The innovative leader has to be prepared for failures and setbacks during the disruptive innovation projects, simply because only limited foundation exist. Furthermore, he needs to be able to put together the right team of people that thrive and excel when working in an uncertain environment, and very important: release them of any bonds that ties them to the past, like maintenance of old projects (O'Reilly & Tushman, 2004; Christensen & Raynor, 2013).

Being aware of changes in either market conditions or technology is critical for disruptive innovation. Organization leaders have to integrate this information and take the required actions. Many studies show that incumbent leaders were very aware of changes in the environment – and that these changes ended up disrupting their own business. In fact, they actually even pioneered them in some cases. Nonetheless, other companies often ended up harvesting the fruits from this technology maturing process (Paap & Katz, 2004). This illustrates that idea generation and technology maturing is not a guarantee for success. It is also vital to fully understand the market and know how to launch a disruptive product in an optimal way.

5.2 Market

In the 18th century, Benjamin Franklin stated that you should *Drive thy business; let it not drive thee*. This business philosophy was the typical innovation attitude up until the 1960s, where the viewpoint was that the company knew what the best product was and the costumer was not really considered as being a part of the innovation process at all. In the mid-1960s, companies began moving from this technology-push approach to a more market-pull orientation, where the needs and wishes from customers were used as input to a linear innovation and development process. Up though the 1970s the importance of constantly tracking the customer needs and requirements was realized, and this information was now used as an integral part of the product development. The trend of involving the customers more and more has continued until present, where the concept of user-driven innovation today is a fully accepted method of conducting product development.

In his very famous book, *The Innovators Dilemma*, Christensen (1997) presents the *Disruptive Innovation Model*. This model predicts how entrant companies disrupt incumbent companies. Typically, the incumbent companies serve an existing market with incremental innovation. According to Christensen, the performance improvement pace offered by a given technology exceeds the rate at which the market can absorb new technology as illustrated in Figure 2. This means that a continuous product improvement rate will at some point in time *overshoot* the market absorption capability. This situation will typically be the case for incumbent companies being very focused on serving their existing market using Technology A. The incumbent company will now be very vulnerable for entrant companies offering cost effective products or services based on a disruptive technology B. Often the incumbent is fully aware that the low end of the market is now being served by the entrants. However, no alarm bell is activated, simple because the incumbent firm can now focus on the profitable high-end market. As time goes by, Technology B eats its way up through the market, while the efforts of further improvements of Technology A will not pay back. Typically, the incumbent company will react too late, and the market is lost to the entrants. Christensen (1997) calls this phenomenon *low-end disruption*. Several real-world examples are given from steel mills being disrupted by mini-mills to hard-disc drive products being disrupted by new magnetic plate technologies.

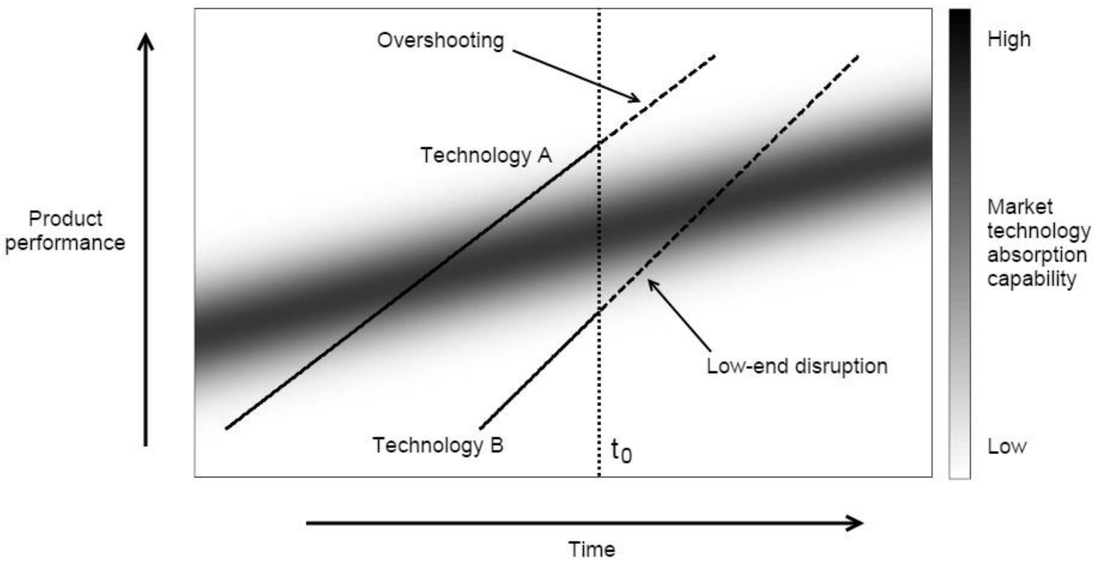


Figure 2. The Disruptive Innovation Model (Christensen, 1997).

Christensen distinguishes between low-end disruption and *market disruption*. In the latter case a new market is created for the (previously) non-consumers, which are the group of customers that now can afford the product and/or understand how to benefit from it – and this situation is optimal for a company due to the lack of competition.

In the follow-up-book, *The Innovators Solution* from Christensen & Raynor (2013), it is stressed that a company need to focus on the *job-to-be-done* for a given new product or service:

Companies that target their products at the circumstances in which customers find themselves, rather than at the customers themselves, are those that can launch predictably successful products. Put another way, the critical unit of analysis is the ***circumstance*** *and* ***not the customer*** (Christensen & Raynor, 2013).

In the book, this is further exemplified by a story about the attempt to boost the sales of milkshakes in a fast-food chain of restaurants. As a first attempt, the customers were segmented into categories and an optimal milkshake were designed to each category trying to please each group in the optimal way. This effort had only a slight effect. The next attempt was to observe the buying pattern. During that process it was quickly found that two typical "milk-shake situations" existed. The first situation was in the morning, where individuals bought the milk-shake to-go – the second situation was in the evening, where parents bought it as a dessert for their kids after a meal. It was discovered that the "morning shake" had the purpose of pastime for commuters that had to sit in their car for 30-60 minutes. To design an optimal milk-shake for that purpose, it had to be able to preserve its viscosity longer than the typical shake. For the "evening shake", the size of the milk-shake was found to be critical, since the child drinking it after a meal, typically did not have any room left for a large milk-shake and the consequences were that the parents were yelling about the children not eating their food. This situation explains very well why you should focus on the circumstance rather than the customer only. In a new product definition phase this is done most efficiently by first observing the customer and asking questions later (Christensen & Raynor, 2013).

In their article from 2006, Slater & Mohr discuss how optimal commercialization of a product based on new technology is carried out. They seek to find the best fit between *Market Strategy*, *Market Segment*, and *Customer Orientation*. Their model is presented on the rightmost part of Figure 3 (page 15) along with the innovation adoption lifecycle curve (left). As other authors (Rogers, 2003; Moore, 1999), Slater & Mohr distinguish between the following different market segments. (1) *Innovators*, which are typically enthusiastic about new technology and feel a pride in being a part of a technological revolution. Further, they tolerate initial glitches existing in the new revolutionary product. (2) *Early adopters*, which can be looked upon as visionaries that are attracted by the high-risk, high-reward nature of radical innovative products. In contrast to the innovators, they are primarily engaged in new technology because of its potential economic gain seen over a longer time horizon and they expect quick-response technical support in case of "bugs" in the (often) non-matured products. (3) *Early majority* consist of pragmatist that are motivated by evolutionary changes, which potentially causes increase in productivity. Moving from the early adopter to the mainstream market has always been considered a huge challenge, because this dominant part of the market requires proven and reliable products. The challenges of moving products based on new technology from early adopters to the mainstream market is the well known phenonema *Crossing the Chasm* (Moore, 1999). (4) *Late majority* are conservative customers that require a 100% bulletproof solution that has proven its worth over many years on the market. They are very technology shy and risk averse. (5) *Laggards* are very skeptical towards new technology and prefer the status quo. They will resist new technology and do not believe that innovation can increase productivity. Only when all other alternatives are worse and cost of the new technology is very favorable they will engage in using it.

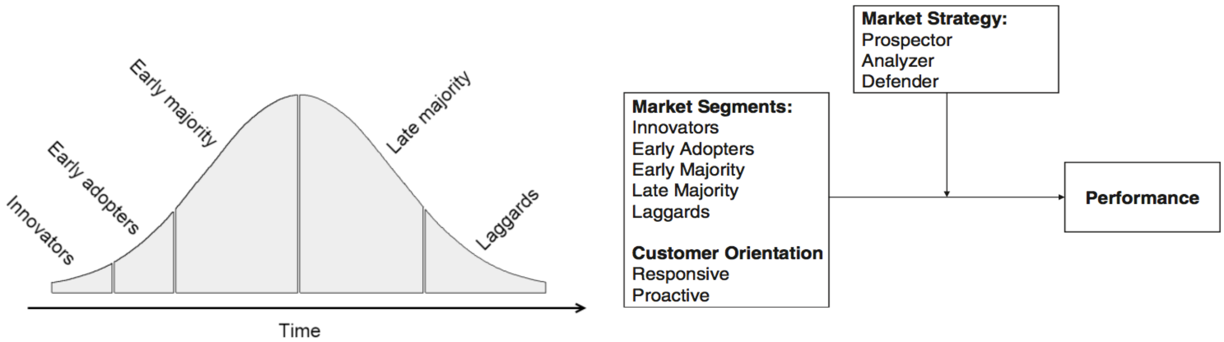


Figure 3. Commercialization of technological innovation (Slater & Mohr, 2006).

According to Slater & Mohr, commercialization of a disruptive innovation poses a threat. Particularly for companies having an *Analyzer* or *Defender* market strategy. Such companies are typically very focused on serving the current needs of their existing customer, which represent a barrier for taking disruptive innovation to the market. Therefore, they suggest that a more proactive market orientation should be taken, in which the company has to be more committed towards understanding both the expressed needs and not least, the latent needs of their customers. In their study, they present initiatives that will enable such understanding: (1) A direct contact between customer and cross-functional team representing the company developing the disruptive product. Ideally, this contact is established through face-to-face meetings, where many aspects are discussed – both businesswise and technical and this requires meeting participants with different skill-sets. The direct contact further help in getting rid of potential "communication filters" that distort the true picture of the customer's problems and needs, if communication has to travel both up and down the hierarchies in technology providing and technology buying organizations. (2) Using *empathic design*, by *observing* the customer problem-solving process, more than just listening to what the customer is actually saying. Often people repetitively solve problems without even knowing it, which makes them unable to see that the problem could be solved much easier with a new system design. The output of the emphatic design is a rich understanding of a given environment and it enables the designer to extrapolate into the future and make a qualified guess on a suitable feature-set for a given product.

5.3 Organization

An O'Reilly & Tushman study from 2004, which according to Google Scholar is cited by more than 1200 authors (May, 2015), describes the *The Ambidextrous Organization*. In their study, they wanted to learn how the relation is between the organization structure and having success in developing and commercializing disruptive products and services. They looked at 35 attempts of making and introducing breakthrough innovation on the market (emerging business), executed by 15 different business units, across 9 different industries. They further categorized these business units into four different organization structures: (1) *Functional designs*, where the project teams working with the emerging business were integrated into the existing organizational and management structure. (2) *Cross-functional teams*, where the project teams working with the emerging business were integrated as in the functional design, but with its own management structure outside the existing hierarchy. (3) *Unsupported teams* that were setup outside the existing organization and management hierarchy. (4) *Ambidextrous organization*, where the functional design is mirrored and the established team operates as an independent unit using having their own processes and cultures, but are still a part of the existing management hierarchy as shown in Figure 4 (page 16).

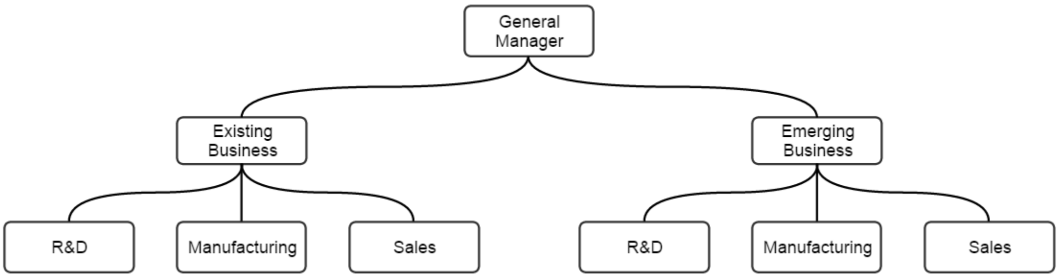


Figure 4. Ambidextrous organization *(O'Reilly & Tushman, 2004)*.

In their study, they found that the ambidextrous organization was superior regarding emerging business success. Within the group of business units organized in that way, the objective was met for nine out of ten projects, where only very few of the business units organized as functional designs, cross-functional teams or unsupported teams reached theirs. According to O'Reilly & Tushman, the advantage in an ambidextrous organization design (for disruptive product development and commercializing) is obvious:

At a theoretical level, it's easy to explain why ambidextrous organizations would outperform other organizational types. The structure of ambidextrous organizations allows cross-fertilization among units while preventing cross-contamination. The tight co-ordination at the managerial level enables the fledgling units to share important resources from the traditional units - cash, talent, expertise, customers, and so on - but the organizational separation ensures that the new units' distinctive processes, structures, and cultures are not overwhelmed by the forces of "business as usual." At the same time, the established units are shielded from the distractions of launching new businesses; they can continue to focus all their attention and energy on refining their operations, improving their products, and serving their customers.

Christensen & Raynor (2013) share the viewpoint that an existing business mindset obstructs projects involving disruptive innovations. They claim that an organization that measures all projects on the same timescale, and expect that disruptive innovation show the same return on investment rate as sustainable innovation, are doomed to fail. Disruptive innovation typically aims for lower markets compared to the existing business and/or other market segments being either the innovators or early adopters. It cannot be expected that these markets can be addressed using the same cost structure as the existing markets. It is believed that in projects having a disruptive nature, the top management should be *patient for growth but impatient for profits*. In other words, it cannot be expected that disruptive products can penetrate the market with the same pace as incremental innovative products, which have references to the market from day one. However, Christensen & Raynor stress that it is important that the new technology quickly show its potential, i.e. *whether real products create enough real value for which customer will pay real money*, to avoid following the wrong strategy for a long time.

Another soft spot in many organizations dealing with disruptive innovation is the middle management. Typically these managers have previously lead teams addressing the mainstream market with sustainable innovations for years – and they have become very good at it. They know how to deal with the political system inside the organization and how numbers should look like to get a project approved. Additionally, they are themselves evaluated on project performance (return on investment), therefore often pushing in the direction of the "safe bet", which is a product based on previously harvested experience having a low level of uncertainties. Further, middle managers are often very focused on reaching the next level in their own personal carrier and therefore they prefer projects having a relative short duration, to be able to prove their worth before they make the carrier shift.

In his very relevant study from 2012, Chang points at the following five main innovation inhibitors for radical innovation in established large companies. (1) *Limited organizational searching* is related to the “not invented here” syndrome. Organizations tend to look inward and thus ignoring important new findings through external networks. Further, leaders of established companies cannot fully understand the potential of a new technology, seen over a longer time horizon. (2) *Insufficient organizational planning and evaluation framework*, is the lack of acceptance that radical innovation need to evaluated differently compared to incremental innovation, where stage-gate methods are often used along with various cash-flow analysis methods. This perspective might inhibit the commercialization of radical innovation, which by nature is a higher-risk game. (3) *Rigid organizational routines and culture*. As suggested by other authors (O'Reilly & Tushman, 2004; Christensen & Raynor, 2013), Chang also finds that incumbents have a hard time breaking out of the mindset that are so very focused on pleasing the existing market. The organization culture and values have been built through many years serving this market with incremental innovation and the foundation of the company resides on that. This makes it very hard to suddenly change course; the core competences achieved by serving the mainstream market now become the core rigidities for radical innovation. (4) *Incorrect staffing, compensation and reward systems*. According to Chang, salary-based and fairness-emphasized compensation along with internal staff re-use are among the major barriers to development of radical innovation, thereby suggesting that compensation on a more individual and performance based level would be beneficial. (5) *Reluctance to experiment in unknown territory* is found in most established companies. Typically, several years have been spent in understanding the mainstream markets on which they operate. They are therefore quite reluctant in moving away from well-known and predictable methods and accepting that disruptive innovation is a *process of successive approximation, probing and repeated learning, each time striving to become one step closer to a winning combination of product and market*.

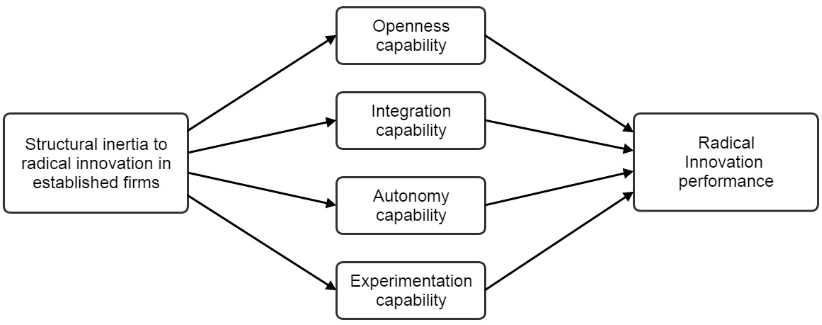


Figure 5. Radical innovation performance as function of organizational capabilities (Chang, 2012).

Based on his findings, Chang presents a model that links four organizational capabilities to the radical innovation performance of a company. An illustration of the model is presented in Figure 5. The hypotheses in his model (relation of the four capabilities to performance) is quantitatively tested through a survey to top 500 Taiwanese manufacturing firms and from answers from 112 respondents, where all four hypotheses were confirmed. To measure the level of Openness, Integration, Autonomy and Experimentation, relevant questions were asked for these factors. A full questionnaire item list is presented in Appendix G.

5.4 Technology intelligence

In a study from 2003 based on several other authors, Bucher et al. present a generic framework for disruptive technology intelligence and evaluation. The framework consists of the five main processes illustrated in Figure 6 (page 18). The framework consists of a *Technical Evaluation* part and a *Technology Introduction* part. The timing of the first process *Initiation* in the technology evaluation part is often critical since it is important to “get on the train” before it is too late. If this is missed, the following processes like technology evaluation and finally technology introduction might be delayed and there is a risk that return on investment will be reduced since technology is obsolete when the products (that use the specific technology) is developed and manufactured and finally ready for the market.

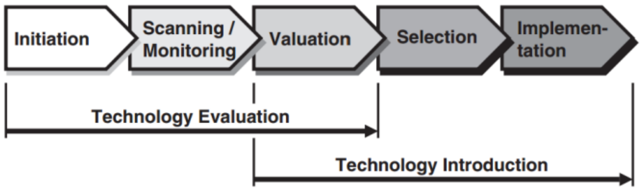


Figure 6. A framework for disruptive technology intelligence (Bucher, et al., 2003).

In the study, Bucher et al. describes the *Scanning/Monitoring* as the process where relevant information about the technology is required. Regarding this process, two perspectives are discussed, (1) *Outside-in* (scanning) and (2) *Inside-out* (monitoring). Originally, these perspectives were presented by Peiffer (1992) and later elaborated by Lichtenthaler (2006). The outside-in perspective has a primary focus on new and (for the market) unknown technologies and follows a strategy continuously scanning for the high-level trends to identify science and technology developments broadly. The inside-out perspective focuses on known technologies, which could be either internal or external. The inside-out perspective is typically more detail oriented with an initial orientation towards a product, which is seen in many manufacturing companies.

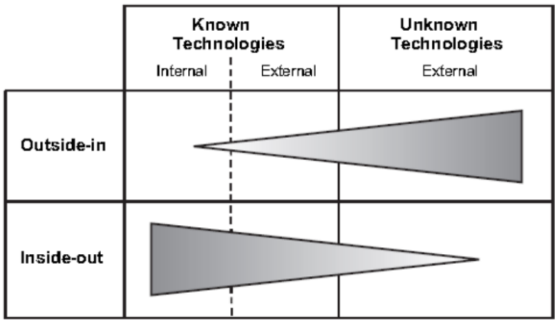


Figure 7. Perspectives on technology intelligence (Lichtenthaler, 2006).

To investigate the potential business impact from the technology the *Valuation* process (see Figure 6) is critical. The following three basic conditions will ensure an effective process: (1) criteria that define guidelines for the persons involved in the process, (2) form (who, when, what) and finally (3) the method that should be used in the valuation process. Bucher et al. (2003) claims that the valuation part is the weak link of the entire technology evaluation/introduction process and special attention should be paid to that particular process. To decide whether the company should utilize the particular technology, the *Selection* process has to be entered. To optimize the quality of this selection process it is beneficial if the decision makers have been participating in the preceding technology validation process. Thereby they hold a bigger insight in the facts regarding the technology, which combined with their subjective preferences, enables them to make the right decision. In the *Implementation* process, the selected technology candidate is integrated into the organization's technology competence base. According to Bucher et al. (2003), there are four ways to accomplish that: (1) internal research, (2) allocation of research assignments, (3) research cooperation's and finally (4) acquisitions. These four approaches can all be represented on a *make-or-buy* scale, where internal research represents "make" and acquisitions represents "buy". It is suggested by Bucher, et al. (2003) that the "buy" option often turn out as the preferred solution and that even large organizations are forced to acquire new technology to continue to be at the leading edge.

In 2006, Kerr et al. published another very important article in the field of technology intelligence. He presents a comprehensive five-layer intelligence framework that categorizes the concepts found on each level (see Figure 8).

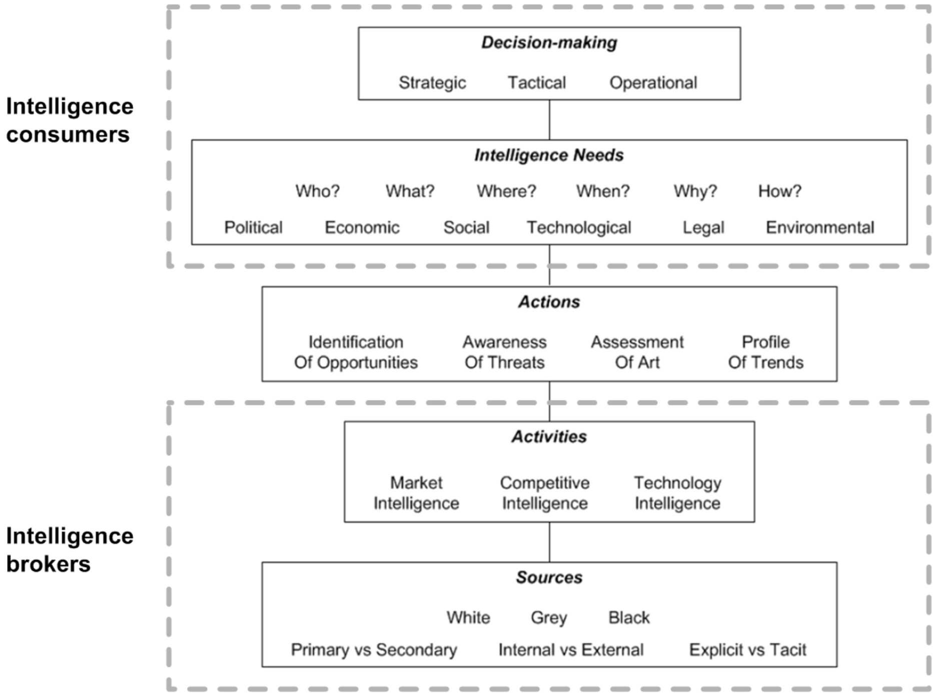


Figure 8. Intelligence framework. Adopted from Kerr et al. (2006).

The framework consists of two groups that are interconnected through the middle *Actions* layer. The *intelligence consumers*, who are typically organization leaders and top management, acquire information from the *intelligence brokers*, who can be attorneys, engineers and sales personnel. The framework enables the organization (in a systematic way) to acquire the required information through the actions found in this layer and further to provide a common understanding of the terms involved in the whole intelligence process.

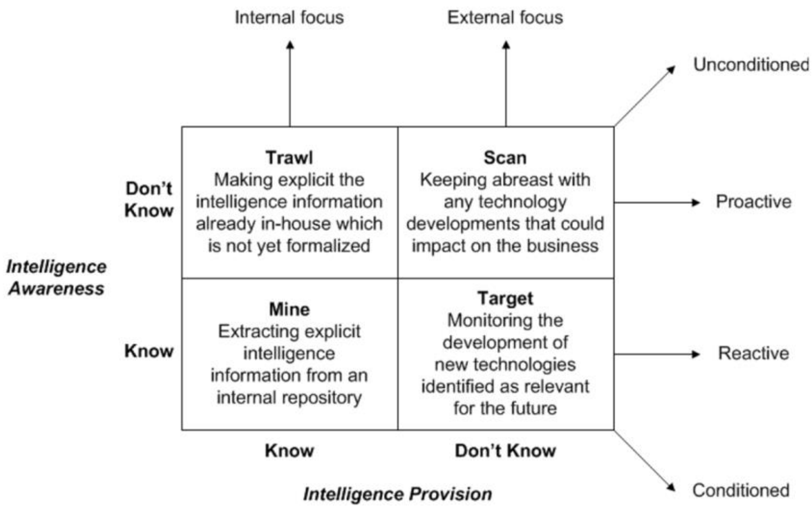


Figure 9. System modes (Kerr, et al., 2006).

Regarding the perspectives on intelligence, Kerr et al. (2006) makes a distinction to Lichtenthaler (2006), in that Kerr adds another dimension to the inside-out/outside-in concept, where he presents the idea of letting the intelligence perspective be a two-dimensional function, in which both *Intelligence Awareness* and *Intelligence Provision* are arguments to the function. Kerr suggests to model the intelligence perspective as a two-by-two model as shown in Figure 9 (page 19) and he terms the quadrants *system modes*. In his model, the y-axis represents to which level the organization is aware of its intelligence needs, in other words: “do we know that we need information?”. The x-axis represents the level to which the organization already holds the required information in-house (*Know*) or if they are forced to go outside the organization and search (*Don’t Know*). Combined with the intelligence framework illustrated in Figure 8 (page 19), this gives the personnel working with technological, environmental and market intelligence tasks a framework that can be used to map out the intelligence needs for the organization and further increases the possibility to get a common understanding of the different concepts in the overall intelligence process.

5.5 Uncertainty and radical innovation

In their study from 2013, O'Connor & Rice (2013) presents *a comprehensive model of uncertainty associated with radical innovation*. Through a longitudinal study of 12 radical innovation projects in large established American firms, they identified a certain pattern of discontinues across projects. During the study that lasted more than five years team leaders, members, and sponsors for each project were interviewed repeatedly. Based on the interviews, project life-cycle diagrams were developed, which were used to identify the discontinuities. Beside project discontinuities (and thus uncertainties) related to technology and market, O'Connor & Rice also revealed organizational and resource discontinuities. From the life-cycle model and interview transcripts, they further identified 5-9 critical issues for each category. Each single issues were observed across several of the projects studied, ranging from 50% to 100% of all projects, meaning that they were common to a large extent.

Beside the four uncertainty categories, O'Connor & Rice further introduced two additional dimensions to their uncertainty model: *latency* and *criticality*. Latency refers to the level to which a given uncertainly can be anticipated and criticality refers to the urgency of the uncertainty. The two latter dimensions forms a two-by-two matrix, that holds the cells *anticipated and routine* (low latency, low criticality), *unanticipated but routine* (high latency, low criticality), *showstopper that can be anticipated* (low latency, low criticality) and finally *unanticipated showstopper* (high latency, high criticality).

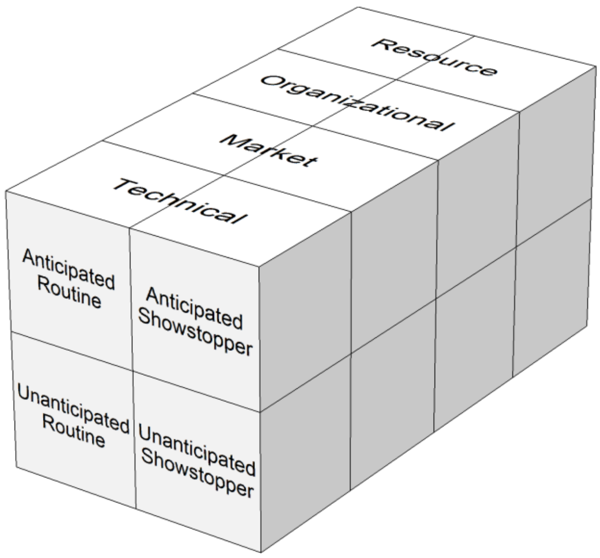


Figure 10. Radical innovation project uncertainties. Adopted from O'Connor & Rice (2013).

According to O'Connor & Rice, firms have an opportunity to reduce uncertainties related to radical innovation by developing new project management competences and organizational structures. One tool that can help in that process is presented in their work as the earlier described list of common issues observed in radical innovation projects. This list may act as a checklist, which can guide the team carrying out project tasks. O'Connor & Rice suggest that the issues relevant for the team can be converted into assumptions and tested. They further suggest that the team must make explicit the uncertainties that must be confronted in the future and that the most important ones must be identified and addressed.

5.6 Summary and reflections

This chapter describes existing literature seen from the five perspectives *Leadership*, *Market*, *Organization*, *Technology intelligence*, and *Uncertainty*. The review does not cover all aspects of disruptive innovation since the amount of literature in this field is exhausting. It does, however, cover the aspects described in the problem statement (chapter 4.1, page 6). Compared to the work offered by other authors, the model presented by O'Connor & Rice (2013) seems to be the one offering the broadest coverage in the context of this study.

6. Research Methodology

The purpose of this study is to identify critical factors and uncertainties regarding the development and commercialization of a potential disruptive product for TCG, which currently aims for incremental innovation. Having identified these critical issues makes it possible to suggest actions, which are expected to be required for being successful with this disruptive product, seen from both an internal and market perspective. To reach this goal, a single case study is carried out inside the TCG organization. The investigation is conducted by the author, who is employed as a technical research engineer, working with emerging technologies and new product development in TCE, which is one of TCG's affiliates. The author has been working for TCG for the past 15 years.

The reason for choosing a single-case study approach is primarily caused by the methods ability to give a rich description of the single instance studied, and that the theory built from the observations done through the study fits to the specific instance investigated. As Eisenhardt & Graebner (2007) puts it:

…single cases can enable the creation of more complicated theories than multiple cases, because single-case researchers can fit their theory exactly to the many details of a particular case.

Further, the fact that the observer has an extensive historical background from within the organization, which is studied, offers him a head start when investigating the organization and trying to make sense of things. However, this situation is of course a double-edged sword, since the background of the observer might introduce bias effects.

The aim of this study is to establish a full and rich picture, corresponding to the situation TCG faces when standing on the threshold to engagement in development and later commercialization of a disruptive product. To solve this task, the holistic framework offered by O'Connor & Rice (2013) is chosen since it encompasses more aspects of "operational disruptive innovation" compared to other models. As described in chapter 5.5 (page 20), the framework is built upon a longitudinal study of 12 radical innovation project, which makes the framework more generic compared to a single-case study. This *"Comprehensive model of uncertainty associated with radical innovation"* identifies four layers of uncertainty in a radical innovation context: (1) Technical, (2) Market, (3) Organizational, and (4) Resources. For each layer, the model further positions a given uncertainty on a latency (ability to predict) and criticality dimension respectively. In this study, the primary focus will be on the high-critical (showstopper) uncertainties seen in a TC Group perspective.

6.1 Approach

To understand the different uncertainty layers identified by O'Connor & Rice (2013) in a TCG context, the following steps were taken in this study:

First, the organization was analyzed using a *step-by-step approach* described by Burton, et al., (2011). The method positions multiple attributes of the organization in a two-dimensional space having the organizational archetypes reactor, defender, analyzer and prospector in each quadrant. The purpose of the method is to identify possible misfit between the attributes. Data for the analysis was gathered from guided interviews with TCG middle and top management. A full description of the organization analysis method is presented in chapter 7.3 and 7.4 (page 28).

As a second step, the market was investigated regarding customers' needs and product requirements. This investigation was carried out using a *Sequential Exploratory Method Design*. In this case, the method consisted of an initial qualitative part, where four key customers and three technology providers were interviewed regarding their opinion about an alternative ceiling loudspeaker installation technology. Data from these interviews were passed through a coding process and then acted as input to the design of a questionnaire, which constituted the following quantitative part of the sequential method. This questionnaire were sent to 34 key customers on the North American market. The market survey method is described in more detail in chapter 8.1 (page 53).

Thirdly, technology suitable for solving the required task was reviewed. This review process consisted of the identification of loudspeaker network building blocks (ingredients), and from these building blocks suitable technologies were found. Using combinations of these technologies, a list of solution candidates were established and scores were given. Chapter 9.3 (page 77) describes the approach in more detail.

As part of each of the three above listed steps, critical factors were identified and discussed, and sub-conclusions given.

Finally, a unifying conclusion was made, describing the implications and suggestions for future actions. An illustration of the workflow is presented in Figure 11.

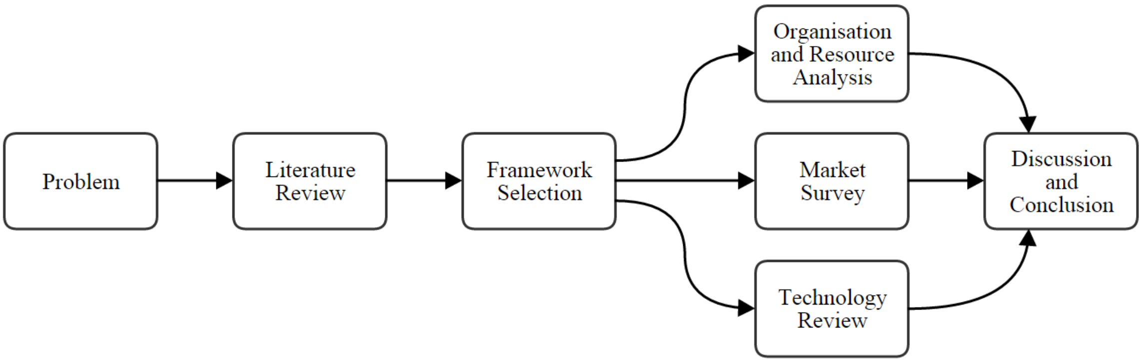


Figure 11. Study workflow.

6.2 Paradigm

The predominant world-view in this study is postpositivistic (Guba & Lincoln, 1994) and it is in general believed that things can be observed, measured and controlled using rational methods and approaches. On the other hand it is acknowledged that a social system of human beings is very complex and can only partly be approximated by models and mathematical functions. In this case study, several approaches have been used like interviews, web-based surveys and analysis based on mathematics and natural science. For the latter, a pure positivistic paradigm is used, since the observer in natural science research has the option of being fully objective. However, in social science research using a postpositivism paradigm (as in this study), it is acknowledged that the observer/researcher cannot be fully objective and that the truth cannot be pinpointed, only approached.

7. Organization and resources

As described by many authors (O'Reilly & Tushman, 2004; O'Connor & Rice, 2013; Chang, 2012; Slater & Mohr, 2006), organizational properties have a huge impact on the ability to perform well concerning the development and commercialization of disruptive products. Since TC Group typically engages in projects that predominantly have an incremental innovation nature, projects having a potential disruptive character might pose a huge challenge for the organization. This chapter will analyze the TC Group organization to identify critical factors and uncertainties in that context.

7.1 TC Group history and structure

The corporate structure of TC Group is illustrated in Figure 12. The Group consist of four audio product manufacturers (Tannoy, TC Electronic, LabGruppen and TC Helecon), one fabless semiconductor manufacturer (TCAT) and two sales companies (TCGI and TCGA). Finance and IT functions are located as shared corporate functions in TC Group.

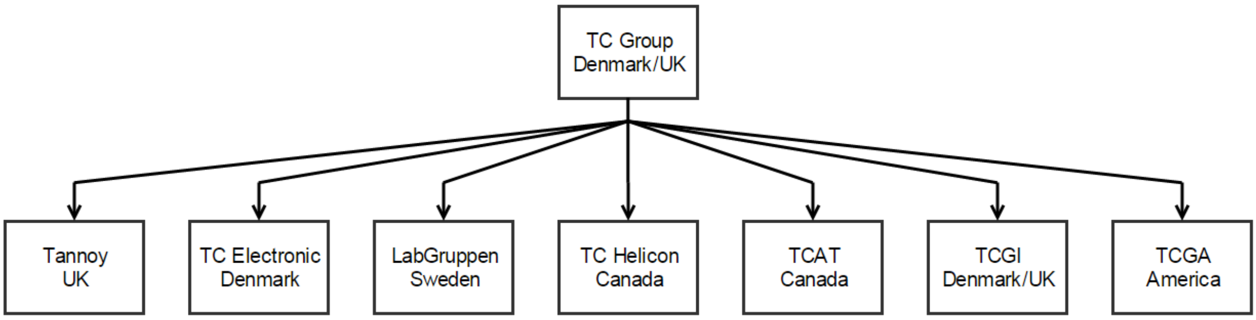


Figure 12. Corporate structure

TC Group (TCG) was formed in 2002 as a merger between the following two groups of existing companies:

TC Electronic, TC Helicon and TCAT
TGI plc (Tannoy, Martin Audio, GLL and LabGruppen)

During the merger, TC Group CEO Anders Fauerskov commented:

"The purpose for wishing to merge with TGI plc is actually quite simple. It is a matter of creating synergy between the TC technology in digital audio processing and TGI's years of experience in developing, producing and marketing speakers. By combining digital technology from TC and the speakers developed and produced within the TGI plc Group, we will be able to develop and market new products, which we believe will have a significant potential in the markets."

However, in spite of the technology synergy opportunities existing in the combined group of companies, the last 10 years have showed that obtaining this synergy has not been a trivial task. Successful product development projects, employing and merging technologies from different companies have taken place to some extent, but the apparent profit of the merger was not something that came "automatically".

Shortly after the merge, Martin Audio was sold and GLL was closed. Below is a very short description of the companies embraced by TC Group today.

<u>*TC Electronic (TCE):*</u> The core company of the old TC Group. It was established in 1976 and the number of employees is approximately 100. It is located in Denmark and has a flat organization with a large R&D

department that is separated in 3 teams: PRO (broadcast and production), Guitar and Integrated Amplifiers (IA). Most products are manufactured in Thailand, however expensive products for professional audio are assembled in Denmark. Primary core competence is audio digital signal processing equipment to both the professional audio industry and performing artists.

TC Helicon (TCH): Was originally a 50/50 joint venture between IVL (a digital signal voice processing specialist company) and TC Group, but is now 100% owned by TC Group. The number of employees is approximately 20. It is located in Canada and has a flat organization with a large R&D department relative to the total number of employees. All products are manufactured in Thailand and China. Core competence is vocal digital signal processing equipment for performing artists (one-man-bands).

TC Applied Technologies (TCAT): Is a TC Electronic spin-off company, producing and selling audio networking/interface IC's to the professional audio industry – also to competing companies. The number of employees is approximately 5. Is Located in Canada with a flat organization and is highly specialized in digital audio networking.

Tannoy (TNY): An 80-year-old loudspeaker manufacturing company with approximately 180 employees. Located in Scotland and has a more hierarchical organization structure comparing to TC Electronic. It has a large manufacturing department, but low cost products are produced in Asia. The core competence at Tannoy is designing and manufacturing passive loudspeakers. Primary markets are installation (airports, hotels, restaurants, houses of worship) and residential (high-end HiFi).

LabGruppen (LAB): A 30-year-old power amplifier manufacturing company. The number of employees is approximately 80. LabGruppen is located in Sweden and claims to be world leaders in very powerful (20000W) audio amplifiers used for touring and large venues. Same technology is also used for making amplifier solutions for install. LabGruppen is solely oriented towards the professional market. Production takes place in in both Sweden and Thailand.

TC Group International (TCGI): Is the distribution arm of TC Group, responsible for all territories in EMEA, Asia and the Pacific regions. TC Group International is active in the local markets of more than 60 countries in separate market segments, which are defined as MI, HD/Broadcast, Install/Touring and Residential.

TC Group Americas (TCGA): Is a sales and support organization responsible for TC Group owned and distributed brands in North America, Central America, the Caribbean and South America. Structure and set up revolves around the vertical markets known as Install/Tour, MI, HD/Broadcast and Residential. All activities, order processing and account management are centralized in Kitchener, Ontario.

7.2 Unit of analysis

In 2009-2010, a new organization structure was rolled out and is presently the "way of thinking" in the organization. The structure is based on four market verticals, each utilizing R&D, marketing, sales and operations functions from the different companies. This structure is illustrated in Figure 13. Seen from the perspective for the project examined in this study, the relevant group of people that will be studied is the people belonging to the Install vertical.

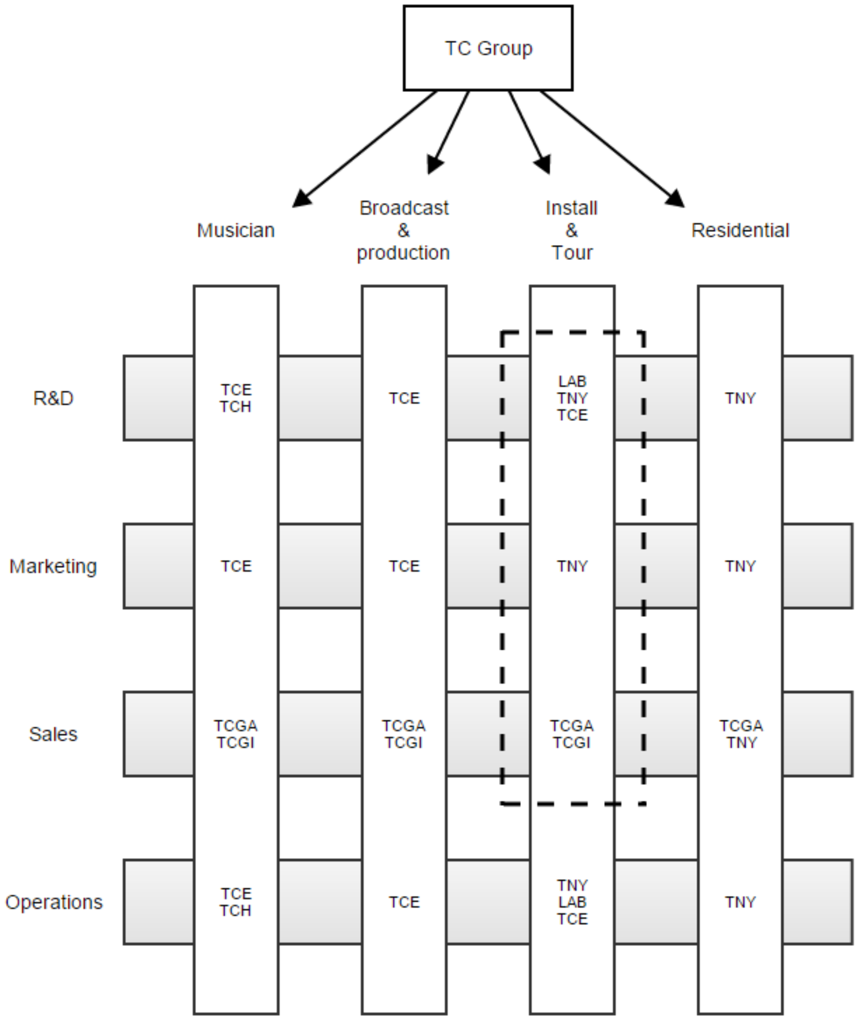


Figure 13. Organization, by market verticals. Unit of analysis bounded by dashed line.

As illustrated in Figure 13, Operations is left outside the dashed rectangle (the unit of analysis). This is a deliberate choice made, since it is expected that this function will only be affected slightly by the project compared to the functions inside the rectangle. Operations is not as such involved in neither product definition/development, nor in market (customer) related activities. The primary product related activities for Operations is component sourcing, establishing of test setups, production, packaging, shipping and logistics. Based on current knowledge it is estimated that these functions will be "business as usual". Technical building blocks is expected to be very similar to building blocks found in the existing TC Group product portfolio: electronics (same/similar technology), loudspeaker enclosure and the loudspeaker driver itself.

Figure 14 (page 27) illustrates how the unit of analysis (UA) interconnects. R&D team-specific steering group meetings are held approximately every second month. The meeting participants are the steering committee and all R&D team members in the specific team. During these meetings project status are reported back to the steering group along with suggestions for new projects. Based on the meeting discussions instructions are finally given from the steering committee to the team. The steering committee consists of the top management (Chief Executive Officers of TCG, TNY, LAB, TCE and TCH), the Chief Financial Officer of TCG, the Chief Technology Officer of TCG, the Chief Operating Officer of TCG, the LAB/TCE/TCH R&D manager and finally the VP of Install Business Management.

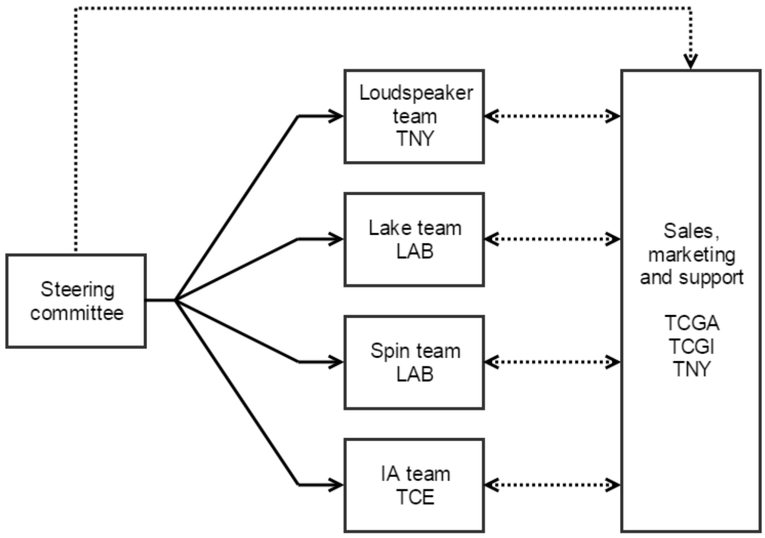


Figure 14. Unit of analysis and interconnections

As illustrated in Figure 14, the R&D team connects to the steering committee via steering group meetings but also on an ad hoc basis, primarily to the LAB/TCE/TCH R&D manager and VP of Install Business Management. Links between R&D teams and sales/marketing is handled almost 100% by the Product Manager (PM) in each R&D team. These links are illustrated as dotted lines because the information bandwidth is rather limited ("single person interface") and that PM and sales/marketing are not located on same location. The connection between the steering committee (seen as a single entity) and sales/marketing does not exist, but communication flows from individual members of the steering committee to sales/marketing, both through sales meetings and on an ad hoc basis through the hierarchical and/or matrix view on the organization. This link is thus illustrated as a dotted line.

7.3 Organization analysis

To be able to evaluate the UA's capability with regards to handling the tasks related to defining, developing, and selling a new and novel networked loudspeaker system, an analysis of the organization subset has to be made. The scope of the analysis is the combined group of people illustrated in Figure 14 (page 27). This scope is critical to keep in mind during the analysis phases. The organization analysis is carried out as described in Organizational Design (Burton et. al., 2011). This book describes a five step approach for analyzing a given organization (or subset of an organization) using 14 attributes, each categorizing the organization for the given attribute. Finally, the analysis is used to evaluate if there is a fit between different attributes – and if not, the misfits are identified and potential interventions can be discussed.

As mentioned above, 14 organization attributes are estimated. Each of the attributes are based on a two-by-two coordinate system, so in total 28 parameters (two per coordinate system) have to be carried out. For most parameters a five level Likert scale is used, with the steps: *very low* (1), *low* (2), *moderate* (3), *high* (4) and *very high* (5). The 14 attributes correspond to the following sub-chapters. Each chapter contains a description of each parameter and how they relate to the UA. The 14 attributes are categorized in five groups as listed below.

A. Getting started
   1. Goals

B. Strategy
   2. Strategy
   3. Environment

C. Structure
   4. Configuration
   5. Organizational complexity
   6. Geographic distribution
   7. Knowledge exchange

D. People and process
   8. Task design
   9. People
   10. Leadership style
   11. Organizational climate

E. Coordination and control
   12. Coordination and control systems
   13. Information systems
   14. Incentives

7.4 Methodology

As a part of the analysis, two interview/discussion meetings were held with the CEO of TCG (*CEO*), the VP of Install Business Management (*VP*) and finally with the program manager for the IA R&D team (*PM*). All three persons have a deep insight in the TCG. Further, it should be mentioned that the CEO of TCG has been located in both TCE (Denmark) and TNY (Scotland) for several years, and that the VP of Install BM has been located in both TCE (Denmark) and LAB (Sweden) also for several years, which makes these persons the most qualified in answering question about the Install vertical. The two meetings were held in November 2014. The first with both the CEO and the VP present along with the author, the second with only the program manager and the author. Originally, only a single meeting was planned, but due to sickness, the single meeting was split into two.

Audio recording was used as a tool to allow the author to focus on the discussion during the meeting. Text extraction from the audio recording was carried out after the meeting and this information was used for further analysis.

To minimize the time consumption for the interviewees before, during and after the meetings, they were carried out as compact four-step meetings. In the first step, the overall purpose of the analysis was explained, namely to get a snapshot of the organization and discuss how this snapshot can be used to evaluate how far the organization is from an optimal state with regards to a potential disruptive project. As a second step the scope of the analysis (UA) was explained. During this step, it was emphasized that the discussion was narrowed in to that scope only and "forget" about the remaining part of the organization. Further, it was underlined that the analysis should only deal with the present condition of the UA and not consider any wishes, dreams or projections into the past or future. The third step consisted of a quick introduction to the analysis method described in "Organizational design: a step-by-step approach" (Burton, et al., 2011). In this step, the basic idea of analyzing an organization (or as in this case a part of an organization) using 14 two-by-two systems was presented. In this step it was not "revealed" how the fit/misfit principle works, where the ultimate goal is to position all parameter intersections in the same quadrant. The reason for not explaining this organization design target was an attempt to keep the interviewees unbiased regarding the tendency people might have in placing the intersection point in the "right" quadrant as a function of their previous answers.

As the fourth and last step, the parameters belonging to each of the 14 two-by-twos was presented and scores were given. This step handled each two-by-two system one at the time, focusing on the parameter (axis label of coordinate system) meaning - and not so much on the archetype labels found in the four quadrants. Prior to the meeting, the "step-by-step approach" (Burton, et al., 2011), had been boiled down to 14 pages, one page per two-by-two system (see Appendix A). Each page contained short explanations and definitions of the two parameters used as x-axis and y-axis along with the two-by-two system including axis scales. As a last part, snippets from the book was used as "true/false examples", seen from the author's own perspective. An example of such statements, belonging to the "knowledge exchange" coordinate system, could be:

True:

- Inward focus, gaining knowledge by developing it inside corporate boundaries, inside specialized groups, or by acquiring knowledge externally and then harboring it inside the firm.
- Share knowledge on an as-needed basis.
- Rely on person-to-person contacts or small groups (two to ten people) whose members are all from inside the organization (or organizational unit) to share knowledge on an as-needed basis.

False:

- Linking teams, business units, or even the firm itself with parties outside the organizational boundary in order to gain knowledge.
- Relies on information technology-based systems, to manage knowledge exchange.

Using this one-page per two-by-two with quite direct and specific statements worked well as a discussion opener and a quick enabler for establishing an alignment of the parameter interpretation.

7.5 Attributes of the UA

In the following 14 sub-chapters, the findings for all parameter-pairs are described.

7.5.1 Goals

The unit of analysis (UA) has several goals. On the short-term horizon, the goal is to continue to grow its market share and to maintain and expand business with existing partners, which today is primarily in Europe and the US. On the longer perspective, the UA aims for moving in the direction of being a system provider to a higher extend compared to the primarily component sales today. Some of the successful competitors in the audio install manufacturing business put a lot of effort in service functions, where they offer guidance to audio contractors regarding dimensioning of an entire audio/video installation. Often this guidance is used directly towards the audio installer (the equipment customer) and of course, this guidance recommends equipment from the particular brand that offered the design guidance in the first place. Such an approach of course requires that the manufacturing brand is able to offer all of the components that exist in the full system, which is currently not the case for the UA.

The UA has no explicit goal statements regarding the parameters *Efficiency* and *Effectiveness*, which are the two dimensions in the *Goals* coordinate systems of the analysis. The focus on these two parameters varies a lot seen across the three brand companies found in the UA. TNY comes from a background of manufacturing high quality traditional loudspeakers through several decades. TNY does not aim towards being a first mover in the market, but continues to focus on its core competences and tries to make small incremental steps in improving its products. LAB and TCE on the other side, have historically aimed for technology leading positions in the market. LAB towards being the provider of very efficient audio power amplifiers (ten years ago claiming to be world leaders in wattage per function of rack space unit) and TCE towards being among the world leaders in the market of digital audio signal processing equipment for recording and broadcast studios.

Since the introduction of the market vertical organization structure, the goals and focus have shifted. This is a fact across all departments in the UA. The focus today is much more oriented towards manufacturing the right product for the current market, but also selecting the products that have the best fit to the current shape of the organization. There is high awareness on how R&D department resources are spent in an optimal way, seen over a relatively short time horizon. The ROI (return of investment) estimates for the different proposed new development projects are calculated over a 3-year perspective. This approach will of course favor smaller and faster projects, since investment-heavy research and development along with large market penetration tasks will look bad seen over a 3-year period, seen from an investment perspective. To reach the goals of making the optimal products using existing resources in the four R&D departments, efficiency is more important than effectiveness. The UA is also characterized by its reluctance in engaging in new product development aiming for being market leader.

Compared to the R&D departments that pay high attention in spending resources in an optimal way, the sales and marketing functions in the UA are more focused on generating revenue. The philosophy of many sales persons (also in the UA) is that “the end justifies the means”. This means that Effectiveness for sales persons and sales support functions is more important than efficiency.

Seen as an average score over the four meeting participant’s ratings, the parameter Efficiency got a score equal to 3.5 and the Effectiveness a score equal to 3.1. This positions the UA in the D quadrant, but only with a very little margin to the B quadrant. The individual scores were given as an average across all departments in the UA. It was acknowledged that big deviations existed, especially between R&D and sales departments.

7.5.2 Strategy

To reach the goal of continuing growth, *exploitation* of existing technology building blocks and existing market channels and connections are used to a high degree. New products are almost solely based on existing well-known technologies and only when forced by very appealing economic reasons, new technology and knowhow is acquired by either investing time to study and integrate this knowledge internally or to hire external consultants to carry out designs based on the new technology and through that approach getting familiar with the new technology. For most people in the R&D department a new product development process using existing building blocks and well-known technology is the optimal choice. Approaches in sales and marketing are also primarily based on approaches used previously. Marketing approaches are to a high extent still aiming for the printed media, in Magazines for audio installers and in printed brochures used in campaigns during tradeshows.

Sales forecasts are based on numbers found from the past sales, market-share of predecessors and similar products. Estimation of product development time is based on numbers found from the past projects that are comparable.

The *exploration* level in the UA is relatively low. Innovation is not something that are being chased and no efforts are done to systematically try to explore new opportunities and technologies. New products are often specified by looking at the price, feature set and performance found in the products made by the competitors and specifications for the new product are set accordingly.

If opportunities appear, and they look promising on a short term horizon they are investigated, but if taking a risk is a part of that opportunity, they are abandoned. This is the case for all departments in the UA. The R&D departments mostly stick to the technology and procedures they are familiar with, thus keeping risk at a low level with regards to the development time.

On the current audio installation market there is a trend of installations being more and more IT heavy. This is also the case for audio installations and many of the audio installations carried out today is now being handled by IT installation companies. From the top management in TC Group, there is for that reason a wish to approach these IT companies and try to engage in close partnerships. The sales departments in the UA, however, are a bit reluctant to engage in new partnerships and prefer to focus on the existing customer base. This is also a sign on a low exploration level. According to some of the meetings participants, sales in the UA were relatively more reactive than proactive.

The average score for exploitation equals 4.0 and the average score for exploration equals 2.1. Among the meeting participants, there was a high level of agreement on these numbers and it was found that the numbers were representative for all departments in the UA. This places UA in the B quadrant that resembles the *Defender* strategy.

7.5.3 Environment

For the UA, the environmental *complexity* is quite high. Many factors affects business and several of them are interdependent. The most important factors for the UA is probably (1) the part of TGC that control the UA, (2) customers, (3) competitors, (4) partners, (5) TCG Operations, (6) suppliers, (7) certification organizations, (8) educational systems in the countries where the UA operates and availability of skilled personnel, (9) the financial market and finally (10) the political systems on the markets TGC operates in.

The *interdependency* of the different forces mentioned above is estimated to be medium to high. One obvious example of dependency exists between TCG top management and TCG operations. The TCG COO (Chief of Operations, head of TCG Operations) is represented in the steering committee for the install vertical R&D departments. This has the potential effect that events causing a sudden change in focus prioritization among the different other business areas for TCG operation potential has a huge impact on the business for the UA. This has happened recently, where a flooding of the production facilities in TCGs main electronic manufacturing partner in Thailand created a severe bottleneck in production of finished goods for several months. In that situation, the top management had to prioritize among a long list of products regarding what to manufacture on the short timeline. Moreover, since many of the products originating from the UA are quite complex, both regarding manufacturing and test, it was judged that simpler products from other business areas should be “first in line” regarding manufacturing. This is just a single example of how the UA steering committee and TCG operation are associated.

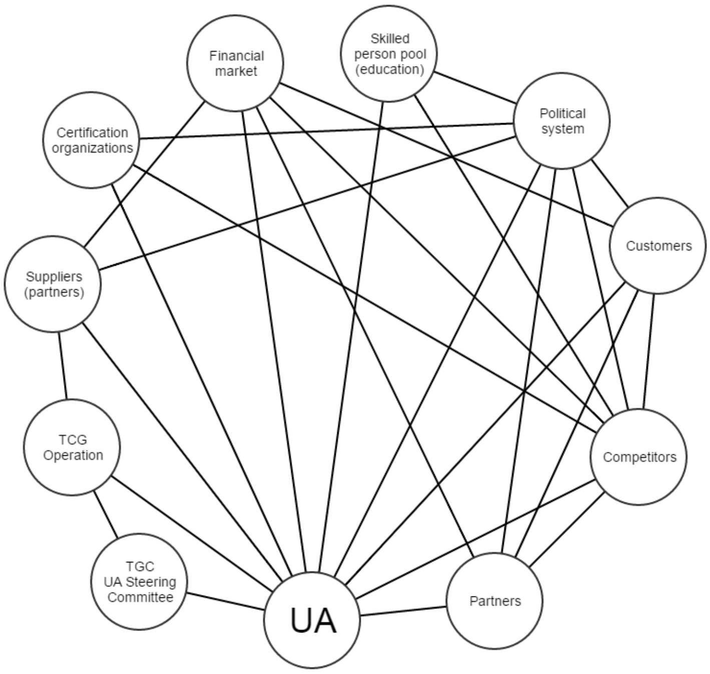


Figure 15. Interdependency of factors

Figure 15 is a simplified diagram of the interdependency between the forces that affects the UA. Important forces are of course the financial market situation, which affect in principle all other forces directly or indirectly, and the political systems that function in different ways in different countries. As an example of a political force is the increased focus on sustainability and energy efficient systems in both Europe and the US. This has a big impact on the organization that handles the certification process of Energy Star rated equipment and thus indirectly on both the UA and on its competitors. The same political decision puts pressure on the customers/partners in using energy efficient equipment and in the construction and/or refurbishment of public buildings, it is often an inescapable requirement to use such equipment.

Based on statements during the interview/discussion meetings, the *unpredictability* of the environment is estimated to be moderate. A few factors were judged to be hard to predict, like political forces when executed as trade embargos. This has been seen in China where import of electronics can be a difficult task to carry out since rules are suddenly changed or interpreted in new ways. It is also quite difficult to predict exactly which products the competitors will launch in the future and to predict the global and regional economies.

Among the easier things to predict is the internal forces like the overall TCG strategy (steering committee) and TCG Operations. It is also judged that the customer needs and requirements are relatively easy to predict on the quite conservative audio installation market.

Calculated as an average values across the ratings from the meeting participants, the complexity parameter received a score equal to 3.8 and the unpredictability parameter received a score equal to 2.9. Regarding the complexity parameter, there were deviations among the position taken be the meeting participants ranging from “low to moderate” to “high to very high”. The average numbers position the UA in the B quadrant of the Environment coordinate system corresponding to a *Varied* environment. This fits very well to the description given by Burton, Obel, & DeSanctis (2011):

“The varied environment is complex as there are many factors to take into consideration and they can be interdependent (i.e., they influence one another), but these factors are relatively predictable and/or they tend to change within known limits. If a firm has many products and sells them into markets where the markets are predictable, we say it has a varied environment. In such a varied environment there are many factors for an organization to consider, but it is possible to predict what will occur.”

7.5.4 Configuration

The UA is primarily configured with a focus on the market it is aiming for: professional audio installation equipment. The UA is a subset of the TCG vertical *Install & Tour*, which indicates that the market focus is high. The four different R&D teams in the UA all have names that relate to their output. An example of that are the *Integrated Amplifers* team in TCE or the *Lake* team in LAB. The latter is a brand technology that is integrated in most of the more expensive installations amplifiers. All R&D departments in the UA operate as individual business units that define their own products (which has to be accepted by the steering committee) and in many respects pursue their own destiny. The typical department has personnel with very different skillsets and is not as such organized after function. The success of each subunit, being R&D, sales or marketing is measured on the how the products are selling on the market. The most visible KPI numbers are related to how each of these subunits are doing seen from an economic perspective. For each department working with a given product, there is a high focus on reaching the estimated budget and sales numbers for that particular product. The above indicates that *Product/service/customer* focus is quite high for the UA. All four meeting participants gave this parameter the ranking 4.0 corresponding to “high” on the 5 level Likert scale used by Burton, Obel, & DeSanctis (2011).

To some extent, the UA is also configured by *functional specialization*. This is particular the case for sales and marketing that has more uniformed skill-sets within each subunit. However, the working focus in these subunits is still very much focused towards the products and market.

Compared to other companies making products with similar complexity, which require a high level of specialized expertise, the level of functional specialization in the UA is estimated to be low. For the three R&D subunits in LAB and TCE, they all contain expertise within the fields of software development, hardware development and mechanical development. In other words, a very diverse skillset, meaning that tasks within the subunit cannot be taken over by colleges within the same subunit. However, they aim for different markets. Five years ago, the same people were sitting in dedicated hardware, software and mechanical developing units in their respective brand companies (TC Electronic and LabGruppen), so a big change has happened during this period of time for the people now sitting in the UA regarding configuration.

The average score of the functional specialization parameter was found to be “low” (1.8) with a high level of agreement. This number along with the high level (4.0) of focus on Product/service/customer places the

UA in the *Divisional* C quadrant, which matches very well with the description for this quadrant given by by Burton, Obel, & DeSanctis (2011):

In the divisional configuration the focus is not so much on the internal specialization but more on the outside products and services that the firm produces, or on the customers it serves. There is an executive level that oversees subunits, which are relatively independent of each other and have limits on their contact with the headquarters. Each subunit is its own business, frequently organized as a simple or functional configuration. Within the subunit, each division is externally focused and has its own markets and customers. It pursues its own destiny within the constraints and policies of the headquarters.

7.5.5 Organizational complexity

Organizational complexity describes the vertical and horizontal differentiation of task management in the UA and how the configuration is divided into its several subunits.

The first dimension (parameter) in the organizational complexity coordinate system is *vertical differentiation*. This parameter describes the distance from top management to “the man on the floor” or in other words the depth of the hierarchy.

Looking at the UA, the vertical differentiation is low. The distance from the top management (steering committee and CEO) to the lowest level employee is very short. For most of the subunits (see Figure 14, page 27), only a single middle manager sits between the end-nodes of the hierarchy, having a primary focus on resource allocation and finance.

The second parameter in the organizational complexity coordinate system is *horizontal differentiation*. This parameter describes the “width” of the UA and is by Burton, Obel, & DeSanctis (2011) proportional to the number of horizontal subunits. Using this approach, the horizontal differentiation for the UA is quite high, with the following subunits: (1) R&D Loudspeaker team, (2) R&D Lake team, (3) R&D Spin team, (4) R&D IA team, (5) Marketing, (6) TCGI and finally (7) TCGA. So considering that the total number of people in these groups together is only approximately 100, the number of subunits is high.

On top of that, you could argue that the horizontal complexity is increased with the rather complex setup in the TC Group organization. Part of the top management takes postions in more than one brand company. This is the case for the LAB/TCE R&D manager, who has responsibilities for the R&D units in both LAB and TCE and for the TC Group CEO, who also operates as CEO for LAB, TCE and TCGI. Often brand company strategy and wishes affect the decisions being made in the company verticals (see Figure 13, page 26), so even if the decicion path from CEO to lowest level employee is short, the decicion process is often complex since many stakeholders hold an opinion that potentially could influence the decision. This is in particular the case for the R&D IA team that is shared as R&D team between the install vertical and the musician vertical.

Based on the rating given from the meetings participant, the average value of vertical differentiation was found to be 1.8 and the average value of horizontal complexity was found to be 4.0. This places the UA in the C quadrant named *Flat* in the Organizational complexity coordinate system with a good match between perception of meeting participants and quadrant definition.

7.5.6 Geographic distribution

The two parameters that describe the *Geographic distribution* is *Optimal Sourcing* and *Locally Responsive*.

Optimal sourcing describe to what extent the UA is physical located at its current location, because of customer contact, cost efficiency, human resource skill need or any other reason that brings the greatest advantage to the firm. This parameter varies across the different subunits. The location of both LabGruppen (R&D Lake team + R&D Spin team) and TC Electronic (IA R&D team) are caused by historical reasons. In both cases the company was founded close to its current location and during the company growth over the years from company founding to the present, both companies were able to recruit personnel with the required skillsets, most likely due to the proximity of Gothenburg and Aarhus respectively, which both have higher-level technical education institutions. The main reason for the location is not based on optimal recruitment but simple based on the residence of the company founders.

The current location of Tannoy, however, is primarily a result of attractive economic business conditions for medium sized companies located in the so-called “Silicon Glen” area (Glasgow area) in the 1980s. Deindustrialization took place rapidly in the 1970s and 1980s and most of the traditional industries drastically shrank or were completely closed down. As an attempt of developing this region, it was in Great Britain politically decided to support small and medium sized companied, particular in the high-tech business areas. To some extent, you could therefore argue that Tannoy has a relative high score on the Optimal sourcing scale. On the other hand, the availability of skilled personnel is quite low, since many individuals graduating from Scottish universities seek towards the London area, so Tannoy is currently experiencing challenges in both recruiting and holding on to qualified staff.

The main sales office of TCGA is located in Kitchener, Canada and the majority of sales personnel with direct customer contact is located close to their respective markets. The main office of TCGI with many different back office functions is located in Aarhus, Denmark, primarily due to historic reason as mentioned above.

Seen across all persons belonging to the UA, the overall work effort is thus distributed across many locations, which imply a high level of Local responsiveness and the resultant average score of this parameter was found to be 3.8. Concerning the Optimal sourcing parameter, it is argued that the UA has a low level since most of the subunits have locations due to historic reasons. The score of this parameter equaled 1.8. These numbers places the UA in the *Multi-Domestic* C quadrant of the Geographic distribution coordinate system.

7.5.7 Knowledge exchange

Historically the three brand companies (LAB, TNY and TCE) represented in the UA all originates from small start-up companies. In such small entities, knowledge sharing is typically something that “happens by itself”. Everyone knows what all people in the company are doing and has a clear picture of “what is going on”. What is more important: this picture of “what is going on” is often perceived to be identical across persons in the small organization. However, as the organization grows, the “natural” knowledge sharing does not takes place to the same extent as in the small organization. One example is the distance from market information to the R&D departments, where these functions in the small organization may be physically close to each other, maybe even sharing office space and thus also information. For the larger organization, such functions are typically physically separated, meaning that the valuable information flow is aborted if no other knowledge sharing means are introduced.

To characterize the *Knowledge exchange* attribute of a given UA, Burton, Obel, & DeSanctis (2011) uses the two parameters *IT infusion* and *Virtualization*.

The IT infusion parameter describes to what extent a firm relies on IT-based systems, including data processing and computer-based communication systems, to manage knowledge exchange. Almost all organizations today use IT to acquire and transfer knowledge, but some firms rely more heavily on IT-based systems for knowledge exchange. Other firms rely more on face-to-face or manual systems to handle the required knowledge exchange.

The virtualization parameter describes to what extent the UA has an outward focus. A company that has a high level on the virtualization axis put a lot of effort in linking units together to share and gain knowledge. These units can be either internal teams within the firm but it can also be entities outside the organization like business partners or universities. At the other end of the scale, you will find companies that prefer to develop knowledge inside the company boundary and/or to acquiring knowledge externally and then keeping this knowledge "hidden away" internally.

Looking at the UA, IT infusion is quite low. Of course all sub-units use IT systems in their daily work, but no big effort is put into sharing information across subunit boundaries. A major part of the R&D teams output exist in explicit form like design of electronic systems, schematics, software design and code, thermal design and fan control principle. All this information exists in documents that potentially could be accessible and searchable for all R&D employees. However, this opportunity of information sharing is not exploited. It is not that people deliberately hide information from each other, but for most employees the knowledge sharing process is not seen as a task that is worth spending time on, which also has to do with the historical background of the R&D departments from the different brand companies, all originating from small "single-office" systems. Looking at the sales and marketing departments, things are quite similar. Customer meeting reports are not shared among sales persons and/or product managers – if made at all. Again, the position taken by most employees seems to be that the information/knowledge you gain as an individual is probably not valuable for anybody else in the organization.

The IT tools used to share information is primarily email and to a smaller extent Microsoft Sharepoint. With the current implementation of these tools in TC Group, they do not offer effective search and visualization mechanisms. Often it is claimed that knowledge actually *is* shared with the phrase: *"…but I placed an Excel spreadsheet on the server that explains this..."*. Yes, that knowledge is explicit and existing, but no very likely to be shared if nobody knows it exists or if the location is hidden.

Historically all brand companies in TC Group have operated with the "keep your cards close to your chest" paradigm. This probably explains why the UA has a quite low level of Virtualization. Most projects have been carried out with a certain degree of secrecy, with the fear of leaking information to competitors before product launch or product presentation on a trade show. And even within the organization, new product information was kept inside the R&D departments, which are physically located in restricted area zones. This internal concealment is caused by a fear that sales would remove its focus on selling "what we have now" and instead thinking ahead for the customer and trying to predict which new products would solve the job in a better way in the future. Further there is also the risk of leaking information about the new products with the morale: the fewer that know about this, the lower risk of information leakage.

To the present time only a few attempts have been made to engage in joint development across brand companies, which of course also explains why knowledge sharing across subunits is almost non-existing. People do not see any particular reason for sharing their knowledge and often this knowledge is not requested. Instead, the same task is simply carried out again. Many examples can be found in the organization with similar problems being solved several times. Some of these incidents can be explained with the diversity of IT tools found across sub-units, like different electronic schematic editors, different PCB layout tools and different software tool chains, but the main reason is probably caused by the organization culture, which does not reward knowledge sharing. Statements like *"…if I give him this information, I am sure he will come back to me and ask questions.."* have also been used as an argument for not sharing information. Since people in the organization are measured by their subunit performance, there is a natural reluctance in helping other subunits, since this will take resources away from their own subunit.

From the rating given from the meeting participants, the average value of both IT infusion and Virtualization was found to be 2.0 with no disagreement at all across meeting participants. This score places the UA in the A quadrant named *Ad hoc communications* in the Knowledge exchange coordinate system with a good match between perception of meeting participants and quadrant definition.

7.5.8 Task design

For the R&D teams in the UA, the stage-gate model (Cooper, 1994) is used to decide which product ideas are allowed to pass the different gates in the new product development model (see Figure 16).

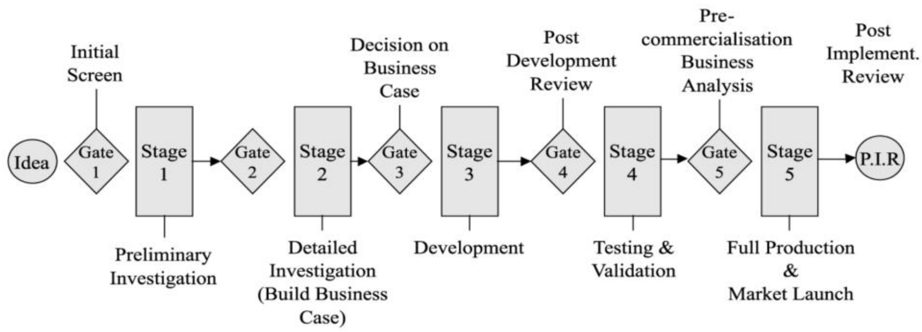


Figure 16. Stage gate model (Cooper, 1994).

Gate 1 and 2 decisions are typically handled by a business manager and often exist "under the radar". The steering committee decides whether or not a project should be allowed to pass gate 3 and 5. If a product idea passes gate 3, the development phase is entered, which is very time and resource consuming. During this phase, a high number of tasks have to be carried out, where most of them are interrelated and thus require a high level of coordination.

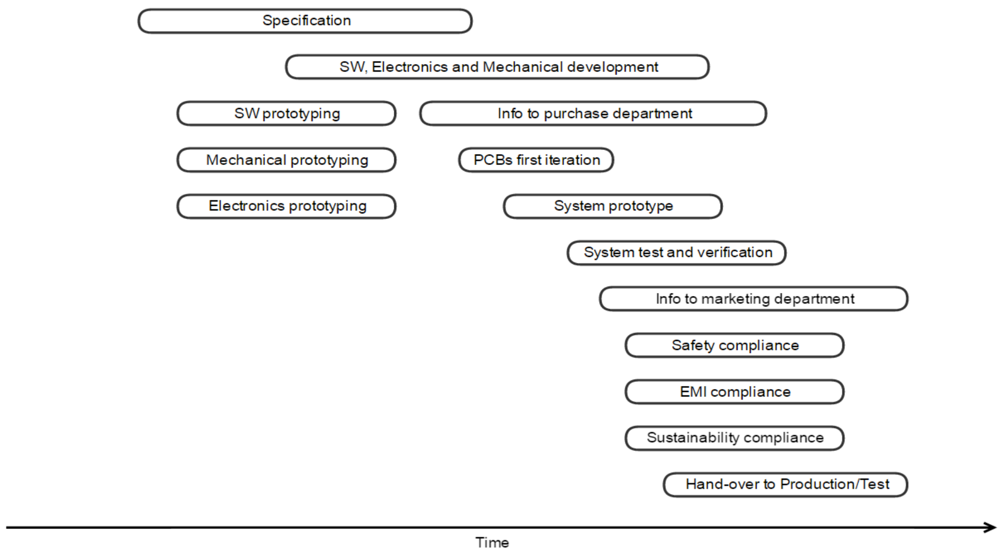


Figure 17. Typical R&D tasks in an audio amplifier development process

Figure 17 (page 37) illustrates (in a simplified way) the tasks found in a typical audio amplifier development process. Most of these tasks have a high level of interdependency. Final software have to operate within the boundaries of the chosen electronics (microprocessor, RAM and DSP), electronics has to physically fit into the physical space given by the mechanics, system parts have to be either manufactured or sourced - preferably from existing suppliers and the final product has to pass safety tests, EMI (Electromagnetic interference) tests and energy consumption tests. Most of these tasks have impact on other tasks and some tasks might lead to additional development iterations.

The sales and marketing task structure might be slightly simpler, but these functions also requires tight coordination between subunits to ensure a consistent price structure and sales strategy in general, across markets and customers.

Burton, Obel, & DeSanctis (2011) uses the two parameters *Divisibility* and *Repetitiveness* to describe the organization attribute *Task design*, where divisibility measures to what extent a given set of subtask requires a high level of coordination and repetitiveness measures to which level different subtask are conducted repeatedly. If a given set of subtasks are interdependent, the tasks have low divisibility. If the task is not standardized and varies in how it is carried out, it has low repetitiveness. Looking at the UA, these parameters are thus both relatively low. Subtasks are typically very dependent on each other and only few of the tasks can be standardized, since new problems/challenges occur during a new product development phase. The average score of the divisibility parameter was found to be “low” (1.8). This rating along with the low level (2.0) of repetitiveness places the UA in the *Knotty* D quadrant in the Task design coordinate system.

7.5.9 People

The attribute *People* is measured by the number of people found in the UA along with the education level of the same people. The people found in the UA consist of R&D personnel (approximately 50 persons), marketing personnel (10 persons) and finally sales and back-office personnel (approximately 35 persons). This equals “very low” (1.0) on the *Number of people* parameter.

Close to 100% of the R&D personnel hold either a Bachelor or a Master’s degree, and looking at the marketing team the majority of persons also holds a university degree. The formal education level of the sales personnel is a bit more diverse but most of the persons in the field have extensive experience from current and previously jobs. Among the meeting participants, the parameter *professionalization* was found to be “high” to “very high” (4.4). Combined with the low head-count, this places the UA in the *Laboratory* C quadrant.

7.5.10 Leadership style

The leadership style in TC Group has changed radically over the last decade. As mentioned earlier, all brand companies originate from small startup companies, that has been under heavy influence of their respectively founders. In these days, a very large portion of the decisions being made had to pass the top management (company founders), who typically had an opinion on every little detail. At the same time, another spirit existed in the companies, compared to the present. There was a clear feeling of “everything is possible” and “only the sky is the limit”. Such a feeling also meant that there was a high degree of willingness for taking chances.

Today, TC Group is driven with a high degree of responsibility to the financial performance of the company and to avoid uncertainty, new projects that have a fast and safe payback period are often selected. Only rarely projects with a long duration are launched since it is acknowledged that the future can be very hard to predict and that the arguments for engaging in a long-lasting project may not necessarily be valid when looking 2-3 years ahead in the future. The decision of choosing projects with a relatively short payback period is enhanced by the fact, that the Return On Investment (ROI) model used in the UA is identical to the models used in other business areas, such as electronic guitar pedals (which typically have a much shorter lifetime compared to an installation amplifier). In these ROIs, the time period used is 3 years. The reason for choosing identical models is caused by the wish of being able to compare projects across business areas.

During the interview meetings with the CEO, VP and PM a high level of agreement was found regarding the willingness of delegation of decisions down the hierarchy of the UA. The VP commented: *"…I have always felt that we (VP and install vertical director) were given free hands to manage the vertical…"* and the CEO commented: *"...Decisions are preferable made by the persons that have the knowledge and thus also have the responsibility…".*

To describe the organization attribute *Leadership style*, Burton, Obel, & DeSanctis (2011) uses the two parameters *Uncertainty avoidance* and *Preference for delegation*. These parameters are quite self-explanatory: preference for delegation is the degree to which the top management urges middle managers or other employees to make decisions about what and how work is done and uncertainty avoidance is the degree to which the top management avoids making choices that involve major risk.

Both these parameters were given the average score 4.0, placing the UA in the D (*Producer*) quadrant in the leadership style coordinate system. The comments made and the position taken by the meeting participants have an almost perfect fit to the definition of the Producer:

The producer style is delegation with detailed oversight and a focus on the short term to avoid uncertainty. The strength of the producer's leadership style is the delegation to others, but the producer does this with an oversight that can assure decisions are made according to his or her preferences and that those actions are coordinated across the subordinates.

7.5.11 Organizational climate

The *Organizational climate* attribute is characterized by the two parameters *Tension* and *Readiness to change*.

Tension describes the level of stress in the UA. Tension is proportional to conflict and scapegoating. Tension is inverse proportional to trust and leader credibility. Readiness to change describes the willingness of changing direction and work processes among the people in the UA. This is required when new and unanticipated challenges are faced. Readiness to change is further proportional to the feeling of having adequate resources to handle the change.

The Organizational climate across the teams found in the UA is quite diverse. As described earlier, TC Group was formed as a *merger* between two existing groups of companies. However, the so-called merger between the groups was primarily experienced as such by the employees of the "mother company" TC Electronic. When asking employees in the acquired group (Tannoy and LabGruppen) about the merger, they see it more as a hostile takeover, in which their management has been replaced.

At the outer ends of the UA Organizational climate scale, we find the R&D teams in TCE and LAB respectably. The TCE team is characterized by having very low internal tension. People are comfortable with each other, trust each other and their managers. Furthermore, they have a desire to resolve conflicts before they deadlock. At TCE economical bonuses are rarely used to reward employees. Now, turning to the LAB teams, they are more skeptical towards the management, since they have been through several major changes that were imposed by TCG. During these changes, they have seen popular mangers having to leave the company and felt that decision power to some extent has been taken from them. LAB uses a performance (sales) based bonus system that further increase the tension, since TCG decisions may favor the install vertical instead of LabGruppen branded projects (that triggers the bonus). During the last couple of years several senior R&D employees has left the company because of this situation, which also increases the stress level. With the low-to-moderate tension found in the remaining teams, the overall Tension score was found to be 2.6.

Regarding the Readiness to change parameter, things are also very diverse across the teams. In general, there is a high level of change willingness when looking at the younger employees. Moreover, in both LAB and TCE there are quite a few young opinion leaders that influence their team colleagues. Further, the trust level is high at the TCE team, which probably enhances the willingness to change, since it is believed that the top management has best intentions for both the company and the different teams. At the other end of the scale we find the TNY R&D team which primarily consists of senior employees with many years of experience. They have a harder time adjusting their work habits and believe that change is not necessarily a good thing. The overall average score for the Readiness to change parameter was found to be 3.3, positioning the EA in quadrant C (*Developmental*) of the Organizational climate coordinate system. However, with both scores relatively close to "moderate"

7.5.12 Coordination and control systems

The attribute *Coordination and control systems* is measured by the two parameters *Formalization* and *Decentralization*. Formalization describes to what extent the organization specifies a set of rules to control how work is done. Formalization is high if such rules are very detailed and consistently communicated to organizational members and that it is very clear and explicit how work is to be done and by whom.

Decentralization is the level of subunit coordination and control responsibility. The decentralization parameter distinction is particular focused on operational kind of decisions. Coordination and control systems are thus more concerned with the design of work process rather than setting the company strategy.

The formalization level in the UA is quite low but has increased over the last decade with the introduction of the Stage Gate product development model (Cooper, 1994), the steering committee and the Scrum development framework (Schwaber, 2009). Up until the introduction of these methods, no formal rules existed about how work was carried out or by whom. This approach can of course be explained by the historical background of all the three brand companies represented in the UA, as being small start-up companies where the "master-plan" was found inside the head of a single or very few persons. This is not the case anymore, but since each team is allowed to handle matters as they see best fit, without any detailed and consistent set of rules, the level of formalization is still relatively low and positioned as being "very low" to "low" (1.6) on the formalization axis.

The decentralization parameter for the UA was oppositely found to be quite high across the meeting participants, which all ranked this parameter to "high" except the PM who noted that many, if not most, of the important decisions are being taken by a few individuals. However, across all meeting participants there was a high level of agreement in that all teams in the UA were given very free hands to operate as they see best fit, meaning that most decisions regarding daily operation of the teams were taken locally. The average score on the decentralization parameter was found to equal 3.5 and together with the formalization score on 1.6, this places the UA in the C (Market) quadrant of the Coordination and control coordinate system. The following paragraph specifies the Market quadrant (Burton, et al., 2011):

In the market model governance is relatively decentralized, meaning that groups or business units oversee themselves with high autonomy relative to corporate headquarters. A market organization is risk-taking, tactical, and innovative. With few stated rules, things may seem chaotic to the newcomer who is trying to figure out 'the rules" and "how to get things done". But for those who work inside the organization, low formalization and high decentralization foster innovation. Subunits may not police themselves equally well, and there can be a tendency toward conflict if the various units develop quite different ways of executing work tasks.

The description mentioned above fits quite well to the UA with the exception of the stated willingness to take risks. On the other hand, you could argue that the UA actually is willing to take risks, but only on an operational level (contrary to a strategic level), which also has the primary focus when looking at the Coordination and control systems attribute.

7.5.13 Information systems

The *Information systems* attribute is measured using the two parameters *Amount of information* and *Tacit nature of information*.

The Amount of information is the total quantity of data that the UA has to gather and digest. If tasks are repeated hundreds of times per day (e.g. a bank or large retail chain), then the amount of information that must be processed is large. On the other hand, if tasks are few, fragmented or knotty, the amount of information to be processed is smaller. However, a low quantity of data to be managed is not the same as implying that information processing is an easier task compared to the processing of a high quantity of data.

Michael Polyani (first a chemical engineer, then a philosopher of science) framed the term "tacit knowledge". He means that there is a type of knowledge that is not captured by language or mathematics. Tacit knowledge is knowledge that the actor knows he has (how to catch a ball, tie a knot, mark a line) but which he cannot describe in terms other than its own performance: "*the aim of a skilful performance is achieved by the observance of a set of rules which are not known as such to the person following them*" (Polanyi, 1958). Tacit knowledge is not easily put into a set of facts or rules, and is thus difficult to transfer. On the opposite end of the "Tacit nature of information scale", we have explicit knowledge that can be formulated into as a system of symbols and facts, and is thus much easier to communicate and share.

Looking at the UA, the amount of data that has to be processes on a daily basis is quite low. However, there is a big spread of data amount across the different teams found within the UA. The numbers of incoming phone calls and/or emails per person in the R&D departments is in the range of ten per day, whereas this number is significantly higher in the sales teams, covering both personnel that has direct customer contact, but also for the back-office function personnel, that has to process orders and handle logistics. Nevertheless, compared to a large retail chain that has to process thousands of orders on a daily basis, the number of data processes in the UA sales companies is more in the neighborhood of "moderate" on the "Amount of information axis". Together with the very low amount of information found in the R&D teams, the combined and average score of this axis was found to be "low" (2.1).

The nature of information in the UA is to a high degree tacit. A very big portion of the knowledge found in both sales and R&D teams primarily exists in peoples heads. This is caused by the very difficult task of making things explicit and describing the best way to approach a given customer, the habits/humor/desires of the different customers, finding the optimal product for a given market, implementing a new desired feature in a new product development, etc. Of course many things are possible to describe through rules and other explicit expressions (primarily tasks that have been carried out previously), but the majority of knowledge within the UA is tacit. The level of Tacit nature of information was found to be “high” (4.3) by the meeting participants, placing the UA in the C (*People-driven*) quadrant of the Amount of information coordinate system. For both parameters belonging to this system, there was a very high level of agreement across the meeting participants.

7.5.14 Incentives

The attribute *Incentives* is measured through the parameters *Target of incentives* and *Basis of evaluation*. In contrast to the remaining 13 attributes in this analysis, the scales of these parameters are not measured on low-to-high axis.

The Target of incentives parameter specifies whether incentives are targeted towards individual work or towards group work performance and is thus measured on an Individual (1) to Group (5) scale. This parameter is concerned about “who”. The Basis of evaluation parameter measures whether incentives are targeted towards “hardcore” results (outcome, sales) or towards behavior (procedures) and is thus measured on an Behavior (1) to Results (5) scale. This parameter is concerned about “what”.

This attribute is very diverse across persons and teams in the UA. The sales personnel has a salary structure that contains a large portion of sales related bonus, which is 100% individual measured. The personnel in the TCE R&D departments has a fixed salary and only very rarely financial incentives are presented. The personnel in the LAB R&D departments has a group bonus arrangement that is triggered if Lab.gruppen branded products exceed a certain threshold relative to the budget.

The scores given on the two parameters classifying the attribute were quite diverse across the meeting participants, probably caused by the non-public and “invisble” salary structures found through the different personnel groups with TCG. The average score found for the Target of incentives parameter was 2.3 (more individual than group) and the average score found for the Basis of evaluation parameter was 3.5 (more results than behavior) which positions the UA in the C (Bonus-based) quadrant of the Incentives coordinate system.

7.6 Discussion

The scores from all 28 parameters and the resulting quadrants are presented in Table 1. This chapter will discuss these findings with the objective to identify suitable organization interventions, for the optimization of the organization capabilities required to engage in the development and commercialization of disruptive technology.

Attributes and Parameters		Score					Quadrant
		CEO	VP	PM	AUT	AVG	
(1) Goals:	Efficiency	3	3	4	4	3.5	D
Efficiency	Effectiveness	3	3	4	2-3	3.1	
(2) Strategy:	Exploitation	4	4	3-4	4-5	4.0	B
Defender	Exploration	2	2	2-3	2	2.1	
(3) Environment:	Complexity	4	4	2-3	4-5	3.8	B
Varied	Unpredictability	3	3	2-3	3	2.9	
(4) Configuration:	Functional specialization	1-2	1-2	2	2	1.8	C
Divisional	Product/service/customer	4	4	4	4	4.0	
(5) Organization complexity:	Vertical differentiation	2	2	1	2	1.8	C
Flat	Horizontal differentiation	4	5	3	4	4.0	
(6) Geographic distribution:	Optimal sourcing	2	2	1	2	1.8	C
Multi-domestic	Locally Responsive	4	4	3	4	3.8	
(7) Knowledge exchange:	IT infused	2	2	2	2	2.0	A
Ad hoc communications	Virtualization	2	2	2	2	2.0	
(8) Task design:	Divisibility	2	2	1	2	1.8	D
Knotty	Repetitiveness	2	2	2	2	2.0	
(9) People:	Number of people	1	1	1	1	1.0	C
Laboratory	Professionalization	4	4	5	4-5	4.4	
(10) Leadership style:	Uncertainty avoidance	4-5	4	4	3-4	4.0	D
Producer	Preference for delegation	4-5	4	4	3-4	4.0	
(11) Organizational climate:	Tension	2-3	2-3	3-4	2	2.6	C
Developmental	Readiness to change	3-4	3-4	2	4	3.3	
(12) Coordination and control:	Formalization	2	2	1	1-2	1.6	C
Market	Decentralization	4	4	2	4	3.5	
(13) Information systems:	Amount of information	2-3	2	2	2	2.1	C
People-driven	Tacit nature of information	4-5	4	4-5	4	4.3	
(14) Incentives:	Target of incentives	2	2	4	1	2.3	C
Bonus-based	Basis of evaluation	4	4	4	2	3.5	

Table 1. Categorization of attributes

In the analysis framework used in this study, Burton, et al. (2011) distinguish between four archetypes of organizations: *Reactor, Defender*, *Analyzer* and *Prospector*. These archetypes are well known to the literature and have previously been used by several authors (Blumentritt & Danis, 2006; Ireland, et al., 2003; Slater, et al., 2014). According to these authors, an organization having the prospector profile is characterized by being engaging in radical product innovation, focusing on customer satisfaction, technology advantage, product quality, and on using entrepreneurial opportunities to act quickly. Further, they are searching for market opportunities, possess flexible technologies, and are the creators of change and uncertainty. Blumentritt & Danis (2006) places the defender and prospector at opposite ends of a continuum of strategies, with the analyzer being located between these archetypes.

To perform well in the development and commercialization of disruptive technology you need the capabilities of a prospector organization, at least to a certain degree (Slater & Mohr, 2006). These capabilities correspond well to the characteristics of quadrant C in the 14 two-by-two systems presented by Burton, et al. (2011), meaning that the optimal organization profile for the prospector would correspond to "all C's" in Table 1 (page 43), which is not the case for the UA.

Burton suggests that the ultimate goal for a company is to be located in the same quadrant for all 14 attributes. Regardless of strategy type, it will be beneficial for an organization (unit of analysis) to assume same quadrant location for most (ideally all) of the attributes. As an example, it would typically be best for a defender organization to be functional configured and let the coordination and control system operate as a *Machine*, to optimize for *Efficiency*. Similarly, it would be best for a prospector organization to assume a *Flat* organization complexity along with *Developmental* climate to optimize for *Effectiveness*. However, identical quadrants for all 14 attributes is very rarely seen, and in many cases, it is not viable to change that situation because of two main reasons. First, because changing one of the identified misfits may create new misfits and things might be worse compared to the status quo situation. Second, because some of the attributes are very hard or even impossible to change. One example is the *Environment*, which of course in not very realistic to change.

In his work, Burton measured the *Change difficulty*, through a questionnaire handed out to his MBA students (that all are practicing managers) and found that environment, ownership and management were the most difficult things to change, whereas diversity, centralization and formalization were the easiest things to change as presented in Figure 18.

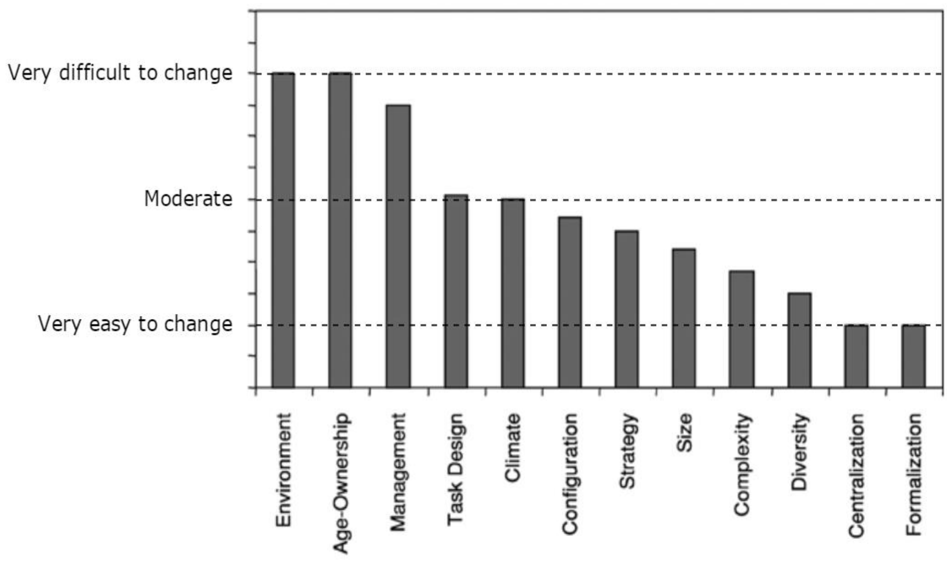


Figure 18. Change difficulty. Adopted from Burton, et al. (2011).

7.6.1 Organizational misfits

The findings presented in Table 1 (page 43), derived from the interviews, reveal that the majority of attributes of the UA, belong to the C (prospector) quadrant. However, six attributes are located in non-prospector quadrants. These attributes will be elaborated in this sub-chapter. A graphical representation of the 14 attribute locations is presented in Figure 19, where the identified location of the attributes are highlighted by being underlined and having a bold typeface.

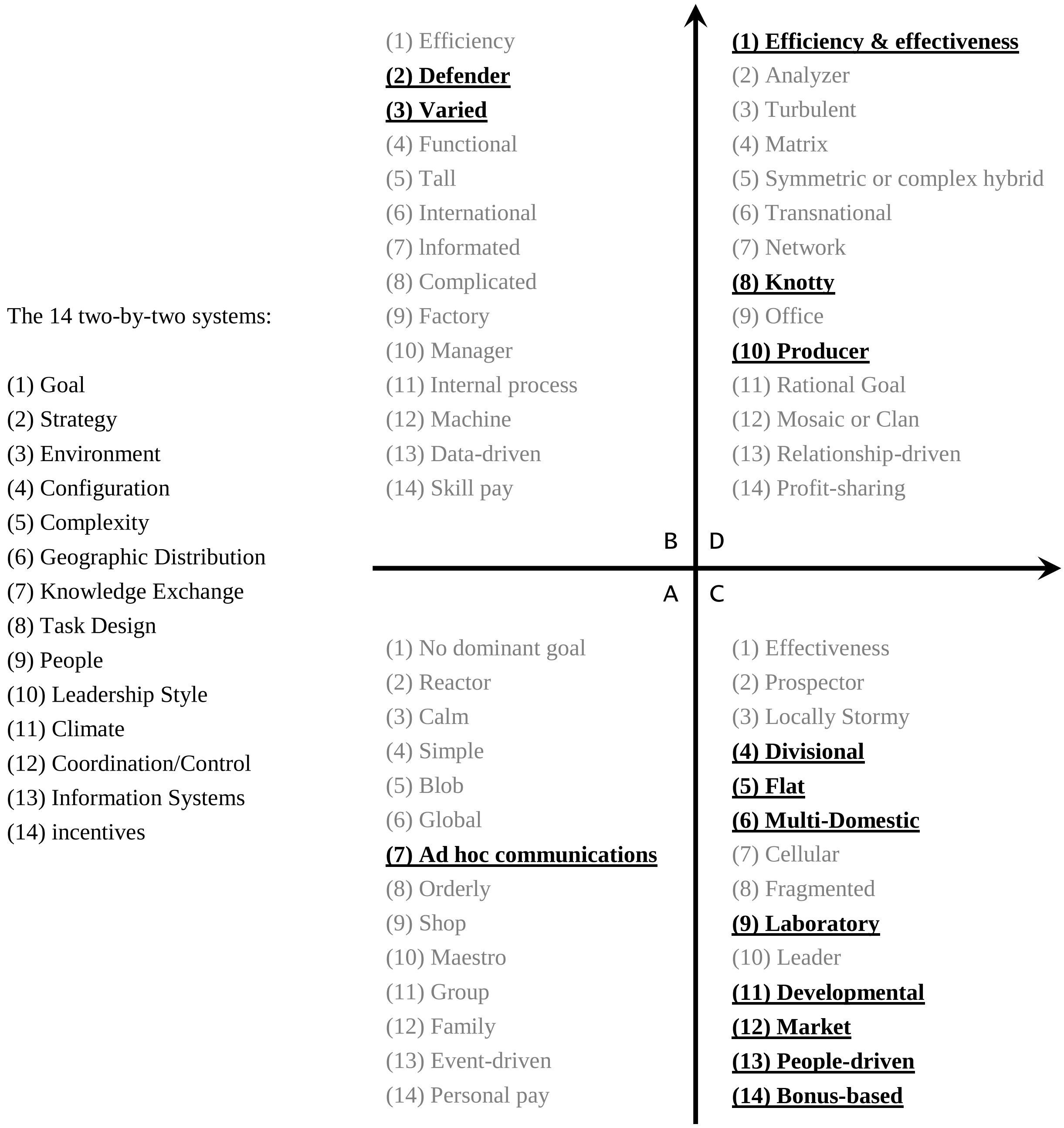


Figure 19. Location of UA attributes in the A, B, C and D quadrants

As described in chapter 7.5.1 (page 30), the current priority in the UA is efficiency over effectiveness. New product development decisions are based on fast return on investment rather than seizing the market with leading-edge innovation. However, the *Analyzer* categorization based on the finding is not very distinct. The score on Efficiency and Effectiveness was 3.5 and 3.1, where 3.0/3.0 represents the origin in the two-by-two system. However, to focus more on the chance of being first on the market with a disruptive product

and gain a first mover advantage higher focus on effectiveness would be beneficial, which probably would mean that efficiency would have to be sacrificed to some extent.
Since the defender and prospector are opposite poles (Blumentritt & Danis, 2006), the strategy in the UA is likely to be the most critical property among the six deviating attributes. To aim for a first mover advantage, it is required that you (as an organization) engage in projects that are not 100% bulletproof. Moreover, you have to accept that you cannot lean up against well-established products on the market and add an incremental feature, increase performance a bit or lower the price. You need to agree that the product success on the market cannot be fully predicted, and you have to be willing in taking that chance up front. Further, you have to accept that an increase in R&D and marketing spendings will be required. Typically, you need to carry out technology research pre-projects before you engage in the actual product development phase. On the marketing side, you probably have to invest in large market introduction campaigns, where the new technology is presented (maybe even on a new market). It is not for free to push a new message to the market. Finally, you have to make sure, that all distribution channels understand and accept the new product, even if the product potentially may kill some of the existing business.

Largely, such risk-willingness has not been present in the UA for almost a decade. In general, the project proposal showing the least risk along with quick payback has been selected over more risky projects introducing new technology. From the author's perspective, this is quite simple: you cannot succeed in the development and commercialization of a disruptive product with the mindset of the defender. The UA needs to focus more on exploring (technology/market) and less on exploiting (resources) to be successful in such a process.

Looking at the environment for the UA, it appears to be *Varied*, based on the score for *Complexity* and *Unpredictability*. However, the latter received a combined score of 2.9, actually meaning that the environment is right on the borderline between Varied and Turbulent. As found by Burton, et al. (2011), the environment is the hardest attribute to change, but many of the impacts from this environment can be predicted. It is assumed that the most unpredictable factors in the UA environment illustration (see Figure 15, page 32) are the customers, partners and political systems. Seen from the perspective of disruptive product commercialization, the customers and partners will introduce the biggest change relative to commercialization of incremental innovation, since it is harder to anticipate how they will receive a disruptive product.

Through the interviews, the Knowledge exchange attribute for the UA was found to be located in the quadrant A, as *Ad hoc communication*. This might pose a problem for the development of the technology behind the disruptive product, since the UA typically takes an inwards attitude towards R&D. However, the project will most likely introduce new building blocks not necessarily mastered in-house. It is therefore important to identify these technologies and acquire this knowledge from outside the organization.

To be able to succeed with both the development and the commercialization of disruptive technology, it is important that the team(s) allocated to this mission is not burdened by task of maintaining the existing business (O'Reilly & Tushman, 2004; Christensen & Raynor, 2013). Today, the UA appears to be *Knotty* in its task design. This forms a misfit to the capability of being agile and effective (*Fragmented*). To aim for this capability, it may be required that the mentioned teams are isolated from any maintenance tasks of the existing business to effectively operate as an individual organism running at its own pace without heavy coordination tasks towards the remaining organization.

The last deviating attribute identified is the leadership style, which was categorized to being *Producer*. This attribute location represents a misfit to the prospector profile, since the Uncertainty avoidance parameter was found to be high, which is a clear conflict of the required risk-willingness discussed earlier in this chapter. To engage in projects involving disruptive innovation, you have to accept a higher risk compared to incremental innovation (Christensen & Raynor, 2013).

7.6.2 Organizational related uncertainties

In the framework presented by O'Connor & Rice (2013), a table holding *Categories of Uncertainty* is presented. This table includes organizational and resource specific questions identified through their research, which will be discussed in the following.

OQ1. What capabilities must the project team embody?
The team has to be able to "think-out-of-the-box", both on technical and market topics. It is vital that the team members are willing to engage in a project being more risky compared to the traditional incremental innovation projects carried out in the UA. It is also important that the project participants are mentally prepared for an increase in the frequency of course changes during the product specification and development, since they will be moving through unknown territory.

OQ2. Who should lead the project team? How do we recruit these individuals?
Preferably, the team leader is a person that has no responsibility for the existing market. This allows him to focus on the potential of the new technology and have this as his primary focus. This further puts him in a position, where he is better at fencing the team against any burdening tasks from the existing business. Currently, such a profile is hard to spot in the existing organization, which is primarily oriented towards pleasing the existing professional audio install market with incremental innovation.

OQ3. How do we deal with unanticipated changes in the team and changes required by the maturation of the project?
Most teams in the UA follows the Scrum developmental principle. Not necessarily using exact same "rules", but all teams understand and accept that things cannot be planned and predicted far out in the future. These Scrum teams work with a 2-3 weeks recurring planning procedure, since it has been found that things begins to "slide" after this period of time – and a new plan has to be established. Having used this system for more than 5 years puts the teams in an excellent situation when change is required. If large organizational changes are required, it is judged that it would be advantageously to involve the team members in the process to avoid resistance towards the required change (Cummings & Worley, 2008).

OQ4. How do we define the relationships with the rest of the organization, one or more business units; central R&D; senior corporate management?
It is assessed that it would be beneficial to (at least to some extent) establish an ambidextrous organization, meaning that the team(s) being assigned to projects having disruptive character, is being allowed to focus 100% on these matters. Preferably, R&D, marketing and sales would be included in this "task force", since these functions would be heavily influenced by the disruptive nature of the project. R&D faces a new set of challenges that maybe requires a new skill-set, marketing and sales needs to "unlearn" the traditional values they have obtained through many years of orientation towards the existing technology and market. To penetrate a market with a new solution, enthusiasm is required. The sales and marketing function have to appreciate the new technology and they have to benefit from this technology on both a team and personal level, otherwise they will seek back to business as usual. It is, however, not expected that the manufacturing part of the value chain is required to be included in the group fully oriented toward the emerging business, since this process is predicted to be unchanged compared to manufacturing the existing technology. This slightly contradicts the model (see Figure 4, page 16) presented by O'Reilly & Tushman (2004), by excluding the manufacturing part.

OQ5. How do we stay on the radar screen of corporate management and meet expectation?
It is judged that information, from the project teams to the management, with a regular frequency, is key. It is the author's experience that technology demonstrations are a very powerful means for showing progress

and/or to be used to convince decision makers that a new technology has a business potential. Another example is the findings and results from market research. It is important that such information reach the corporate management to ensure that the project gets continuous attention. According to an interesting model presented by De Meyer (1991), regular occurring face-to-face meetings between different project stakeholders are beneficial for keeping a high confidence level (see Figure 20) and keeping stakeholders aligned. During the recurring steering group meetings for the UA, such a mechanism is automatically being brought into play.

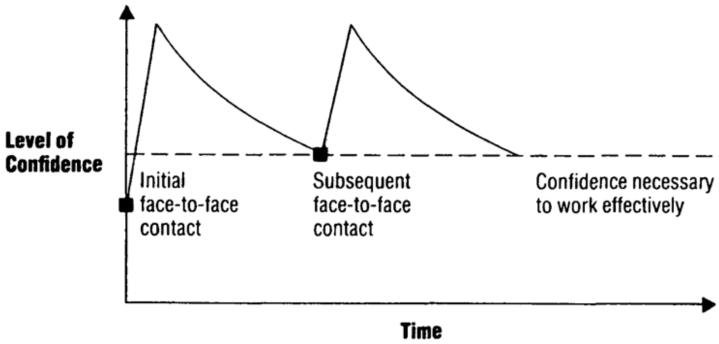


Figure 20. Confidence threshold level (De Meyer, 1991).

OQ6. What will be the oversight process for the project? How will it change over time?

It is assumed that the project process for a project having disruptive character could be identical to the current setup, with the steering group as the highest authority. This oversight structure can be designed to resemble the ambidextrous organization layout (see Figure 4, page 16). On a longer time perspective, the technology created and matured by the teams working with the emerging technology, would be passed on to business units working with the existing business in order to utilize their capabilities of working on the mainstream market.

OQ7. How do we manage the interfaces with internal and external partners?

As described earlier, the core team working on the disrupting product should be shielded against tasks related to the existing business as much as possible. It is therefore important that a "filtering" functionality is established to counteract this, for example as a middle-manager that could judge whether team interruption could be justified. Regarding external partners, it is very important that tight bonds are established to early-adopter type of companies that can help in "spreading the word" in a given industry (Slater & Mohr, 2006). This interface is vital, especially in the developing the product concept, since a thorough understanding on the market requirements and needs (both expressed and latent) is required. Such interface should be nourished through professional relations between e.g. product managers from both organizations.

7.6.3 Resource related uncertainties

RQ1. What resources and competencies are required to complete the project tasks?

To define, develop and commercialize a product that potentially will challenge the exiting 70V/100V installation topology, the following resources are required:

(a) Market research personnel that can help in a better understanding of the "work to be done" (Christensen & Raynor, 2013) by this product. Initial research has been conducted within the study (see chapter 8, page 53), but a more comprehensive investigation should be carried out to increase the chance of defining a system having an optimal feature-set and scope. Further, this research group should look for other markets than the dedicated professional audio installer market. It is envisioned that this technology is a good match towards today's non-consumers (Electricians and IT installers), which today often avoid installing audio systems because they do not understand the dimensioning and installing process. They prefer to leave this job to the audio professionals.

(b) Product and Technology champions. Persons that consistently keep on pushing the disruptive product idea internally to ensure that the product stays on the top management radar. This is particularly important in a company that has a clear focus on incremental innovation, since the project involving disruptive innovation has to compete internally against other - less risky - projects.

(c) One or more firms having an early adopter characteristic. Such firms can help in both the product definition phase, but also as means for entering the mainstream market as described in chapter 7.6.2 (pages 47-48).

(d) A product development team with the right skill-set. This team has to comprise competences like:

1. System concept development
2. Networking (both system internally and network interfaces like AVB, Dante, AES67)
3. Audio signal processing
4. Efficient Class-D power amplification
5. Ceiling loudspeaker mechanical design
6. EMC and safety certification procedure

With respect to other supporting functions like manufacturing and marketing, these functions are expected to operate as "business as usual" for the project.

RQ2. Which of these are currently available to us?
From the list above, (b) and (d) can be found in the organization today, however (from the author's perspective) there seems to be a gap between the UA and the full understanding of the "work to be done" for the product. This is particularly the case for new potential markets.

RQ3. How should we acquire missing resources, through internal development or partnering?
As suggested by Slater & Mohr (2006), partnering up with firms to fully understand their needs can be very powerful. They describe a tool-box, which can be used to gather market information (see Appendix H). Internally, the UA needs to strengthen their market research function to implement at least some of the methods suggested.

RQ4. Who are potential partners and how do we form partnerships?
Fortunately, close bonds already exist between the UA and several of the large audio installation companies in the USA. Some of them exhibit the characteristics of early adopters. This is companies like AVI-SPL and Whitlock, which are large audio/video installation companies covering a vast scope of applications, from the small retail shop to large and advanced corporate installations with hundreds (if not thousands) of ceiling loudspeakers per contract. When approaching these companies with an invitation to collaborate in the development of a potentially disruptive product, it is vital that benefits exist for all entities in the value chain. Seen from the UA perspective, the benefits are obvious (market information), but for the partner maybe not particularly striking. It is thus important to put together a business model that will encourage the partner to join such collaboration and ensure that the motivation of the partner is kept at a high level throughout the project duration.

7.7 Organization and resource related critical factors and sub-conclusion

In this chapter, a sub-set of the organization has been analyzed, using a holistic approach offered by Burton, et al. (2011). This method positions 14 attributes of the organization in a two-by-two system, where each quadrant corresponds to different archetypes of organizations. For the relevant project investigated in this study, the quadrant of interest belongs to the Prospector, which offers the best properties when dealing with development and commercialization of disruptive products and services (Slater & Mohr, 2006; O'Reilly & Tushman, 2004). Based on the organization analysis findings, misfits to the optimal organization profile have been discussed and actions suggested in chapter 7.6.1 (pages 45-47).

Further, a set of organizational and resource related uncertainties identified by O'Connor & Rice (2013), are discussed. From the organization analysis and the mentioned organizational and resource related uncertainties (OQ1-OQ7 and RQ1-RQ4), the following critical factors are identified.

The first and paramount critical factor is the UA strategy. With the mindset of a defender, it will be very hard to appreciate the required investments required to aim for new innovative products that might disrupt things. Today, projects are chosen as a function of how well they pay back the development investment over three years. This method is not suitable for the long term investment related to game-changing products, which often have impact for decades. The fact that the UA has been operating as a defender for several years also poses a risk with regard to the UA’s capability to operate as a prospector. To some extent, the original organization values from the “entrepreneur period” of the individual brand companies has been exhausted as a function of the high focus on efficiency.

The second critical factor relates to virtualization, or rather the ability and will to engage in boundary-spanning knowledge exchange. Since the UA has a low score on that parameter, meaning that they hold an inward attitude to product development, this could be critical. In case technology, not mastered in-house is required, it is important that this is identified at an early stage, to be able to establish a relationship to third-party companies. On a longer time-scale it is further suggested to strengthen the relationship to the academic world, e.g. by offering supervision for Bachelor, Master and PhD projects, which would open up knowledge sharing channels, beneficial for innovation in general.

The third critical factor is the conflict between existing business and emerging business interests, which again are related to the overall strategy of course. To be able to be efficient and very focused on a single new development project involving disruptive innovation, research has shown that such a process is best operated outside the frames on the original organization structures and values (O'Reilly & Tushman, 2004). For the UA, an entirely new organization structure seems like a quite dramatic step to take though. However, it should be considered if a part of the UA could be taken out as a focus team that was not “held back” by the repeating tasks of maintaining the existing business. Moreover, and very important, the person leading such a focus team should have no obligations for the existing business, since this would most likely change priorities and take away focus from the “key project”.

The fourth critical factor is related to the visibility in the organization, or rather how to ensure a sustained focus on the project from the top management. To achieve this, it is important to identify product and technology champions that can carry the project forward and operate as evangelists. It is important that such persons truly believe in the project themselves to succeed in such a role. Further, they need adequate decision power when it comes to resource allocation. According to O'Connor & Rice (2013), *the persistence of project champions in acquiring resources is critical to the ultimate success of their ventures*. Further, it is very important with reports to the top management at a regular basis, showing the project progress. This is key for staying on the radar screen.

The fifth critical factor comprises the interface to external partners and how to manage this. As identified in both chapter 7.6 (page 43) and later in chapter 8.5 (page 67), collaborating with an early adopter type of company will potentially be very beneficial for the UA. Both when it comes to the product definition phase, but also as a means for “spreading the message” in the industry. According to Slater & Mohr (2006), this is the most important mechanism regarding the ability to cross the chasm. However, such partnerships do not come “out of the blue”. Like all other entities in the value chain, the partner has to have a benefit also. Finding this attractive benefit is key. It is further recommended that a close relationship is established, where both parties put something at stake, which ensures a natural motivation.

The sixth and last critical factor is related to the bottleneck identified between the UA and a comprehensive market understanding. Today this task seems to be left to a single product manager, which today has the primary focus on pleasing the existing market. Seen from the author’s perspective, there is a clear mismatch between the vast amount of resources spent on technical R&D tasks, compared to the resources spent on market research. Similarly to the observations made by Christensen & Raynor (2013), where top management believe they are making the decisions, but are only presented with “filtered” options presented by the middle manager, is here a situation, where information is not flowing from the market to the UA in a transparent manner. For the team (dealing with this potentially disruptive product) to be effective and aim for the optimal solution, they need unfiltered information, possible from more than one market.

High-critical factor	Latency	Required action
Strategy	Both high and low	Risk has to be accepted. Other methods (than ROI) have to be established to evaluate disruptive innovation. Be patient for growth but inpatient for profit. Monitor values (focus on effectiveness).
Virtualization	Both high and low	Identify any technology or technical discipline that is not mastered internally. Establish relation with external functions that can solve these problems.
Organization structure	Low	Evaluate if the organizational structure requires a change, in particular around the team that handles the development and commercialization of the disruptive product. The leader of such a team is preferably a person without ties/interests to the existing business. In the extreme case, a pure ambidextrous organization layout is required.
Organization focus	Low	To get the required focus in the organization, product and technology champions should be identified and given an adequate level of decision power. To stay on the top management radar it is vital to report project progress with regular interval.
Interface to external partners	High	Establish a business model involving early adopter type of partner. Identify benefits for the partner.
Market research function	Low	Establish an objective market research function. Identify possible markets for the new technology.

Table 2. High critical factors, organization and resource related.

7.8 Reflections

The organization analysis carried out in the chapter uses an effective method offered by Burton, et al. (2011). The method gives a holistic image of a given organization, but the image is not very detailed. It simply offers a multidimensional number that represent the properties of the organization. It does not offer a rich description of the underling beliefs, values and culture in the organization. However, for this purpose of investigating which properties of the organization that might conflict with the wish of engaging in the development and commercialization of a disruptive product, it does solve the task.

The analysis approach used in the chapter was based on discussions with top and middle management. This quite narrow group of people might bias the results in favor of how management think (or wish) reality looks like. Ideally, a larger group of people, representing all layers of the organization should have been included in the discussions. This task would be an obvious choice of further research.

Further, bias effects might exist in the analysis part, during interview of the top management. In one of the meetings, two interviewees participated (CEO and VP). This had the effect that the parameter scores were often “negotiated”, rather than individually given. On the other hand, these discussions gave a rich output, seen from a qualitative perspective. Many of the statements made, would not have been made in a classic one-to-one interview situation. Further, the discussion between the CEO and the VP had the purpose of aligning the meaning of the parameter, which to some extend was lacking in the second meeting, where only the program manager and the author were present. However, one should be careful in placing an employee and a company leader in a discussion together and expect that the employee is unbiased and unaffected by the position taken by the leader. In this case, it is most likely that the VP would had answered and rated differently had the CEO not been present.

8. Market

Approaching an existing market with a new and potential disruptive technology poses a big risk for a company. In this case, the primary market for the install vertical in TC Group is North American professional audio installation companies. The typical audio installation business model in the United States comprises both an *audio consultant* and an *audio contractor*.

When a new installation is required, for example as a part of a new building project or during a building refurbishment, an audio consultant places a bid on that installation. This bid is based on experience from previously made audio designs and typically contains a detailed list of the required capabilities of the components that forms the entire audio system. Most often, a specific preferred system component is listed as an example in the system description. The list can be very detailed, even down to specifying which cables that must be used to interconnect the different components in the system. The key components in such audio installs are typically microphones, audio sources (CD-players, FM radio receivers, internet audio streaming devices and other playback devices), mixers, amplifiers and loudspeakers. Most often, the consultant also handles the design of video and lighting systems as a part of a full AVL (audio, video, and lighting) package, in which video plays a larger and larger role with in-store flat-screen display used for commercials, now driving a large part of the audio/video installation market.

The audio contractor company is the company that actually carries out the physical installation work as described by the consultant, who operates as a third party in this process. The basic task of the consultant is to design the sound system, oversee its proper installation and then perform the final adjustments to ensure its proper working order. Depending on who does the actual installation, he may or may not need to actually be on the installation site very often. It is more likely that his input will be given during periodic visits to check on the progress of the installation job. An independent consultant acts as an advocate, protecting his customer's interests and his own reputation by assuring that equipment is properly selected and installed; his primary profit is from design and oversight, not equipment sales margins.

Some larger audio integrator companies comprise both the consultant and contracting capabilities and these companies represent a dominant portion of the TC Group key customer list.

8.1 Acquiring market information, methodology

To learn about the preferences and requirements of large audio consultant companies in the United States regarding loudspeakers installs, a *Sequential Exploratory Method Design* has been used. A sequential exploratory design is a *Mixed Method* in research design and is an approach where either (1) a quantitative method is followed by a qualitative method or (2) a qualitative method is followed by a quantitative method (Creswell, 2009).

The sequential exploratory design was chosen for two main reasons. First, the method increases the quality of the second part of the method. That is, if the quantitative method part precedes the qualitative method part, the researcher can use the analyzed data from the quantitative part as a guide (part of input) to the interview design process. Likewise, if the qualitative method part precedes the quantitative method part, the researcher can use the qualitative findings to help him select and formulate the (typically closed-ended) questions in a questionnaire (Creswell, 2009). This way you can get "the best from both worlds": a rich description of things through the qualitative interview combined with a broad and cost/time efficient method through a quantitative survey. Second, it is the author's experience that top management pays much more attention to "hard data" (numbers) compared to "indicators, observed through conversation" (verbal/textual expressions), which would be the case if no quantitative method was used.

The qualitative part in this study is based on interviews carried out during the 2013 InfoComm tradeshow in Orlando with the following five key customers: *(1) AVI-SPL, (2) Forward Compatible Group LLC, (3) Vantage Technology Consulting Group, (4) WJHW, (5) McKay Conant Hoover inc* - and with the following three technology providers *(1) Audinate, (2) Cisco Systems Inc, (3) Network Technologies Inc*.

The quantitative part was carried out as a web-based questionnaire, which was sent out in 2015 to already existing TC Group contacts working for the following firms: (1) *Affiliated Engineers*, (2) *Anderson AV*, (3) *VDB Group*, (4) *AVI/SPL*, (5) *Avitecture*, (6) *AVR*, (7) *Cardone, Solomon & Associates*, (8) *CompView*, (9) *D.L. Adams Associates*, (10) *DSS Incorporated*, (11) *Electrosonic*, (12) *Engineering Harmonics*, (13) *FSG Electric*, (14) *Go MultiMedia*, (15) *HB Communications*, (16) *Immedia Integrated Technologies*, (17) *Jaymarc AV*, (18) *K2 Audio*, (19) *MCH*, (20) *McSquared*, (21) *Poll Sound*, (22) *Pro Sound & Video*, (23) *Shen Milsom Wilke*, (24) *Shen Milsom Wilke*, (25) *Technical Innovation*, (26) *Technology West Group*, (27) *Technomedia*, (28) *The Sextant Group*, (29) *Waveguide*, (30) *Westbury National*, (31) *Western AV*, (32) *Whitlock*.

These firms were selected by the CEO of TC Group Americas (the sales organization of North and South America) as being the most important customers for TC Group regarding the installation business.

The scope of the questionnaire was limited to ceiling loudspeaker networks, since this type of loudspeaker (by far) represents the largest business for TC Group, when looking at professional loudspeaker installations. Before the survey design, it was decided that a clear focus would be beneficial and would help avoiding ambiguous questions that could potentially be interpreted differently as a function of loudspeaker topology. Another argument for choosing ceiling loudspeakers as a focus is that a large development project combined with a radical new way of interconnecting loudspeakers would not be interesting or relevant if this new technology would only cover e.g. wall-mounted loudspeakers. To make sense for TC Group to engage in such a venture, ceiling loudspeakers have to be a part of the solution.

The purpose of interviews and survey was the following:

1. To get a better understanding of which requirements the professional audio installation business has to ceiling loudspeaker installation technology (what exactly is “the job to be done”).
2. To learn which existing features/properties are “must have” and which are “nice to have”
3. To learn to what extent the audio professionals are willing to deviate from the existing technology market standards.
4. Get an indication of the perceived value of potential new features enabled by a new technology.
5. Get typical-values and maximum-values of ceiling loudspeaker installations regarding loudspeaker count, cable length and amplifier power.

8.1.1 Interview Methodology

The interview meetings were conducted as informal discussions, using a short PowerPoint introduction as “kick-starter”. The meeting participants were all 30-50 year old males, with two persons representing TC Group R&D and 1-3 persons representing the firm being interviewed. The key customers were represented by audio consultants and the technology provider firms were represented by persons having a sales or an application engineering function in these firms. The PowerPoint presentation included two examples of a concrete loudspeaker installation. One using the traditional 70V technology, and one using a network based technology (see Appendix C). During the discussion of these slides, the differences between the traditional installation compared to the network based installation were explained. The objective through this explanation was to stay neutral regarding technical preferences trying to avoid biasing the interviewees, but it was of course important to highlight main differences that potentially could have a big impact on e.g. mounting procedure and the total price of a given system. Following the installation example slides in the presentation was an agenda – or rather a list of topics that was open for discussion (see Appendix B). Since some of the interviewees had a strict program during the tradeshow, they could only spend 20-30 minutes on the interview, meaning that not all of the topics were covered with all eight groups of interviewees. The average duration of the meetings was 45 minutes.

The interview strategy was to aim for an open conversation, trying to avoid closed questions with the goal of not steering the interviewees in a certain direction. Notes were taken during and immediately after the meetings. These notes were later analyzed using *coding* by hand, to find patterns in the statements gathered across all interviewees (Saldana, 2013; Creswell, 2009). According to Creswell (2009), the coding process can be defined as:

Coding is the process of organizing the material into chunks or segments of text before bringing meaning to information. It involves taking text data or pictures gathered during data collection, segmenting sentences (or paragraphs) or images into categories, and labeling those categories with a term, often a term based in the actual language of the participant (called an in viva term).

8.1.2 Survey Methodology

Based on the findings and impressions obtained from the interview meetings, a set of questions were formulated with the purpose of acquiring quantitative data of preferences and requirements of loudspeaker network installations, which could consolidate the qualitative findings. Further, it was decided to design additional questions that would help TC Group in better understanding the typical application.

The survey was carried out as a web-based questionnaire through the web service SurveyMonkey. The questionnaire held a combination of multiple choice answers and open-ended questions. The multiple choice answer options were placed either on a five-level Likert scale or as values in a multiple-choice drop-down menu. The graphical user interface met by the respondent when activating the survey link is shown in Appendix E.

The five-level scales listed in Table 3 were used to measure the terms: *importance*, *preference* (between X and Y) and *value*. These scales (with minor modifications) are found to be well suited for research purposes (Brown, 2010; Siegle, 2010). Further, it has been assessed that it would be best for this survey to re-use existing scale templates as much as possible to avoid altering existing “standard scales” and thus increasing the risk of introducing new and perhaps unfamiliar and ambiguous terms for the respondent.

Score	Importance	Preference (between X and Y)	Value
5	*Very important*	*X is much preferred*	*Extreme value*
4	*Important*	*X is somewhat preferred*	*High value*
3	*Moderately important*	*X and Y are preferred to the same level*	*Some value*
2	*Of little importance*	*Y is somewhat preferred*	*Limited value*
1	*Unimportant*	*Y is much preferred*	*No value*

Table 3. Survey Likert scales

The five-level Likert scale is the most common type of scale used for surveys and is thus also used in this survey. Five levels have proven as a good compromise between precision, unambiguity and simplicity. In the literature there has been some discussion of whether the four level scale would be a better option, but is has been argued that in case of bipolar answering options, the lack of the "neutral answer" would introduce a bias in the respondents answers (Ron, 1991).

Multiple-value dropdown menus were used to measure *loudspeaker count* ("2" to "80" in 18 logarithmic spaced steps), *cable length* ("3m" to "3000m" in 19 logarithmic spaced steps), *conductor thickness* ("AWG10" to "AWG30" in 21 linear spaced steps) and *ratio* ("0%" to "100%" in 11 linear spaced steps) of several parameters. The purpose of these fixed answer options was to ease the respondents' task, thus being able to fill out the questionnaire quickly without having to type in numbers. The fixed set of options also served the purpose of completely avoiding "unit errors", which potentially would have been an issue since questionnaire invites were sent to persons in both the United States (feet, AWG) and Canada (meters, mm^2).

It has previously been investigated which layout would yield the highest response rate. From one perspective, a structured page oriented questionnaire logically guides the respondent through the questions. From another perspective, a scrollable "single-page" questionnaire can potentially be quicker to fill out since it does not require any mental task switching when going from one page to another and such a task switch might cause the respondent to quit the questionnaire without finishing it (Couper, et al., 2001; Fan & Yan, 2010).

For this particular survey, several groups of questions are asked, each group belonging to a certain *mindset* of the respondent. As an example, questions are asked regarding the present state of ceiling loudspeaker installation in one group - and in another group, questions are asked regarding the perceived value of new hypothetical features. This requires that the respondent has to shift mental focus during the questionnaire filling process. To handle this shift in mindset, it was decided to divide the questionnaire into three major groups (pages): (1) *Requirements*, which primarily focused on the hard requirements of ceiling loudspeakers installations, (2) *Features of intelligent ceiling loudspeakers*, dealing with new, potential features of future loudspeaker networks and finally (3) *Ceiling loudspeaker installation today* that contained questions related to the loudspeaker interconnection media. Each page contained a short introduction to guide the respondent into the right mindset.

To reduce the risk of introducing ambiguous questions, some of the questions were supplemented with an illustration. This was the case for (1) questions regarding a physical network topology to be precise about the terms *daisy chain* and *network branch* – and for (2) specific cable and connector types. Literature suggest that visual aids, like drawings and other illustrations help the respondent during the survey (Couper, et al., 2001).

8.1.2.1 Survey test

Before the survey invitations were sent to the respondents, the survey was tested and debugged internally using TC Group personnel working within the field of audio installation. This process was quite fruitful and helped in refining the question formulation to decrease the level of question ambiguity and to remove region dependent issues, like requirements only relevant for European audio installs (EN54).

The questionnaire was also tested across the various platforms: Windows, Mac OS, iOS (iPhone/iPad) and Android smartphones. The following internet browsers were used to test the survey: Internet Explorer, Google Chrome, Safari and Mozilla Firefox. All platforms were able to present the questionnaire in a reasonable readable and usable format. However, the smartphones tended to scale the graphical user interface as a function of the widest image (pixels), which made the font size of the text quite small.

A small pilot test (3 test subjects) was carried out to verify 100% that all parts of the survey worked as intended – including the data gathering from the SurveyMonkey database. This test and above tests are found to be critical by other authors (Fan & Yan, 2010; Simsek & Veiga, 2000).

8.1.2.2 Survey invitation

Aiming for a high response rate, it was decided to use the following measures:

1. Send the survey invitations as individual personal emails, directed to only one person per email. This technique has been found effective as a means for encouraging the email receiver to take the survey (Simsek & Veiga, 2000).
2. Use a well-known and respected person (for the respondents) as the email invitation sender. The fact that the respondents know and respect the person requiring the survey answers put the respondent in a situation where he is more motivated in filling out the questionnaire (Fan & Yan, 2010). In this case the email sender was a Lab.gruppen product research manager, that had many years of experience in the field of audio installations for professionals and further – maybe more important – have previously had face-to-face meetings with most of the email invitation recipients.
3. Use wording in the invitation like "we need to spar with key people in the industry" makes the recipient feel he is a part of a small important group of people, which also increases his motivation for taking the survey (Fan & Yan, 2010).

The body text of the invitation is listed below. The full invitation can be found in Appendix D.

Dear Xxxxxxx,

At Lab.gruppen we continuously try to figure out how we can improve the amplifier solutions for the professional audio contractor. We are right now looking at different approaches that potentially would make things easier and more cost-effective for the customer. One of our focus areas is how to best power and monitor loudspeakers that traditionally are driven with 70/100V. We are evaluating technology that can provide a simpler installation procedure while offering several new advantages, which you will not find in existing 70/100V installation systems.

To be able to aim for the right technology and feature-set, we need to spar with key people in the industry - and we would very much appreciate if you could spend 10 minutes on answering 25 questions about this topic.

Please click on the link below that will take you to the survey. If you are not able to answer some of the questions, then you are free to leave answers blank. You can change your answers during the survey.

Looking forward to your answer!

Best Regards,

Klas Dalbjörn, M.Sc.E.E.
Product Research Manager - Install & Tour
Lab.gruppen – Lake

8.1.2.3 Sample

The invite was sent to 34 males. They all worked for North American companies (see chapter 8.1, pages 53-54), doing business within the field of fixed installation of professional audio. The 34 males can be placed in two catagories (*Leaders*) CEO, company owner, president and general manager or (*Technologists*) design engineer, consultant and technology specialist. The distribution of these two groups was 15 leaders and 19 technologists. All invitees had several years of professional experience with audio installations.

8.1.2.4 Survey data acquisition and analysis

Three weeks after the survey invitation was sent out, the respondent's data was imported from the SurveyMonkey database via an Excel spreadsheet. This spreadsheet data was imported to Matlab (a computer math tool, used intensively by many engineers and scientists), where histogram were constructed and results plotted. Average and median (50th percentile) values of the results was also calculated. An example of such a histogram is illustrated in Figure 21.

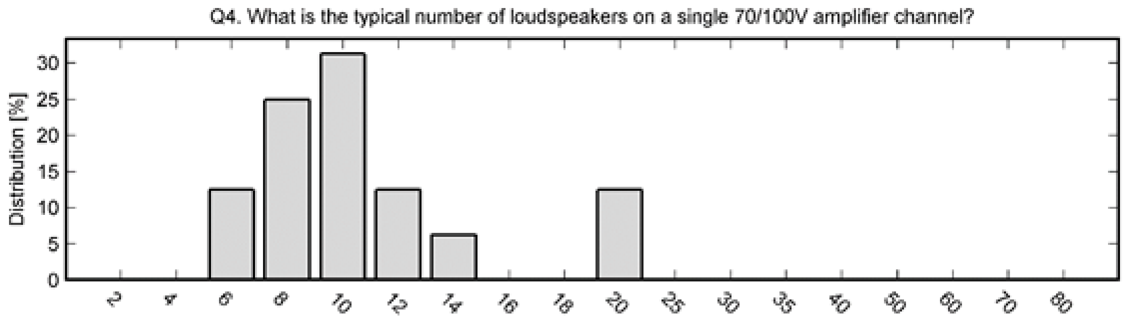


Figure 21. Histogram of answers to question #4 (average = 10.8, median = 10.0)

A further cross-correlation analysis was conducted, using Matlab's built-in function `corrcoef` to look for relationships between the different parameters (data columns). However, no clear relation between any of the data columns was found.

8.2 Interview results

Based on the interview notes, the interviewee statements and general opinions were grouped into categories (coding) corresponding to the topics found in Table 4.

Topic	Sub-topic	Finding
Installation process	RJ45/screw-terminals	Screw-terminals preferred. Worries about RJ45 connection to Ethernet socket would fail over years. Stranded cable and screw terminal has proven its reliability.
	Above ceiling mounting (*Plenum space*)	Worries about powered electronics above ceiling due to (1) increased safety level, (2) not practical seen from a servicing perspective: much easier to repair/replace a device in a central server room compared to a meeting room during a meeting or conference space during a show (perhaps even standing on a ladder). It was preferred that electronic equipment was placed in local racks rather than having electronics sitting in the plenum space.
	CAT5/Conduit	In general, it was stated that conduit is not required for Ethernet cables.

Interconnectivity	Open/closed network	According to the interviewees, most audio/video streams using IP technology would run on its own infrastructure in large installations like university campuses and enterprise systems. Typically, IT departments in such entities are not familiar with audio/video real-time requirements. Therefore, they will not allow high-priority routing for these services, which they consider a threat to the general security of their IP backbone. So in most large installations comprising real-time audio and video services, two isolated networks are typically found (perhaps connected through a simple gateway).
	Compatibility to other brands	Regarding compatibility, the most important finding was controllability. It was found that any system node should preferably be controllable from a third-party controller.
Local and remote control	Control panels	It was advised that the task of designing, manufacturing and distributing control panels (and systems) should be left to others (other than TC Group). Judging from the interviewees statements, the controller market is “red ocean” and is not considered as a TC Group core competence from a market perspective. It would be required for a given network node that it was compatible with industry standard controllers from e.g. Crestron (a market leading audio/video control system manufacturer).
	Which end-user parameters	The single most important parameter in commercial audio installation is “level control”. The second most important parameter is “source selection”. Typically, the end-user does not require controls to more sophisticated sound effects like EQ, delay or various other sound enhancements.
	Remote diagnostics, control/monitoring	Today, after-sales service packages are offered to the customer after the audio system has been installed. The price of the service is relatively high and customers tend to choose the service/repair task on “as-needed-basis”. If a new technology could offer a remote monitoring system that would enable a new and more attractive price point for the customer that could potentially be interesting for the consultant/installer.
Physical attributes	Form factor	This topic related to the specific design network based example (see Appendix C). Preferably, the local PoE amplifiers are small and can be mounted using two screws nearby one of the ceiling loudspeakers.
	Amp, on or inside speaker enclosure	Preferable the electronics is placed inside the loudspeaker enclosure, since this space is not considered plenum.
Audio properties	Audio enhancements	The term “audio quality” is not on the top of the priority list. However, speech intelligibility has a very high priority. None of the suggested audio enhancement ideas

		(bass enhancement, speech/music discriminator) was found valuable.
	Power requirements	It was commented that the power requirement for a single loudspeaker can vary a lot. Typically from a few watts to hundreds of watts. In the latter case PoE is not the right technology.
	Different tappings in a single zone	Different tappings within a single zone do happen, however not seen in most applications. Examples are corridors/toilets sharing zone with a restaurant space.
Alarm systems	Separated or combined	Typically, alarm systems and background music systems are isolated.
Sustainability	Importance of different parameters	Sustainability is getting more and more important. Most often installations carried out for the public sector require a minimal environmental footprint. Often Energy Star rated equipment is preferred or even required.

Table 4. Findings from interview meetings.

8.3 Survey results

When the survey was ended and data gathered from the SurveyMonkey 17 respondents had filled out the web questionnaire, which corresponds to a 50% response rate. No email reminder was sent to the remaining 17 persons not answering, primarily due to the wish of trying to avoid disturbing key customers with emails they might consider as spam.

The following will briefly describe the main observations made during the analysis of the results.

First noticeable observation is that all respondents filled out their contact information regarding name, email and company. This information was not mandatory and in the invitation they were informed that they could choose to fill out the questionnaire anonymously if they desired to do so.

In the following three chapters, a list of the remaining questions and their results is presented.
Raw results from the survey can be found in Appendix F.

8.3.1 Requirements

Q2. How important is daisy-chain-ability for ceiling loudspeakers?

Based on the answers on this question, the ability to daisy chain loudspeaker is vital. The average answer on the 5-level Likert scale was 4.8 and the median equaled 5.0, corresponding to a clear *"Very important"*.

Q3. How important is the capability to make branches on an amplifier channel?

The property of being able to introduce branches on a loudspeaker installation line (daisy chain), was found to be "*Moderately important*" to "*Important*" with average and median values equal to 3.5 and 4.0 respectively.

Q4. What is the typical number of loudspeakers on a single 70/100V amplifier channel?

The typical number of ceiling loudspeakers driven with a single amplifier channel was found to be in average 10.8 with a median value equal to 10.0.

Q5. What is the maximal number of loudspeakers that you are comfortable putting on a 70/100V amplifier channel?

The maximum number of ceiling loudspeakers driven with a single amplifier channel was found to be in average 33.9 with a median value equal to 25.0. (average number is heavily influenced by two “80 answers”). Further, it should be noted that one of the respondents answered “4” on this particular question, which has to be an error, since no respondents answered that low in the “typical number of loudspeaker” question.

Q6. What is the typical cable length to the last loudspeaker (the one furthest away from the amplifier)?

From the answers, the typical cable length was found to be in average 281 feet (86 meters) with a median value of 200 feet. Again, the average value was influenced by a single “1500 feet” answer, which seem to be extreme for a typical cable length.

Q7. What is the maximum cable length to the last loudspeaker (the one furthest away from the amplifier) that you are comfortable with?

The maximum cable length was found to be in average 1159 feet (353 meters) with a median value of 500 feet. The average value was heavily influenced by two “5000 feet” answers.

Q8. How important is loudspeaker-individual level control (tapping)?

The importance of individual level control was found to be “*Important*” to “*Very important*” with average and median values of 4.6 and 5.0 respectively.

Q9. What is most preferable when installing and inter-connecting ceiling loudspeakers: RJ45/CAT5 versus Phoenix screw terminals and 2-wire speaker-cable (mounting, reliability, price)?

Loudspeaker cable + Phoenix connectors was preferred with an average value on the Likert scale of 4.2 and a median value equal to 5.0, meaning that 50% of the respondents found that “*Loudspeaker cable + Phoenix connectors was much preferred*”.

8.3.2 Features of intelligent ceiling loudspeakers

Q11. What is the value of remote, step-less loudspeaker-individual level control?

This potential new feature was not found to be very attractive. With an average score of 3.1 and a median value of 3.0, this feature is found to have “*Some value*”.

Q12. What is the value of remote individual loudspeaker monitoring (impedance, temperature)?

This potential new feature was not found to be very attractive either. With an average score of 3.2 and a median value of 3.0, this feature is found to have “*Some value*”.

Q13. What is the value of remote individual amplifier channel monitoring (fail, standby, temperature, power consumption)?

The option of monitoring the amplifier channel, however, was found to be attractive. With an average score of 4.0 and a median value of 4.0, this feature was found to have “*High value*”.

Q14. What is the value of (remotely controlled) loudspeaker-individual DSP processing (EQ) per loudspeaker?

This potential new feature was not found to be very attractive. With an average score of 2.6 and a median value of 3.0, this feature is found to have only "*Limited value*" to "*Some value*".

Q15. What is the value of (remotely controlled) preset capabilities (change the "zone profile" in a bar/restaurant, dynamically change which individual speakers belong to a given zone)?

This potential new feature was not found to be very attractive. With an average score of 3.2 and a median value of 3.0, this feature is found to have "*Some value*".

Q16. What is the value of ambient noise sensing capabilities as a part of the loudspeaker network (one or more sensors per zone)?

This potential new feature was not found to be very attractive. With an average score of 3.2 and a median value of 3.0, this feature is found to have "*Some value*".

8.3.3 Ceiling loudspeaker installation today

Q18. In what percentage of 70V/100V installations are conduit required?

Conduit was found to be required for in average 46% of installations (median = 40%). Very interestingly, this requirement spreads almost evenly across the entire scale from 0% to 100%, showing that this requirement varies a lot across applications.

Q19. What percentage of the total loudspeaker wiring is constituted by home runs for 70/100v systems?

According to the respondents, home runs constituted 49% in average of the total wiring (median = 40%). The distribution of answers seems to be located in two clusters with centers around 25% and 85% respectively. It is quite surprising that 7 respondents (41%) estimate that home runs represent 80% or more of total installed loudspeaker cables.

Q20. What is the most common loudspeaker wire gauge for 70/100v systems?

The most common wire gauge was in average found to be AWG 16. In the "*Do you have any other comments or concerns?*" field belonging to this question page three respondents argued that the question was ambiguous, since cable thickness dimensioning was related to the required length of the cable for a given installation.

Q21. In what percentage of 70/100v systems are shielded cable used?

From the data it was found that shielded cables were only rarely used, in average in only 8% of installations (median = 0%).

Q22. In what percentage of 70/100v systems are twisted-pair cable used as loudspeaker cable?

Twisted-pair cable was used as loudspeaker cable in 51% of installations (median = 50%). The distribution seen on the histogram placed the respondents in two groups either using twisted pair for all installations or not using twisted pair at all. This finding is however questionable, since all recommendations made by cable, amplifier and loudspeaker manufacturers point to twisted pair cables for 70/100V loudspeaker installations due to the twisted pair's superior performance regarding robustness towards the environment (Crosstalk/EMI/EMC). In the questionnaire, this particular question was complemented with a sketch that illustrated the difference between twisted pair cable and straight parallel pair cable. Even with this sketch, there is a risk that the respondent has interpreted the twisted pair cable as a category cable (CAT5), which of course would affect the answer.

Q23. What percentage of new ceiling loudspeaker installations are an active part of a voice evacuation system?

According to the respondents, 19% of new installations is a part of a voice evacuation system (median = 10%).

Q24. What percentage of ceiling loudspeaker installations cost is constituted by labor (wire pulling, speaker mounting, interconnecting, testing)?

The labor cost relative to the entire cost of installation was in average found to be 38% with a median value equal to 30%.

8.4 Discussion

This sub-chapter contains discussion of the findings obtained through the interview and survey along with a discussion that takes a point of departure from the market related uncertainties presented by O'Connor & Rice (2013).

8.4.1 Interview meetings

The interviewees appeared to be open-minded and excited to be a part of a discussion about future technology. It was however quite clear that all were very much locked on to the mindset regarding traditional centralized installations. Even with an Ethernet based technology that offered full distribution of both processing and amplification, the interviewees could not grasp the idea of an audio installation without a central installation space comprising mixer, signal processors and amplifiers. This installation topology is so very entrenched in the professional audio installation business and has been the industry standard for almost a century. It will be a huge challenge to turn this overnight.

Imagine convincing a mason that this particular new type of synthetic brick is much better regarding the brick laying process, better for insulation and for reducing energy consumption while producing and transporting them. If the mason (and all his colleges and professional network) has spent his entire professional career dealing with the good old clay-based bricks, he will be very reluctant towards this new technology - regardless of the several benefits this new technology offers.

When trying to introduce a new technology you also have to realize and accept that the current technology has “earned its right” to be the preferred approach. And that the current technology might have properties that outperforms a new technology. For the 70V/100V centralized topology this could be things like loudspeaker robustness and accessibility for service/replacement function. The latter case was highlighted by several of the interviewees as an important issue regarding repair of a system. One of the interviewees gave an example of a malfunctioning amplifier:

What do you think is most preferable when a faulty amplifier has to be replaced during a tradeshow in a convention center: (A) standing on a 10 feet high ladder replacing an amplifier placed above the ceiling or (B) standing in a server room away from the crowd and replace a rack based product?

Regarding Ethernet based technology it was found that audio over IP would require its own network, since IT departments were critical towards opening up high priority ports for real-time audio due to safety issues. This perspective is, however, imagined to change with the increasing requirements of video enabled teleconferencing now and in the future. The interviews further revealed that an Ethernet connection would be beneficial regarding interconnectivity to third party brand products, primarily controllers and that an Internet connection would potentially open up for an entire new value proposition to the costumer, where a service functionality could be established over an Internet connection if the installed system comprised a self-diagnose capability. This type of business model seem obvious, based on discussions with the firm representatives where they stated that their customers often preferred not buying after-sales recurring service and maintenance packages, primarily due to the high price. And, often customers felt that they did not receive any value for this large recurrent expense, so most costumers chose to handle product servicing on a need basis (when failing equipment is experienced). This observation is supported by the overall status for the United States audio installation industry regarding earning on recurring service functions, where these functions represent less than 10% of the total annual revenue for the vast majority of firms (LeBlanc, 2015). With a technology that could potentially reduce the cost significantly of these service function, it is most likely that many costumers would accept an offer of continuously product status monitoring.

8.4.2 Questionnaire

In general, the findings revealed that the respondents were quite conservative. They tended to lean up against the traditional way of doing things, which can be seen by the way they valued the old properties and the new potential properties of loudspeaker network systems. This is no big surprise since the consultants are more or less forced to use prior installations as reference templates for new installations. They put a pride in doing things in a consistent, reliable and well-known manor. From this perspective, it can be very hard to value new approaches if they are not fully compatible with the exiting (and historical) way things are done.

Looking at the traditional daisy chain installation topology, this seemed to be mandatory (judging from the survey results), which of course also make sense from a practical mounting process perspective. Concerning the ability of making branches on a network, this feature was not found to be quite as important. Similarly, the feature of being able to adjust the loudspeaker level, be selecting a certain tapping is required in the typical application.

Based on the answers from the respondents, the typical ceiling loudspeaker daisy chain (zone installation) is described in Table 5. This is very valuable information, since any new technology trying to compete with the existing technology has to be able to cover this application-size in an efficient way.

Property	Value
Cable length	200-300 feet (60-90 meters)
Cable gauge	AWG 16
Cable shielding	No
Twisted cable	Maybe (51%)
Conduit	Maybe (46%)
Loudspeaker count	10
Part of evacuation system	No
Labor cost relative to entire installation	Approximately one third

Table 5. The typical loudspeaker installation, based on survey answers.

Regarding preferred interface (cable and connectors) between audio source and destination, things seem quite clear judging from the answers: standard loudspeaker cable and Phoenix connectors (again the standard solution is preferred). However, a few of the respondents commented on this question in the "*Do* *you have any other comments or concerns?*" field. They both remarked that their answers regarding preferred cable and connector type were heavily influenced by their cable gauge requirements seen from a traditional 70/100V perspective. One of the respondents formulated it like this:

Phoenix is preferred over RJ45 connectors primarily due to the wire gauges required to deliver signal while minimizing damping losses. We typically specify AWG 14-16 lines for longer runs and these are not supported on RJ45 connectors.

The purpose with the question was to determine if CAT5/RJ45 would be an option in future loudspeaker installations - from a perspective regarding the mounting process, reliability and price. However, comments like above may indicate that this question is better suited as an open question in a qualitative interview – perhaps combined with information about the advantages in DC systems (see chapter 9.2, page 73). Without the knowledge and awareness of the advantages in such DC supplied systems, it would be strange to prefer an interface that had less power capability and perhaps a more complex mounting procedure than the cable and connectors used in today's installation. Most people prefer things they are comfortable and familiar with!

When looking at the rated value among the respondents regarding a set of new, potential features like remote level control, loudspeaker heath monitoring, amplifier health monitoring, DSP processing, dynamic zone profiles and ambient noise sensing, only one of these features was perceived as having "high value": amplifier health monitoring. This finding can probably be explained by the fact that existing safety critical applications like voice evacuation systems often require a so-called "end of line device" to be approved by regional fire/evacuation authorities. Such devices monitor the voltage (amplifier output) on the loudspeaker line and activate an alarm system if an inaudible pilot tone (generated by the amplifier) is not present. In other words, the amplifier health (and cables) are monitored, not the loudspeaker itself – meaning that this principle is worthless (seen from a safety perspective) if the loudspeaker has a defect. Nonetheless, loudspeaker monitoring is not assigned any value simply because safety regulations only comprise the amplifier and cable installation.

Regarding the set of new, potential features one of the respondents commented:

We prefer to keep presets, noise sensing and those types of features inside the DSP. To have the ability inside the DSP for these functionalities is extremely valuable.

This comment clearly shows a mindset that is narrowed to a "centralized installation", where all system intelligence (DSP) is located in a central server room and that loudspeakers are considered dumb passive devices. Again, this is an example where such types of questions should be complemented with rich information about "what is technical possible". This is not feasible in a questionnaire.

Finally, two important things were discovered through the survey. First, it seems that conduit is used in approximately every second installation. Second, the average labor cost relatively to the total installation cost is roughly one third. These findings is good news for low voltage technology, since they invalidate the conduit requirements for installations.

8.4.3 Market related uncertainties

In the framework presented by O'Connor & Rice (2013), a table holding *Categories of Uncertainty* is presented. This table includes market specific questions identified through their research, which will be discussed in the following.

MQ1. How do we know this pursuit is worth the effort?

Compared to a project only comprising incremental innovation, this project will introduce an increased risk. For incremental innovative products you can compare it to similar products on the market, and combined with historical data about the market, you will be able to predict sales performance. This will not be the case for a disruptive product, since no historical data exists. On the other hand, the potential for such a product can be huge. Defining a new “industry standard” with an attractive technology that eases the task and price of installation and servicing, without raising the price, could potential be a *product star* in the product portfolio of TC Group and later turn into a *cash cow* (Stern & Deimler, 2012). One could argue that the established installation market does not have a problem that need to be solved. They are perfectly happy with the current 70V/100V industry standard. However, this is similar to the market situation for other disruptive innovations. A good example is the smartphone market, which was really first moving when customers noticed all the benefits of having camera and internet connection integrated into their phone. In the days before the smartphone, they were perfectly happy with a personal computer, a compact camera, and a Nokia 3210.

MQ2. How can the project team learn about potential new markets that may not yet exist?

A new technology that could potentially obsolete the 70V/100V system, by offering an idiot proof installation procedure and several added values like remote monitoring and multiple zone covering by a single daisy chain, screams for a new market. Such a technology seems to fit perfectly to the non-consumers:

Nonconsumption occurs when people are trying to get a job done but are unable to accomplish it themselves because the available products are too expensive or too complicated. Hence, they put up with getting it done in an inconvenient, expensive, or unsatisfying way. This type of nonconsumption is a growth opportunity. A new-market disruption is an innovation that enables a larger population of people who previously lacked the money or skill now to begin buying and using a product and doing the job for themselves.
(Christensen & Raynor, 2013).

To learn about a new market that maybe does not exist yet, it is vital to fully understand the “job-to-be-done” for the product. One example is: what is hindering the electricians and IT people from installing audio equipment in a new building? They are pulling wires and mounting equipment similar to the audio components, so why not cover the audio part of the installation also? If these questions could be answered correctly, a new market could be reached through a simpler system installation process. One approach would be to understand how these installers carry out their job today, through observations, and learn how this could be combined with the audio installation process. Optimally, the product and system concept would be designed in close collaboration with one or more of such installation firms.

MQ3. What is the value proposition?

Compared to the existing industry standard, the proposed replacement technology (see chapter 9.4.5, page 91) will potentially offer:

- Reduced system price, enabled by (1) obsoleting the large centralized power amplifier, (2) obsoleting the conduit requirement, (3) simplifying the installation procedure, and thereby reducing the labor hours spent on the installation.
- Added feature list, comprising (1) remote system health monitoring, and (2) coverage of multiple zones using a single home run (daisy chain).
- A new business model for after sales service, through the remote monitoring capability of the system.

It is judged that a cost-effective, simple-to-use-and-install system will be able to compete with both the existing technology, but also have the required properties to conquer a new market.

MQ4. What will be our initial application(s)?
It is imagined that the first product line utilizing the proposed technology should aim for audio installation applications like retail shops, conference rooms, classrooms. The system should be able to be used as both a self-contained system (for the retail-shop) or as a network node component in a large audio network (e.g. the classroom application).

MQ5. What is the economic model for the venture? How will we make money?
As other game-changing technologies, a 70V/100V replacement will require time to penetrate the market. It is expected that *innovators* and *early adopters* will be the first market groups to adopt the technology (leftmost part of Figure 3, page 15). This means a slower market penetration compared to a product based on incremental innovation, since such a product will address the mainstream market from day one. To make a disruptive product profitable it needs to serve the mainstream market, meaning that it has to cross the chasm as described by Moore (1999). According to Slater & Mohr (2006), the most critical factor in being able to cross the chasm, is related to *cross-market communication*. This word-of-mouth effect between the early part of the market and the pragmatist in the mainstream market is required to enter the mainstream market successfully.

Christensen & Raynor (2013) argue that sponsors for product projects having a disruptive should be *patient for growth but impatient for profits*. The first part of the sentence relates well to the finding from Slater & Mohr (market adoption) and the last part suggests that a given project should prove its business value on a relatively short term, to avoid that a wrong strategy is followed for years.

MQ6. What sales and distribution infrastructure must be developed to support the business model?
Assuming that it is the existing market (professional audio installation business) that should be addressed with the new product, then existing sales and distribution channels can be used. If a new market should be addressed, like the "semi-professional" market consisting of electricians and IT installers, then the distribution channel need to be directed towards this segment, perhaps via wholesale distributors. As suggested by Christensen & Raynor (2013), reaching new markets often requires disruptive channels. More generally, they claim:

….there need to be symmetry of motivation across the entire chain of entities that add value to the product on its way to the end customer. If your product does not help all of these entities do their fundamental job better-which is to move up-market along their own sustaining trajectory toward higher-margin business-then you will struggle to succeed. If your product provides the fuel that entities in the channel need to move toward improved margins, however, then the energy of the channel will help your new venture succeed.

One could fear that the above would not be the case when addressing the existing market with disruptive technology. Some of the sales and distribution entities might resist the new product since they have no benefit themselves in pushing new technology on a conservative market. For them it would be easier to continue pushing the "good old boxes", which they and their customers are familiar with.

8.5 Market related critical factors and sub-conclusion

In this chapter, the market has been investigated through a mixed method, where results from qualitative interviews were used as input to a subsequent quantitative survey, aimed for understanding the requirements and needs of the professional audio installation industry, when installing ceiling loudspeakers. In general, the market is found to be conservative, prefers things as it is today and requires exclusively bulletproof solutions that have proven their worth over many years on the market. This resembles the *Late majority* of the market.

From the findings, a typical installation profile was identified (see Table 5, page 64). This profile is very valuable when defining the specifications for a replacement technology. As an example, it will be very beneficial if this technology could obsolete the conduit requirements that appear to be required in every second installation. Further, it is assumed that the new technology should be able to handle installations sizes with at least the size found for the typical installation to be considered an alternative to the existing technology.

Via the discussions of the market research findings and the market related uncertainties (MQ1-MQ6), the following critical factors were identified.

The first and paramount critical factor is target market identification (*where*). The inertia in the organization clearly suggests that the existing market should be addressed. However, the existing, conservative market might not appreciate the advantages of the new technology and may claim that the existing technology serves their needs perfectly. On the other hand, aiming for a new market is not trivial either, since this requires (1) insight into the new market (job-to-be-done), and (2) new sales and distribution channels.

The second critical factor is identification of key partners (*who*), who probably need to have (at least some of) the properties found in the market group of early adopters. These partners are required to find the optimal profile of the product regarding performance and features. In addition, and maybe even more important, they are needed as means (cross-market communication) for carrying the product further on to the mainstream market. A list of preferred partners should be possible to establish, based on exiting relations combined with further market research.

The third critical factor related to the value proposition (*what*) and is very close related to the *Product definition* factor identified in chapter 9.7 (page 102). It is important to be perfectly clear about the advantages of the new technology to be able to convince all entities in the value chain. Based on the acquired market research findings (this chapter), combined with the technical insight (chapter 9, page 70), a value proposition could be formulated. It is however most likely that things will change when other stakeholders (key partners) eventual comment on the project.

A list, holding the identified critical factors along with suggested actions, is presented in Table 6.

High-critical factor	Latency	Required action
Target market	High	TC Group has to decide on which market to aim for. Maybe both the existing market and a new market can be addressed at the same time (with differently positioned products).
Key partners	Low	Preferred partners must be identified and addressed. Partners must be presented for the project and preferable be a part of the concept development. It is suggested that the *Research Tools for High-Tech Markets* proposed by Slater & Mohr (2006) is used in this context. Indications from partners, regarding project potential, must be acquired.
Value proposition	Both high and low	Based on findings from this study along with insights established in collaboration from key partners, the ideal value proposition has to be defined.

Table 6. High critical factors, market related.

8.6 Reflections

As a part of the market investigation process, a series of qualitative-based interviews has been conducted followed by a web-based survey. The purpose of this information gathering was to understand the market requirements and the customer's expressed and latent needs. As described in the beginning of this chapter, the persons specifying audio installations (audio consultants) is not necessarily the same, as the persons actually physically mounting and interconnecting the products. The dominating group of data gathered, is from persons having a consultant function (or background). This group is not necessarily the best qualified for answering questions related to things like "ease of install" or "preferred infrastructure", since they are more concerned about fulfilling requirements for a given audio installation – and is not necessarily concerned about whether the installation is carried out in the most efficient way, regarding man hours and material. It would thus be very interesting to conduct similar research towards a population that have a more "hands-on" profile.

Designing a questionnaire is never trivial. The wording of the questions will eventually affect the answers retrieved. Another factor that will bias the answers is the origin of the questionnaire. In this particular case the email sender is a Lab.gruppen employee with a technical background. This particular employee is well known by most of the invitees for his innovative thinking. Lab.gruppen is considered a high-tech company, offering technology-wise advanced solutions. This means that the respondent might answer differently, perhaps (and unconsciously) trying to "please" the renowned person asking the question, compared to a situation where the questions originated from another source.

Another possible error source in the web-based survey is the large amount of CEO's and general managers, who know a lot about audio installation business – but not necessarily much about technical issues. This suspicion is primarily based on the fact that half of the respondents claimed that cables for ceiling loudspeakers today is non-twisted, which is not the case according to the author's knowledge (based on dialogues with leading US cable manufacturers and further desktop research).

9. Technology

As one of the critical components in the disruptive innovation puzzle, technology will be the main topic of this chapter, which will contain a background description of existing technology followed by a description of alternative solutions, all seen from a technical perspective. A methodology chapter explains the approach taken regarding technology the candidate selection process, where three main system ingredients categories are described, culminating in twelve different solutions that are discussed and rated. Finally, critical factors are identified and discussed.

9.1 Background

In most large audio installations found in airports, schools, hotels, shopping malls, and similar, the installation has a star topology. This means that all audio routing to audio input mixers and power amplifiers are centralized and thus physically placed together in a single location. All audio input sources, like local microphones and audio playback devices, have to be connected through wires to the input mixer. The same thing is the case for every speaker line (tens or even hundreds of meters long), which is driven from one of the power amplifier outputs. For the output path from each amplifier channel, a high (compared to residential installations) voltage on the power distribution lines is preferred to avoid power loss. The power loss in the loudspeaker cabling is proportional to the square of the current running in the wires and proportional to the cable resistance:

$$P_{loss} = {I_{line}}^2 \cdot R_{line} \qquad \textit{Equation 1}$$

Assuming a constant power, the current in the line will drop when the voltage is increased (P = U·I). This means that the overall power-loss is reduced, when comparing to a low voltage solution. This is similar to the same technique used when electrical energy is distributed over long distances, from an electrical power plant to the consumer. The voltage on the electrical grid is transformed to several thousands of volts before being transported over long distances and stepped down (near the consumer) to 120V or 230V found in the electrical outlets. For a given line resistance, the power loss will drop when the voltage is increased, assuming a constant power transported through the line.

For audio installations having long distances between amplifier and loudspeaker, the high voltage is typically obtained by either (1) stepping the voltage up using a large transformer capable of handling the required power throughput or (2) by using transformer-less audio amplifiers that can output high voltage directly. Today, the latter is widely accepted and used in most installations, primarily due to a lower product cost, but also due to the lower weight and size offered by a transistor based amplifier. These high voltage audio systems are called *Constant-voltage systems*. In the United States 70V$_{RMS}$ is the most common voltage level for the loudspeaker audio lines, where 100V$_{RMS}$ seems to be the standard in Europe (Crown, 2005). A principle diagram of a 70V/100V amplifier driving four speakers in a single zone is illustrated in Figure 22.

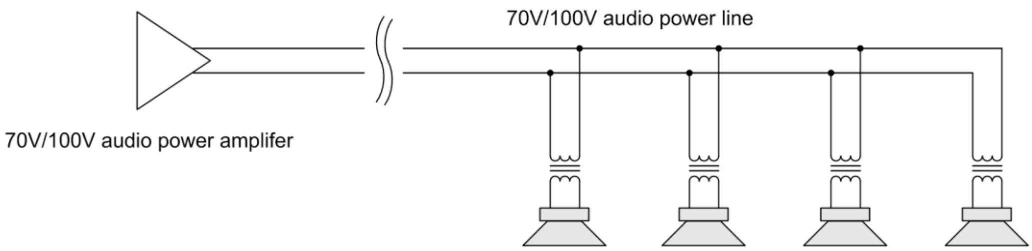


Figure 22. Traditional 70V/100V audio installation (single zone).

Using a high voltage line as the backbone of an audio installation has a major drawback: the voltage has to be brought back to a level, which can be handled by the loudspeaker. With the technology available today in electrodynamic loudspeakers, the viable impedance range is roughly from two to sixteen ohms. If the loudspeaker should operate on the 70V/100V line directly, the impedance should be in the range of several hundred ohms. However, an increased impedance leads to an increase in the number of voice coil windings, meaning that the percentage of lacquer in the voice-coil will cause a significant drop in loudspeaker efficiency, simply by the large drop in voice-coil copper percentage. This means, that a power audio transformer is required to step the high voltage back to a level suitable for the low-impedance loudspeaker.

Beside the obvious requirement for voltage transformation, the transformer has a second purpose. To enable individual power level per loudspeaker sitting as a part of the group of loudspeakers connected to a 70V/100V line, *power-tapping selector* is implemented as a part of the audio power transformer per loudspeaker. This selector functionality is most often obtained using a manual switch, allowing for inputting the 70V/100V signal at different fractions of the primary side as illustrated in Figure 23. This approach keeps a constant impedance level of the secondary side of the transformer constant (regardless of tapping position), which is beneficial seen from an audio reproduction perspective. An unaltered transformer output impedance will help in keeping the system frequency response constant across the different tappings.

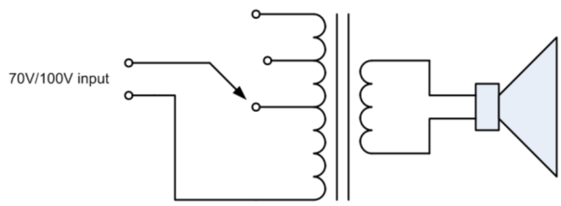


Figure 23. Installation loudspeaker with transformer and power level selector.

As expected, the requirements regarding physical size and weight of the transformer is proportional to the power throughput requirements. However, this is not the only factor that affect the transformer specification. Unfortunately, the size and weight requirements is inverse proportional to the signal frequency that has to pass the transformer (Whitlock, 2001). The very small size of power supply seen today for portable computers etc., is possible because of the SMPS (switch-mode power supply) technology that increases the frequency of the signal passing through the transformer, typically up to several hundred kHz compared to the traditional 50Hz/60Hz, which requires a large and bulky transformer.

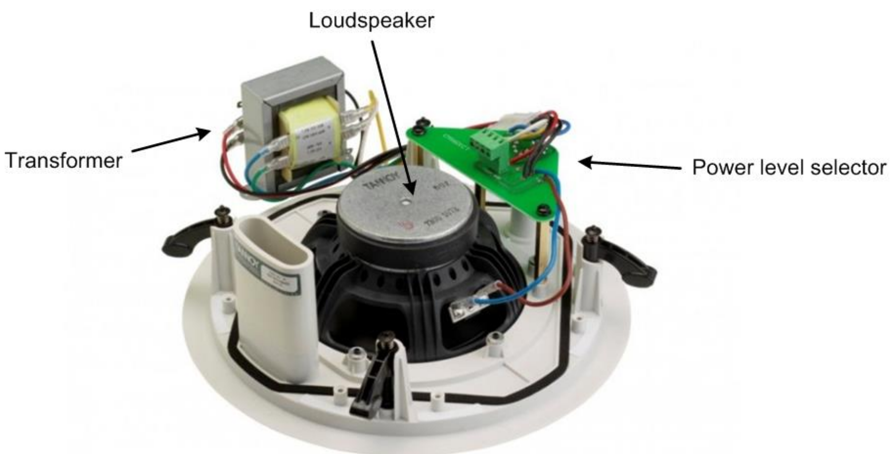


Figure 24. Disassembled ceiling speaker without enclosure, rear view.

In the 70V/100V case, the audio power transformer found in the installation loudspeaker has to be able to pass the entire audio bandwidth (20Hz – 20kHz) to the loudspeaker terminals, which requires a relatively large transformer per loudspeaker. An example of a ceiling mounted installation loudspeaker (without enclosure) is shown in Figure 24 (page 71). As seen in the figure, it is obvious that the transformer and mechanical power level selector represents a big part of the BOM (Bill Of Material) for the entire installation loudspeaker. Often the transformer is mechanically attached to the enclosure, which further complicates the assembly process and after sales service. Finally, the transformer adds to the overall weight of the ceiling loudspeaker system, which is a drawback during shipping and mounting.

Beside the obvious drawbacks regarding price, size and weight, the transformer further introduces a so-called *insertion loss*. This loss is primarily dominated by copper loss in the transformer windings and transformer core and coupling flaws - and are typically in the range of 1-2dB corresponding to 21-37% power loss (QSC, 1999; Williams & Ware, 2011). The insertion loss is most often measured at 1 kHz. However, the dominant portion of the power transfer in audio material is located at lower frequencies meaning that the resulting insertion loss increases due to transformer core inefficiencies. This phenomena is articulated by Williams & Ware (2011) as:

Typical transformer insertion loss measurements are taken at 1000 Hz in order to make the transformer's specifications appear as good as possible. Using this method, typical insertion losses are about 1 dB, a 20% power loss. Most of the power in voice-application audio systems is below 400 Hz, meaning that insertion loss at lower frequencies would be greater.

Now comparing a constant voltage 70V system with an "ordinary" lo-impedance (lo-Z) system similar to typical audio system found in private homes, shows that even though the 70V system introduces less loss in the conductors (compared to the lo-Z system), it has a penalty due to the insertion loss, even without any cable at all.

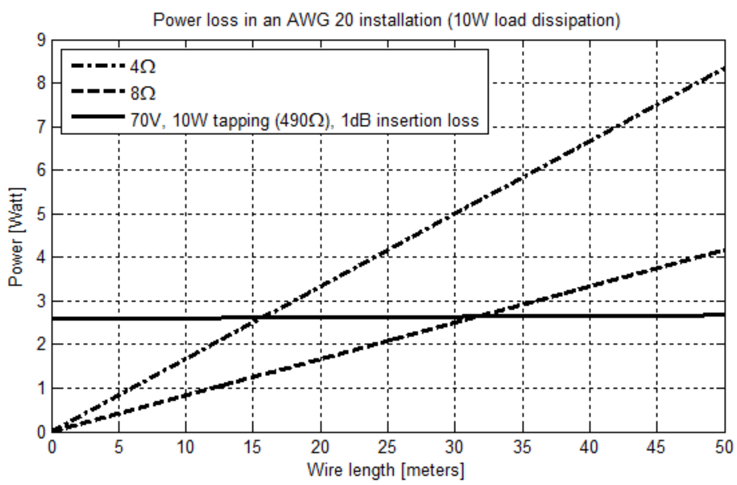


Figure 25. Example of power loss in lo-Z and 70V systems.

Figure 25 illustrates the power loss in a loudspeaker system as a function of cable length. In this case AWG 20 (≈ 0.5 mm^2) is used, which is a common wire dimension for constant voltage systems. The example compares three different kinds of systems: (1) a lo-Z line with a 4Ω loudspeaker, (2) a lo-Z line with an 8Ω loudspeaker and finally (3) a 70V constant voltage line with a transformer based loudspeaker attached. The tapping of the latter is 10W corresponding to a 490Ω load. The insertion loss in the transformer is 1dB. For all three systems, 10W is dissipated in the load. As seen on the graph, the power loss is rising very slowly as a function of cable length, but due to the insertion loss break-even points exist at respectively 16 and 32 meters, meaning that the lo-Z systems are more power efficient at lengths up to these break-even points.

9.2 Alternative audio power sourcing

Figure 26 illustrates two different approaches for delivering audio power to a remote located load (loudspeaker).

Solution A resembles the traditional constant voltage approach. In this case, we have a high voltage source V1 (a 70V/100V audio power amplifier) that sources the loudspeaker(s) through a transmission wire. In proximity of the load, the voltage is stepped down (and current up) to establish an optimal impedance fit to the low-impedance loudspeaker.

Solution B does not transport the audio power signal over the transmission wire. Audio information is instead superimposed on a DC supply voltage V2 that supplies small local amplifiers placed in the proximity of the loudspeaker load, preferably inside the loudspeaker enclosure. This amplification system comprises an audio decoder that reconstructs the audio signal into a format suitable for the amplifier input. In the following, it is assumed that the DC bus voltage equals 48V, which is a commonly used industrial voltage level.

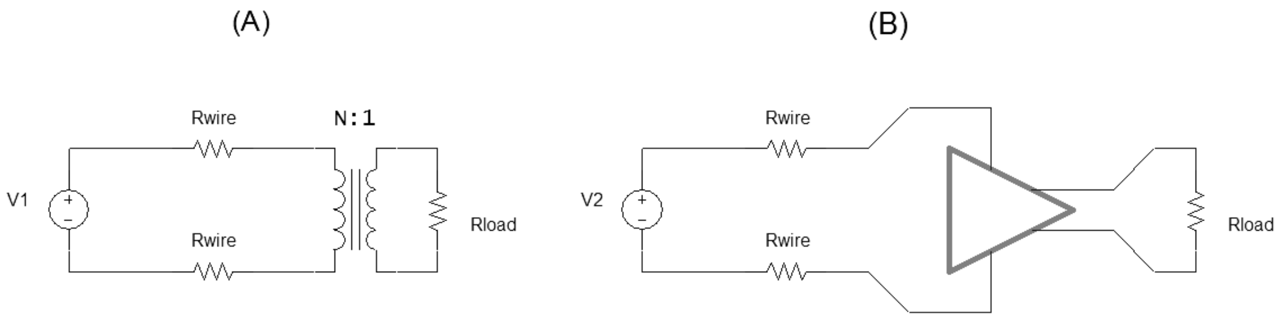


Figure 26. Two different audio power sourcing topologies.

Now, let us compare these two topologies with a concrete example. Let us imagine a remote zone that requires 30W of audio power. An example of such a room could be a classroom, a part of a restaurant or a hallway. Let us assume that the room is located 900 feet (274 meters) away from the amplifier source. According to industry standard guidelines such a configuration requires a wire gauge equal to 20 AWG (American Wire Gauge), when accepting a maximum power loss equal to 10% in a traditional 70V installation (TIC Corporation, 2015).

Wire Gauge	5 watt	10 watt	15 watt	30 watt	50 watt	100 watt	200 watt
16 AWG	10000	7000	4600	2300	1.400	700	350
18 AWG	9000	4500	2800	1400	830	415	205
20 AWG	5500	2700	1800	900	540	270	135
22 AWG	3400	1700	1100	550	330	115	60
24 AWG	2100	1000	700	350	210	105	50

Table 7. Maximum wire run cable length in feet (TIC Corporation, 2015).

Looking at Solution A in Figure 26 (page 73), a load corresponding to 30W on a 70V line (assuming constant voltage across the entire line) corresponds to a line load impedance equal to:

$$R_{load,70V} = \frac{U^2}{P} = \frac{70^2}{30} \approx 163\Omega \qquad \textit{Equation 2}$$

The 20 AWG wire represents a total resistance of approximately 18Ω given that resistance of a 20 AWG wire equals approximately 1Ω per 100 feet and that the wire length is 900 feet forth and 900 feet back, altogether 1800 feet.

To deliver the 30W target power, the required current can be found using Ohm's law, which equals sqrt(P/R) = sqrt(30W/163Ω) = 0.43A. This current correspond to a power loss in the wire equal to $I^2 \cdot R = 0.43A^2 \cdot 18\Omega = 3.3W$, which corresponds well to the above-mentioned 10% loss guideline. Assuming constant voltage across the entire line and thus ignoring the small voltage drop over the line caused by line resistance, the overall power loss for the system can be calculated as:

$$P_{loss,wire} = I_{line}{}^2 \cdot R_{line} = \left(\frac{P_{load}}{U_{line}}\right)^2 \cdot R_{line} \qquad \textit{Equation 3}$$

Now turning to Solution B in Figure 26 (page 73) and keeping the 20 AWG installation line, the required current will be P/U, assuming that the amplifier is lossless. Assuming that the amplifier is supplied with a DC voltage equal to 48V, the wire current equals 30W/48V = 0.63A which causes a power loss in the wire equal to $I^2 \cdot R = 0.63A^2 \cdot 18\Omega = 7.1W$.

A general expression of the ratio between the wire losses found in a 48VDC based relative to the wire losses found in a conventional 70V constant voltage system equals:

$$Power\ loss\ ratio = \frac{P_{loss,48VDC}}{P_{loss,70VAC}} = \frac{\left(\frac{P_{load}}{U_{48VDC}}\right)^2 \cdot R_{line}}{\left(\frac{P_{load}}{U_{70VAC}}\right)^2 \cdot R_{line}} = \left(\frac{U_{70VAC}}{U_{48VDC}}\right)^2 \qquad \textit{Equation 4}$$

Judging from the above example, the traditional topology seems to be superior regarding power efficiency. However, this result is only valid when 70Vrms are actually present on the speaker line, which will only be the case when a full-scale sinusoidal is present. In a speech/music loudspeaker installation, such a high RMS level will never be present, only in very short passages of audio and never in average.

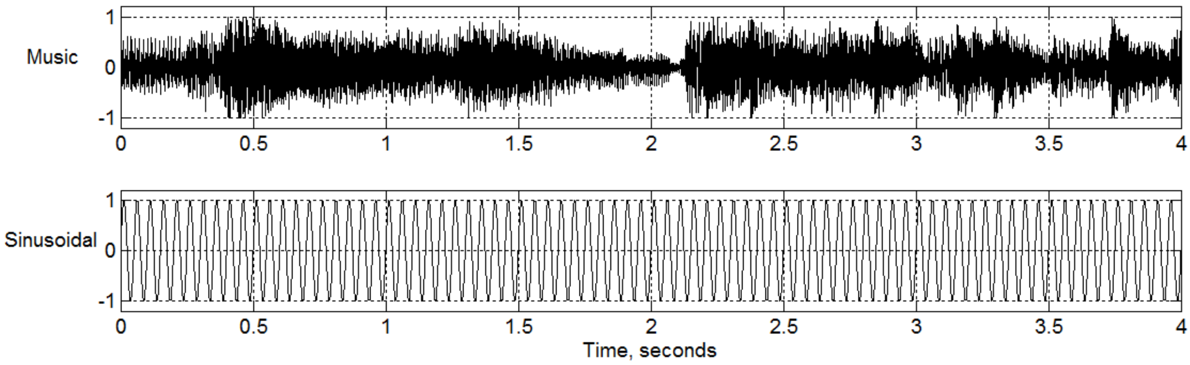


Figure 27. Time domain examples of audio, normalized

A graphical comparison of music and a sinusoid is presented in Figure 27 (page 74) and Figure 28. The former shows the two types of audio in a normalized version in the time-domain. The latter shows the amplitude distribution of the two signals.

Judging from both the time domain and the amplitude distribution of the two signals, it is obvious that they are very different. The music signal has a characteristic bell shaped distribution, similar to Gaussian noise, whereas the distribution of the sinusoid has a "bathtub-cross-section" shape. For music, this mean that the signal statistically often resides at low amplitudes compared to high amplitudes, whereas the properties for sinusoids are the opposite.

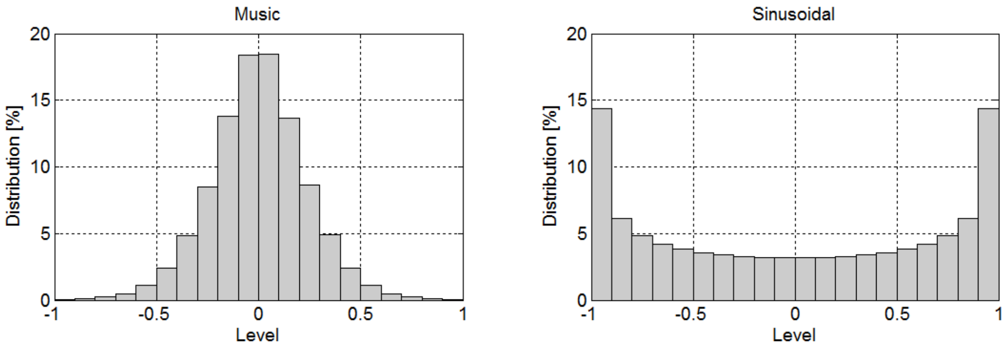


Figure 28. Amplitude distribution of signals illustrated in Figure 27.

To describe the amplitude statistics in audio signals, the *Crest Factor* if often used as a single digit number that specifies the ratio between RMS levels and peak level for a given signal. Typically, this number is presented in decibels as:

$$Crest\ Factor = 20 \cdot \log_{10}\left(\frac{V_{PEAK}}{V_{RMS}}\right)\ [dB] \qquad \textit{Equation 5}$$

A comprehensive investigation of 4500 best-selling pop tracks carried in 2011, revealed that the crest factor for finally mastered audio CD's has decreased from approximately 18dB, which were almost constant in the period from 1970 to 1990, to approximately 12dB in the period from 2000 to 2010 (Deruty, 2011). The sudden drop in crest factor from 1990 to 2000 is related to the so-called "Loudness-war" that was caused by the desire to make finally produced audio tracks to appear as loud as possible in a given playback system (typically portable music players). This "war" was made possible with the appearance of digital audio processing studio equipment that was able to increase the RMS level in the audio material, without introducing hard clipping, through multiband compression and limiting.

Other authors specify a crest factor from around 20dB for "uncompressed audio" to 10dB for "compressed audio" (Sweetwater, 2002; Biederman & Pattison, 2013), which match nicely with the shift from 18dB to 12dB in average crest factor found by Deruty (2011).

Now, turning back to the comparison between the traditional 70V constant voltage system and the 48VDC supplied system, with an "audio-contents-perspective". Taking this perspective, the cable-power-loss ratio between these two topologies has another "winner". Yes, for sinusoids, the power loss of the 48VDC system will be approximately twice as high as the 70VAC loss according to *Equation 4* – but for any real-world music/speech material, the losses in the 48VDC system will be significantly lower compared to the 70VAC system.

Figure 29 illustrates the power loss ratio (*Equation 4*) as a function of crest factor for the audio present on the speaker line on a 70VAC system. With the assumption that most modern music is produced with a crest factor equal to 12dB, the ratio for that crest factor equals approximately 30%. Therefore, in any "normal" audio reproduction situation through a given cable resistance, the power losses in the cables from source to loudspeaker will be three times higher in a conventional 70V system compared to the proposed 48VDC system. This is valid for full-scale (clip-level) audio levels. For normal listening levels, things will look even more advantageous for the 48VDC system, since the RMS level will drop further.

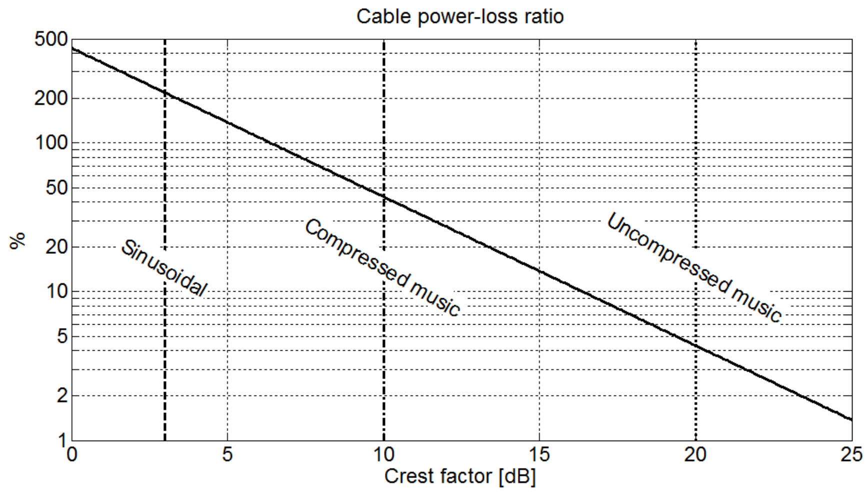


Figure 29. 48VDC system wire loss relative to a 70V constant voltage system wire loss.

The above fact can be utilized in two ways. Either keeping the same wire dimension "rules" and achieving lower power loss in the installation wires – or reducing the copper cross section that result in the same power loss as the 70VAC system with thick wires. The latter will of course reduce the price (and size/weight) of the wires forming part of the installation. The latter seems to be quite relevant since raw copper is a scarce resource and the world market price is rising (see Figure 30). In an environmental report carried out for the European Commission, copper is mentioned to be among the top-8 most critical metal and minerals for the EU and prices are expected to rise further towards 2020 (Ecorys, 2012).

Figure 30. Copper price, historical data from London Metal Exchange.

9.3 Methodology

The workflow of the technology investigation is illustrated in Figure 31. As shown, the process consisted of the following steps:

1. Identification of loudspeaker network ingredients. In this step the required items were identified through a combination of tacit knowledge and existing literature on fixed audio installations.
2. Technology review. From the identified ingredients, a review was carried out, which revealed several technologies capable of solving the tasks for each ingredient.
3. Identification of candidates. Using a combination of above mentioned technologies, a list of suitable candidates were established.
4. Rating of candidates. Each candidate was given a multidimensional score.
5. Identification of IPR. From patent databases, relevant IPR was identified and elaborated.
6. Based on candidate ratings and identified IPR, technical solutions were discussed in the context of product development in TCG. Uncertainties were identified and a sub-conclusion established.

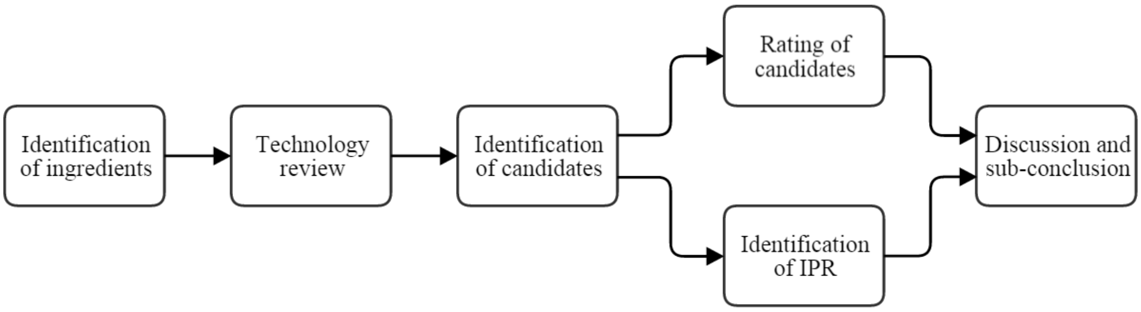


Figure 31. Technology investigation workflow.

Since this chapter mainly focuses on technical issues, which can be measured, modelled and described through mathematics, a pure modernistic perspective is taken.

9.4 Ingredients in an fixed audio installation system

To present audio to a remote listener, you need three things: (1) a method of delivering energy to the loudspeaker, (2) a method of transporting the audio information to the loudspeaker and finally (3) a physical connections from the energy source and audio source to the loudspeaker. These ingredients will be elaborated in the following sub-chapters.

9.4.1 Power distribution

The final energy delivered to the loudspeaker sitting as nodes on the installation line, can be distributed as either an audio power signal or as a supply voltage for electronics sitting in the proximity (typically inside the enclosure) of the loudspeaker.

In the audio power signaling case, the power signal is established in a (for the audio installation) central location, typically in a 19 inch rack-mount amplifier sitting together with other server-like equipment in a (often air-conditioned) *Central Apparatus Room* (CAR). For 70V/100V installations the CAR is the industry standard, but for so-called lo-Z solutions, where the amplifier-connected loudspeakers do not include a transformer, the amplifiers are often located in the same room as the loudspeaker. Such a system resembles the topology of the HI-FI systems found in most private homes. The latter is mostly seen where the audio source is of a local nature such as in conference rooms, where the video from laptops are connected to video projectors and the audio is connected to local amplifiers or in bars where the audio playback system typically resides behind the counter.

Figure 32. Photo taken in a typical Central Apparatus Room.

Energy deliverance via a supply voltage is seen in both standardized and proprietary technologies. Among the standardized technologies utilizing DC supply voltage through the cable, we have *USB*, *Thunderbolt* and *FireWire* (1394). These technologies are well known in the computer industry but are rather limited in cable length, since their typical applications are primarily point-to-point oriented, like connections to computer equipment and cameras. Another DC supply technology seen in the IT domain is *PoE* and *PoE+* (Power Over Ethernet, IEEE 802.3), which is a technology that uses the possibility to transfer DC current for supplying an Etherrnet network endnote. This technology is based on the physical properties found in Ethernet cables and is widely used for supplying remote IP telephones and IP cameras. The spread and usage of PoE devices is rising rapidly where the 2008 world-market (revenue of PoE chipsets for network end-notes) consisted of: VoIP phones (56%), acces points (24%), network cameras (16%) and others (4%) (Janakiraman, 2008). Using the PoE+ standard, approximately 25W is available for consumption per Ethernet port.

Beside the IT oriented bus-power technologies, several standards are found for industrial purposes. These include different variations of the *Fieldbus* standard (IEC 61158). This standard describes a system that is used to both supply energy and communicate between devices connected to the same two-wire bus. *CAN* (Controller Area Network) is another wide-spread bus power technology seen in the industry. This technology is used heavily in the automotive industry and uses four wires on the common bus (CAN-, CAN+, ground, power).

In the group of proprietary supply technologies, many different examples can be found supplying motorized antennas through coaxial cables or as HDMI range extenders utilizing so-called *Power over Cable* (PoC) through Ethernet cables and RJ45 connectors. Another example of a proprietary supply approach is used to supply intelligent DC motors across a two-conductor DC power bus along with bi-directional data to control and monitor the status of the individual motors (Wade & Asada, 2003).

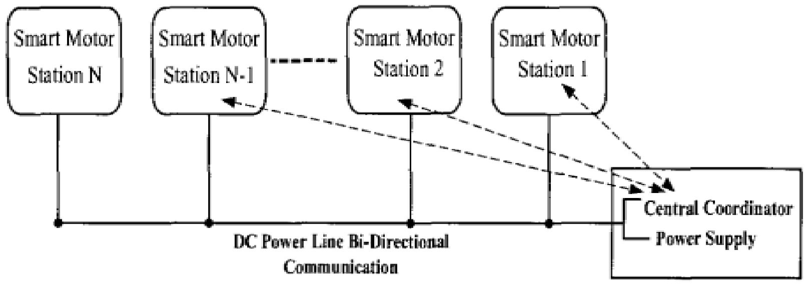


Figure 33. Central unit supplying remote motors with both power and data (Wade & Asada, 2003).

9.4.2 Audio distribution

This sub-chapter describes various technologies that enable transportation of audio from the audio source to the audio destination, in this case the loudspeaker. The technologies described are limited to wired solutions for the following two reasons: (1) Wireless receivers/transmitters in the network nodes (loudspeakers) would increase power consumption and price of the total system. (2) Wireless technologies is still not considered sufficient robust against external disturbances and would today never be used in safety critical installations having an evacuation message requirement.

9.4.2.1 Analog audio distribution

Audio information can be transported from the audio source in either an analog or a digital format. In the latter case the signal can be transported in analog form as the power signal itself for either lo-Z or transformer equipped loudspeakers. Another solution is to superimpose audio either directly or in a modulated form onto the electrical wires carrying the supply voltage for the electronics downstream (receiver/amplifier for the loudspeaker) or to transport audio separate from the energy supply in dedicated electrical wires.

The first could be implemented using transformers and/or capacitors to inject and extract the audio from source to destination. Examples of modulation could be AM, FM or any other suitable modulation technique. Modulation would also enable the presence of multiple audio channels through a single communication channel, just like the methods used in AM/FM radio communication.

The latter (transporting audio though separate conductors) could be carried out using one of the twisted pairs in a CAT5 cable for audio and the remaining pairs for power supply. It has been found that a twisted pair inside a CAT5 cable has excellent audio properties and will be able to transport audio over long distances without degradation (Lampen, 2005). Another example of such a topology is found in Meyersound's *IntelligentDC Systems* in which the interface cable holds five individual conductors for audio and DC power.

9.4.2.2 Digital audio distribution

Digital audio distribution can be split into two subgroups: (1) Dedicated audio networks that support multipoint-to-multipoint (M2M) communication, meaning that each individual network node can receive from and transmit to every other node found on the network. (2) Point-to-point (P2P) or broadcast oriented audio network, in which you often see a master/slave approach, typically along with network topologies such as bus, star or daisy-chain.

In the M2M network types, you will find several Ethernet solutions dedicated to audio (and video). Similar to the “videocassette battle” between Betamax, VHS and V2000, numerous protocols compete to be the preferred standard in digital audio distribution over Ethernet based networks. Currently, in professional audio for both touring and fixed installations, it seems like Dante has a head start (Bouillot, et al., 2009; Hemming, 2015).

Table 8 holds a table that describes main properties of the network regarding its capabilities such as channel count, latency and audio sample rate. All the listed network types have quite high bandwidth (many channels, many channels, high sample rate). When talking about these types of network, you distinguish between *layer 2* and *layer 3* networks. This property describes on which layer in the OSI protocol a given network protocol operates. The higher layer, the higher abstraction level.

Tim Shuttleworth (2012) gives a detailed description of layer 2 and layer 3 mechanisms for audio applications in an article describing pros and cons of the different audio network protocols. The main advantage for layer 2 solutions, is that they offer guaranteed delivery of data regardless of network structure and remaining network traffic, whereas layer 3 solutions require manually engineered networks to ensure that. The main advantage of layer 3 solutions is that these protocols will be able to pass through of-the-shelf Ethernet switch components, whereas layer 2 solutions require dedicated Ethernet switches that support the low-level mechanisms required for layer 2 media streaming. Currently very few vendors offer switches with that functionality (Shuttleworth, 2012).

Protocol	OSI Layer	Channel Count	Latency	Sampling	Licensing	Notes	AES67 Compliant
AVB	2	Effectively unlimited	Minimum 0.25ms	Up to 32 bits and 192kHz	Free and open	AVnu alliance promotes and certifies but not all AVB products compliant.	No
CobraNet	2	Typically 32in/out per interface. Maximum over 3000 ch on a network	Typically 5⅓ ms. Can also operate at lower values	Typically 20bit 48kHz. Can also operate at 16 or 24 bit and at 96kHz	Per node	Development appears to have ceased	No
EtherSound	2	128 ch (ES100)	1.5ms	Typically 24 bit 44.1 or 48kHz Can also operate at 96 or 192kHz	Per node?	Development appears to have ceased	No
Dante	3	Effectively unlimited	Typically 1ms but can vary	Up to 32 bits and 192kHz	Per node		Q1 2015
Q-LAN	3	Effectively unlimited	1ms	Current A-D/D-A are 24bit 48 or 96kHz. Network audio is 32 bit	Proprietry	Q-Sys system also has CobraNet and Dante interface cards	Yes (tested at plug fest, official support unknown)
Ravenna	3	Effectively unlimited	Typically 1ms	Up to 384Khz	Open, some options free	Exclusively used in the broadcast world	Yes

Table 8. List of various audio-over-Ethernet standards available (Hemming, 2015).

Except for the EtherSound standard, all standards listed in Table 8 (page 80) are IP protocols that requires a star topology, meaning that devices incorporating this technology the will not be able to be coupled in a daisy chain – unless an Ethernet switch is inserted between devices (Bakker, et al., 2004).

Another M2M approach is seen in *Powerline Communication* (PLC), which has experienced a steady growth during the last couple of decades. This technology is primarily oriented towards either long-distance data communication over the regional/national high-voltage backbone AC supply networks – or towards domestic applications within the boundaries of a private home, typically from a media server or an internet connection to internet clients and/or audio/video playback systems.

Several techniques and protocols exist in the genre of data communication. One of the most widespread for home applications is *HomePlug*, which is based on the IEEE 1901 standard (Latchman, et al., 2013). Figure 34 illustrates the usage of HomePlug in a private home. Dotted lines represent existing AC household cabling. In each room equipment is coupled to the home network through a PLC modem that plugs directly into 110V/230V AC outlets.

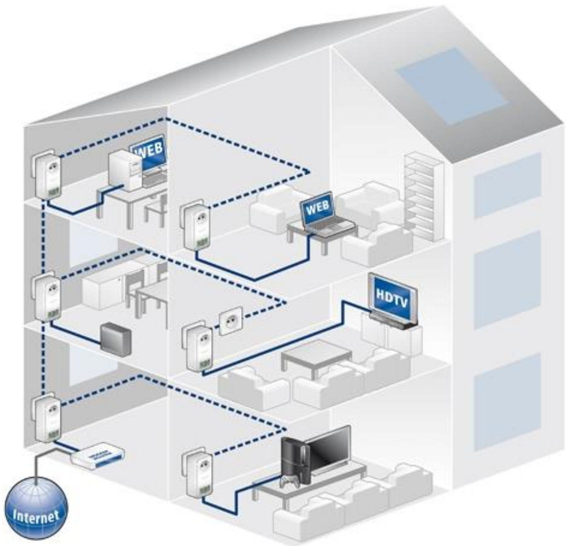


Figure 34. HomePlug network with shared internet and media-server access.

PLC solution for domestic solutions is widespread in the USA but to a much lesser extent on the European market. The main reason for this is the different levels of allowed electromagnetic interference in respectively the USA and the EU. Existing products found on the American market exceed the allowed EU EMC levels (EN55022) by approximately 25dB (Schneider, et al., 2004).

A third group of technologies is seen in the automotive industry. These technologies are used to communicate between electrical devices sitting in the car's infrastructure. This could be devices like valves, lamps, pumps, sensor and actuators. In the last couple of decades, new technologies have appeared offering higher bandwidth from device to device. The MOST (Media Oriented System Transport) protocol (developed in 1998 under the leadership of BMW and Daimler-Chrysler) is dedicated towards media streaming from a media server located in the vehicle to presentation devices like video-screens and loudspeakers.

Bus	LIN	CAN	FlexRay	MOST
Cost/Node [$] (ABIreport: Y08)	1.50	3.00	6.00	4.00
Used in	Subnets	Soft real-time	Hard real-time	Multimedia
Application domains	Body	Powertrain, Chassis …	Chassis, Powertrain	Multimedia, Telematics
Message transmission	Synchronous	Asynchronous	Synchronous & Asynchronous	Synchronous & Asynchronous
Message identification	Identifier	Identifier	Time slot	
Architecture	Single Master typ. 2…10 slaves	Multi-Master typ. 10…30 nodes	Multi-Master up to 64 nodes	Multi-Master up to 64 nodes
Access control	Polling	CSMA/CA	TDMA	TDM CSMA/CA
Data Rate	20 kbps	1 Mbps	10 Mbps	24 Mbps
Physical Layer	Single Wire	Dual-Wire	Dual-Wire (Optical Fiber)	Optical Fiber (Dual-wire)
Latency Jitter	Constant	Load dependent	Constant	Data stream
Babbling idiot	n/a	Not provided	Provided	
Extensibility	High	High	Low	High

Figure 35. Most common digital protocols in the automotive industry (ON Semiconductors, 2014).

The MOST technology uses either an optical medium or a pair of twisted electrical wires to establish interconnection of nodes on the MOST network. The technology seems to be quite mature and is used in more than 100 different car models (Schöpp, 2013).

In the group of the simpler point-to-point or point-to-multipoint technologies, you will find the subgroup *fieldbus*. This technology is not directly intended as an audio transport mechanism. However, the technology has the properties required by an intelligent, loudspeaker installation network: power and bi-directional data over the same cable. The fieldbus is heavily used in industrial application and replaces traditional star-topology approaches (central units that are connected to multiple sensors/actuators, see Figure 36) with a flexible bus structure that allows daisy chains and tree structures.

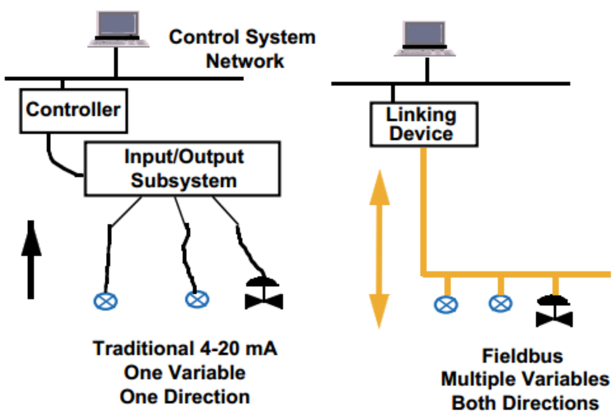


Figure 36. Multiple devices controlled/monitored using the fieldbus technology.

Fieldbus technologies like the *Profibus-PA* and *HART* are both characterized in being able to carry both power and bi-directional data to and from the device sitting on the bus. Typical applications include automation if industrial processes, often with the devices sitting in hazardous areas with risk of explosions. To handle these extreme conditions, the fieldbus power supply part is limited (both current and voltage wise) so that any potential sparks from the electrical wiring and/or devices is not possible. Fieldbuses used outside hazardous areas have relative high bandwidth capabilities (12 Mbit/second) whereas the bit-rates supported by the fieldbuses used in hazardous areas is much lower, typically in the range of tens of

Kbit/second (Berrie, et al., 2006). Most (if not all) of the fieldbus electrical layers are based on RS-485, which is a balanced data transmission scheme that offers robust solutions for transmitting data over long distances and noisy environments.

As the last group of digital transport mechanism is the list of widespread standardized audio interfaces listed in Table 9.

Interface	Physical layer	Bandwidth
AES/EBU	Shielded twisted pair	2 channels @ 24 bit, 96kHz
S/PDIF	Single ended, coaxial. Consumer version of AES/EBU	2 channels @ 24 bit, 96kHz
Toslink	Optical version of S/PDIF	2 channels @ 24 bit, 96kHz
ADAT	Optical	8 channels @ 24 bit, 48kHz
MADI	50 Ohm coaxial	64 channels @ 24 bit, 96kHz

Table 9. Digital point-to-point audio interfaces

All of the interfaces standards listed in Table 9 belong to the group of simple point-to-point connection, which is present in a vast number of audio equipment devices. The AES/EBU is the foundation technology for all these interfaces. The electrical characteristics of AES/EBU are based on RS-422, which again share electrical specifications with RS-485 (Soltero, et al., 2010).

9.4.3 Physical transport media

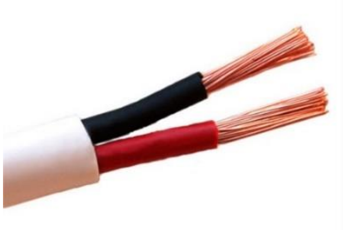
To distribute power from an energy source (audio power amplifier or power supply) to a passive or active loudspeaker, the most obvious choice is copper cables, since copper offers the best conductance for a given price. The only other material offering lower resistance is graphene and silver, however none of these materials are realistic to use because of their price and physical properties. Aluminum could also be attractive, even though its resistivity is higher, since its price/performance is attractive and it actually provides a better conductivity to weight ratio than copper. However, aluminum is not a good fit for standard terminals, like common screw terminal, because metal oxidation will begin to act as an electrical insulator in a thin aluminum oxide layer. Further, the screw terminal requires a larger size to fit the larger wire dimension required to offer similar resistance as copper. Nonetheless, aluminum might be a realistic choice in the future if copper prices continue to rise (Ecorys, 2012).

To distribute audio information in either analog or digital form we have (at least) three options: (1) wireless using radio wave technology like WiFi, Bluetooth, ANR or ZigBee, (2) optical using glass or plastic light-guides (fibre) or (3) electrical using conductive wires.

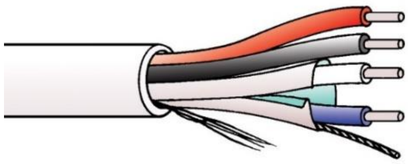
As mentioned earlier, wireless technologies are not presently considered an option in a quite conservative business domain, such as professional audio installation. And for sure not when the installation is safety critical, such as a part of an evacuation system. Based on interview with several professional audio integrators and consultants, the wireless transport mechanism existing today is simply not considered sufficiently robust. So, the otherwise attractive wireless technologies will not be considered as a candidate for now.

Optical data transfer via fiber has several fine properties. First of all the data bandwidth capabilities of an optical link are excellent. Optical fibers offers an extremely high data-rate for a given size of fiber and the signal quality loss, as a function of cable length, is low compared to electrical conductors. The raw material used to manufacture optical cables is either glass or plastic, which are not among materials expected to rise considerably in price. The downside of optical fibers is the termination of the cable. When it has to be connected to a given device, the cable has to be cut and connected to the device through an optical receiver that translates light into an electrical signal. The cutting and mounting process is complicated, compared to a simple RJ45 or screw terminal connector. A further downside is the fact that energy has to be delivered through electrical conductors in the first place, so if an optical audio path is chosen, it would require a composite electrical/optical cable or two different cables running in parallel. Not a very attractive solution.

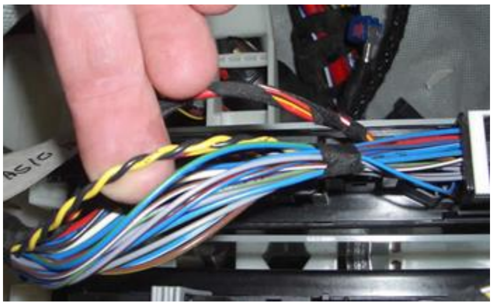
(A) Typical loudspeaker cable



(B) Multi-conductor cable used for transport of both power and balanced analog audio



(C) An example of a CAN bus from an electrical installaion in a car (twisted pair)



(D) An unshielded CAT5 cable, four twisted pairs

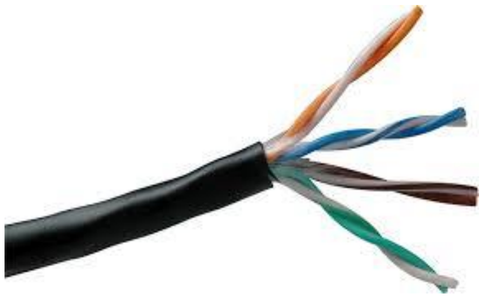


Figure 37. Four different types of physical transport media

Electrical conductors as a means for carrying audio information from a source to a destination is the most widespread and accepted way of solving the audio transport task. In both the analog and digital audio transport case, the approach can be distinguished between *single-ended* or *balanced* signaling.

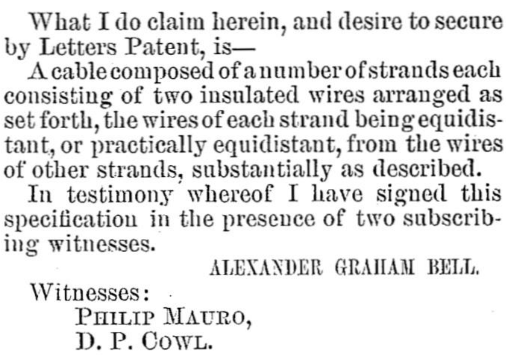
In a single-ended approach the electrical information is placed relative to a common ground potential. This approach is primarily used for short distances, like line-level audio signals from an audio player to an analog power amplifier through RCA or mini-jack connectors. Or in the digital case, a S/PDIF connection from a CD-player to a surround receiver having a digital input. The latter connection is often also through a standard RCA connection. Single-ended connections are the typical solution in the consumer (and thus price sensitive) market. The solution is simple and only requires a single transmitter and a single receiver for a single channel audio stream (analog or digital). However, the topology has a main weakness: lack of *common-mode rejection*.

When two devices (A and B) have to communicate over a single-ended cable, the signal reference is a common ground level. This common ground level is not always well defined and can be affected by long wires and leakage currents caused by a third device coupled to one of the two devices or by a 110/230V connection. So, in the case where a voltage difference occurs (for any reason) between the two ground potentials of the two devices A and B, this difference gets to be a part of the signal. For analog systems, this is very often experienced as *hum*, the typical sound artifact caused by the mains voltage 50/60Hz frequency and its harmonics. For digital systems, the error is perceived at an increase in *BER* (Bit Error Rate), which causes very unpleasant clicks and dropouts of the audio. Similar problems occur when multiple single-ended signals share a single common ground. In this situation *cross-talk* may be the consequence of sharing the common ground connection since current in one of the signal transporting conductors may cause a voltage potential across the two ground potentials (A and B), which causes a false signal on the other channel. A good example of such a connection is the widespread 3.5 mm stereo mini-jack connection that is found on almost any portable device which has audio output capabilities (mobile phones, MP3 players, GPS navigators and so on), however this interface connector is very rarely seen on professional audio equipment.

To overcome the flaws of the single-ended communication topology, balanced signaling is often used. This technique uses two conductors per information stream. The basic idea is to send out the information as a differential signal that holds the information as a *difference* between the electrical voltages on two conductors. Typically, this requires two (identical) individual transmitters that output the utility signal with opposite phase. In the receiver end, the difference is found using a differential amplifier that have a high *CMRR* (Common Mode Rejection Ratio), meaning that any signal component common for the two conductors are cancelled out. This means (in contrast to the single-ended topology) that even though common voltage potential on the transmitter device bounce up and down (relative to the common voltage potential on the receiver), this is not causing any false differential signal seen by the receiver.

Beside the described electrical common-mode advantages obtained when using balanced signaling, the conductor pair also has much better properties regarding potential interference from and to other electrical conductors – in particular if the electrical conductors in the pair are twisted. This fact is by far a new discovery. Actually, this was observed (and patented) by Alexander Graham Bell more than 130 years ago:

…This invention relates to cables for telephone transmission, and has for its object the production of a cable in which the circuits are so arranged that no disturbance will, in use, arise from their inductive action upon one another. The several circuits are composed each of two wires - at direct and a return wire - forming a metallic circuit. Inductive disturbance in the telephone and in other electrical instruments connected with a metallic circuit when the latter is placed in the neighborhood of other electrical circuits arises from the unequal inductive effect of the latter upon the two wires, for it is obvious that if the direct and the return wire were affected equally the current generated in one would neutralize and destroy that created in the other…



What I do claim herein, and desire to secure by Letters Patent, is—

A cable composed of a number of strands each consisting of two insulated wires arranged as set forth, the wires of each strand being equidistant, or practically equidistant, from the wires of other strands, substantially as described.

In testimony whereof I have signed this specification in the presence of two subscribing witnesses.

ALEXANDER GRAHAM BELL.

Witnesses:
PHILIP MAURO,
D. P. COWL.

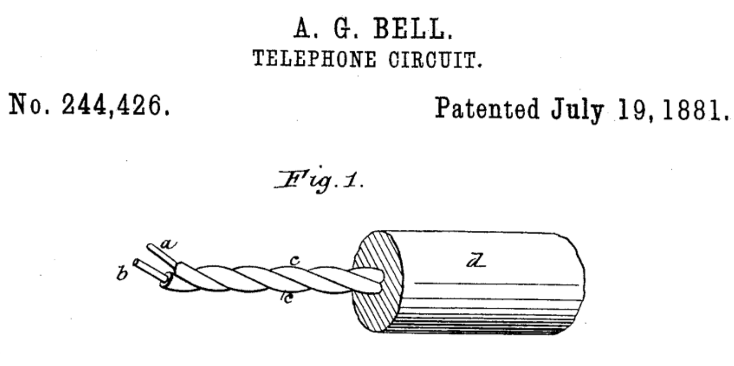


Figure 38. From US244426, patent of equidistant wires (Bell, 1881).

What Bell (1881) discovered and utilized in his cables, was that if both conductors in the cable pair were exposed to exactly the same amount of inductive disturbance, the disturbance cancelled out. A simple way to ensure that both conductors were equidistant, or practically equidistant, to other conductors, was to twist them like illustrated in Figure 38 (page 85). This technique has been used intensively ever since. First in analog telephone systems and lately in high-speed digital communication channels.

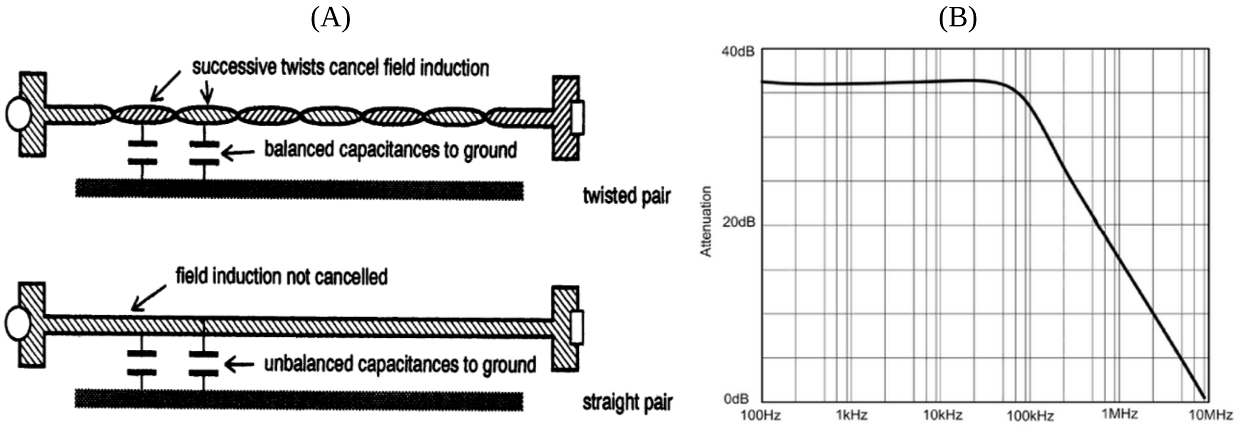


Figure 39. Twisted pair versus parallel conductors (Williams, 2004).

When comparing the two-wire cable consisting of simple parallel conductors with the twisted pair it is obvious that the twisted pair is more robust towards electromagnetic disturbances from external sources. This fact is illustrated in Figure 39. Here it is shown how both inductive and capacitive coupled error sources are cancelled by the twisted wire solution, whereas they are not in the case of simple parallel straight conductors (A). The attenuation curve (B) shows the amount of attenuation in dB, a twisted pair (22AWG) has relative to a pair of parallel 22 AWG wires spaced with 0.032" (0.81 mm), when both are exposed to a magnetic field (Williams, 2004). The same phenomena is experienced in the other direction, meaning that a couple of straight parallel conductors will "pollute" more than a twisted pair (Mui, 2005):

…The greatest electromagnetic interference (EMI) and electric field interference (EFI) occurs from the use of unshielded parallel wire communication links or lines. A substantial reduction in EMI can be achieved through the use of twisted-pair wires because of the electromagnetic field canceling effect of the twisting characteristic…

9.4.3.1 Transmission of digital data over cables

Normally when talking about cables, analog audio and loudspeakers you are often most concerned about the resistive loss in the cable. However, when it comes to transporting signals with wavelengths (speed of light divided by signal frequency) comparable or shorter than the cable length other issues require attention. As an example, the frequency contents of a 10 Mbit/second binary signal can easily exceed 100MHz, which corresponds to a wavelength equal to

$$\lambda = \frac{c}{f} \approx \frac{300 \cdot 10^6 \ [m \cdot s^{-1}]}{100 \cdot 10^6 \ [s^{-1}]} = 3 \ [m] \qquad \text{Equation 6}$$

Since the requirements for carrying the digital signal correspond to considerably longer distances, the cables should be considered as transmission lines. Any pair of parallel electrical conductors can be looked upon as transmission line, which can be represented as a cascade of two-port networks consisting of an inductor and a capacitor as illustrated in Figure 40 (page 87). Further, it can be shown that the transmission line has a *characteristic impedance* (Zo) and that an optimal signal transport channel consists of (1) a transmitter having an output impedance equal to Zo, (2) a transmission line having a characteristic impedance equal to Zo and finally (3) a receiver having an input impedance also equal to Zo (Weisshaar, 2006). When these conditions are met, maximum power is transferred from the transmitter to the receiver and no *reflections* will occur, meaning that the transmission line can be considered as a pure resistive load introducing a certain frequency independent time delay.

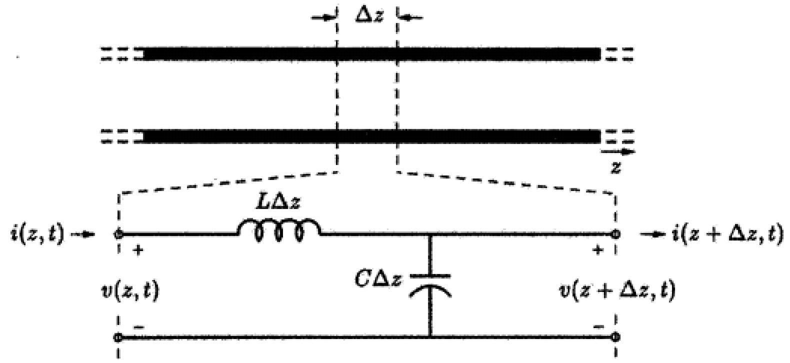


Figure 40. Electrical model of a short section of a transmission line (Weisshaar, 2006).

From the model and the knowledge of the physical properties (geometric distances and shapes along with electrical attributes of insulation material) of a given wire, the characteristic inductance (Henry per meter), capacitance (Farad per meter) and impedance (Ohm) can be found. For two parallel conductors spaced within an electrical isolating material, these parameters can be estimated with equations given in Figure 41.

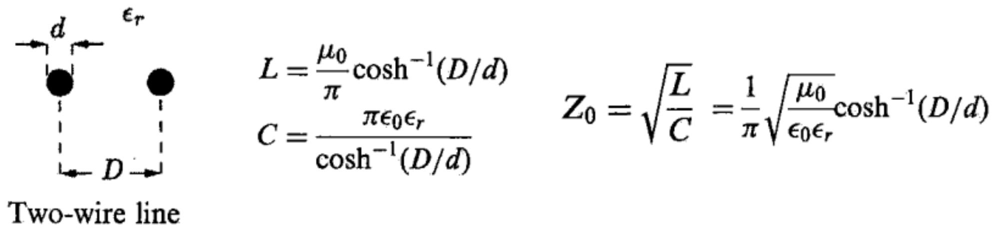


Figure 41. High frequency properties of two parallel conductors (Weisshaar, 2006).

Now looking at a practical example of the properties found in a typical CAT5 cable. From datasheets it can be found that the diameter of the inner copper conductor in a 24 AWG cable equals 0.51 mm and that the diameter of the conductor including isolation (polyethylene) equals 0.96 mm. The two conductors in the twisted pair inside the cable are located adjacent to each other, so the distance from conductor center to center equals the diameter of the conductor plus isolation. From material property tables, the relative permittivity of polyethylene is found to be 2.25. This gives us:

$$L = \frac{\mu_0}{\pi} \cdot cosh^{-1}\left(\frac{D}{d}\right) = \frac{4 \cdot \pi \cdot 10^{-7}}{\pi} \cdot cosh^{-1}\left(\frac{0.96 \cdot 10^{-3}}{0.51 \cdot 10^{-3}}\right) \approx 0.50\ \frac{\mu H}{m}$$ *Equation 7*

$$C = \frac{\pi \cdot \epsilon_0 \cdot \epsilon_r}{cosh^{-1}\left(\frac{D}{d}\right)} = \frac{\pi \cdot 8.854 \cdot 10^{-12} \cdot 2.25}{cosh^{-1}\left(\frac{0.96 \cdot 10^{-3}}{0.51 \cdot 10^{-3}}\right)} \approx 50\ \frac{pF}{m}$$ *Equation 8*

$$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.5 \cdot 10^{-6}}{50 \cdot 10^{-12}}} = 100\ \Omega$$ *Equation 9*

Breaking the cable into small sections (in this case 4 cm pieces), the cable is modelled as a cascade of LC sections, each representing 4 cm (20 nH and 2 pF). In the example below, 25 of these sections are used to model one meter of a twisted pair in a CAT5 cable.

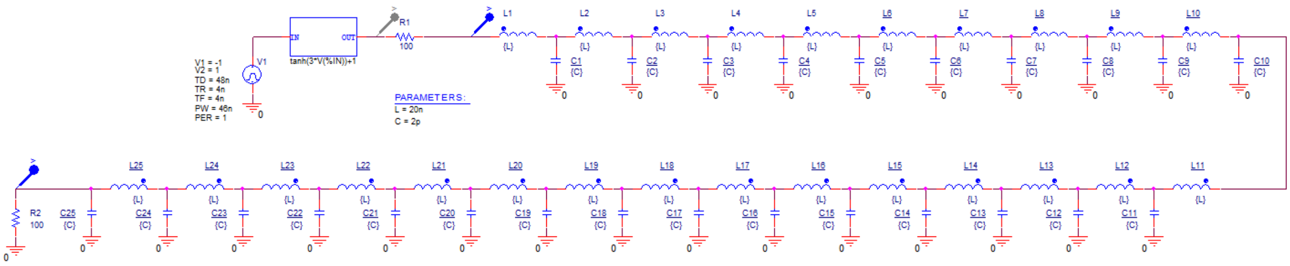


Figure 42. Transmission line model of one meter of a twisted pair.

To investigate the behavior of the cable model illustrated in Figure 42, the simulation tool Spice is used to carry out a time domain simulation. In this case a shaped pulse is used as input stimuli. This pulse is established using a trapezoid waveform created using a pulse generator having finite gradient slopes. The (50 ns) trapezoid waveform is passed through a tangens hyperbolicus function, which output a version of the pulse having smooth “s-shaped” transitions between “0” to “1”. The purpose of this “transition smoothing” is to avoid numerical issues in the simulation (attenuate very high frequency phenomena, which is irrelevant for this example). The shaped pulse is outputted through a 100 Ω resistor that emulates the transmitter output impedance. The signal is then passed on to the delay line model (L1/C1 → L25/C25), which is terminated by another 100 Ω resistor.

Simulation results are illustrated in Figure 43 (page 89). Three simulation results are presented, one in each column. Column A show the result for a 100 Ω transmission line, Column B show the result for a 400 Ω transmission line and Column B show the result for a 25 Ω transmission line. To emulate the 400 Ω and 25 Ω transmission lines, the “4 cm” inductor and capacitor values were changed to 80nH/0.5pF and 5nH/8pF respectively (from 20nH/2pF corresponding to the 100 Ω transmission line). In all three simulations, the source and termination impedance was kept constant at 100 Ω.

The first row in the illustration shows the generator pulse, the second row shows the transmission line input voltage and the third row shows the transmission line output voltage (receiver signal).

The situation in the (A) simulation shows the behavior of an exemplary transmission line. The transmission line acts as a perfect resistive 100 Ω load seen from the transmitter perspective, which can be observed by the fact that the voltage at the delay line input is simple halved compared to the original generator waveform. Further, it can be observed that the receiver signal is identical to the transmission line input voltage – except for a minor delay.

According to theory, L and C determine the propagation delay in the cable (Johnson & Graham, 2003):

$$t_p = \sqrt{L \cdot C} = \sqrt{0.5 \cdot 10^{-6} \cdot 50 \cdot 10^{-12}} = 5.0\ \frac{ns}{m} \qquad \textit{Equation 10}$$

This delay nicely matches the result from the (A) simulation.

In the (B) and (C) simulations, reflections occur since there is a mismatch between source/termination impedance and characteristic impedance of the cable. These reflections are apparent on both input and output of the transmission line. They can be observed as staircase-like phenomena with a step duration of (in this case) 10 ns, which corresponds to an event bouncing from transmitter to receiver and back again (two times 5.0 ns).

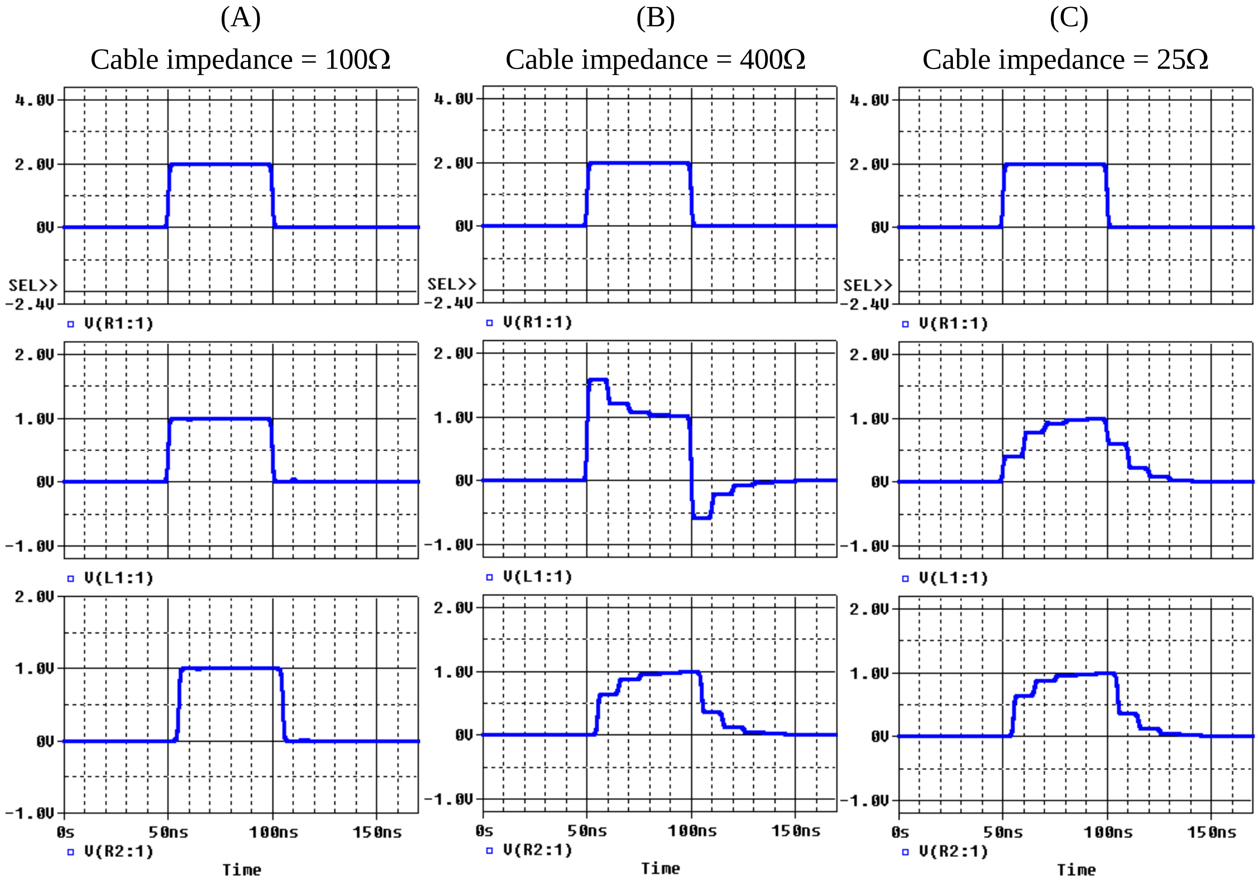


Figure 43. Reflections in cable caused by lack of impedance match.

In this simple example, the (B) and (C) receiver signals (which appear to be identical!) could probably be recovered by the receiver, but imagine a complex signal with a random stream of “ones” and “zeros” along with a propagation delay equal to or longer than the “bit duration”. Then things can get very complicated to predict. The reflections of random bit patterns can cause both constructive and destructive interference and cause bit errors in the receiver end (Spurgeon, 2000; Raju & Salahuddin, 2010).

9.4.4 Loudspeaker installation wiring layout

Loudspeaker network layout can potentially have a big impact on the total combined cable length in a given installation. This sub-chapter will illustrate this, using concrete design examples.

Traditional 70/100V constant voltage systems are typically built up around a CAR (Central Apparatus Room, see example in Figure 32, page 78) with multiple *homeruns*, one from from each zone back to the CAR (*centralized amplification*). In contrast to that, a loudspeaker network can also be built upon a *distributed amplification* topology, meaning that audio is distributed over a network and that amplification is carried out locally either in the proximity of a given zone or in the zone itself.

In the following examples, such two network topologies are compared. For both topologies, the systems consist of different combinations of 2 × 2 zones, where each zone is a square 81m^2 room having nine ceiling loudspeakers distributed evenly in the room. The room (zones) are spaced with 2-meter wide hallways. Such a zone layout could resemble multiple stores in a shopping center or a group of classrooms in an educational institution.

(A) Centralized amplification (B) Distributed amplification

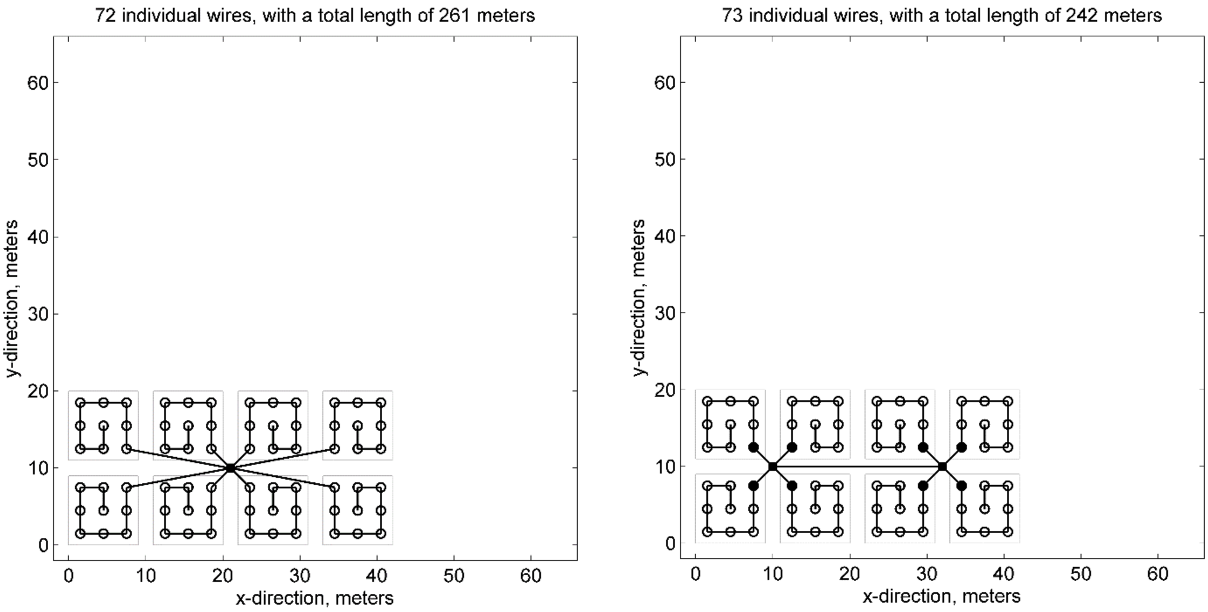


Figure 44. Eight zones, each having nine loudspeakers

In the centralized amplification based systems (topology A), the central amplifier is located in the geometric center of the whole system. In the distributed amplification systems (topology B), amplifiers/hubs are interconnected (daisy-chained) and drive a small cluster of 2 × 2 zones. This kind of structure will cover audio and power distribution systems such as (1) an interconnection scheme where Ethernet PoE switches are daisy chained and each PoE port sends audio and power to a single master loudspeaker in each zone and that this master loudspeaker drives the remaining speakers in the zone in a lo-Z manner; or (2) a daisy chain of digitally interconnected power amplifiers, each driving four zones that are either 70/100V or lo-Z configured; or finally (3) a daisy chain of digitally interconnected power and audio providers (PAP) that each supplies four daisy chains of active loudspeakers with both power and audio.

(A) Centralized amplification (B) Distributed amplification

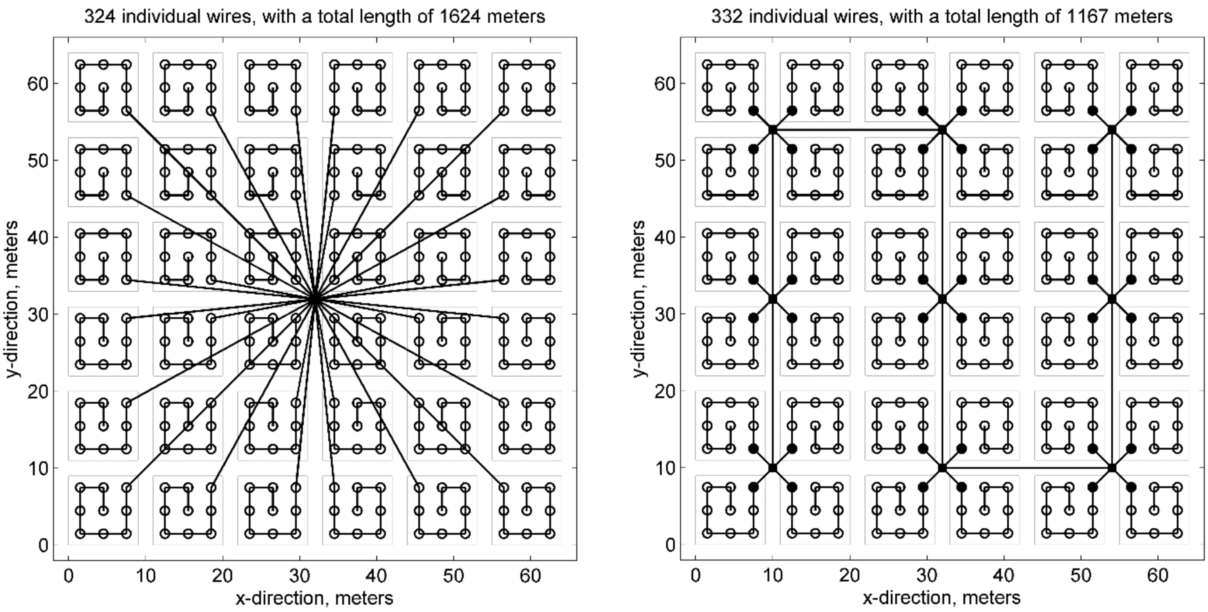


Figure 45. Thirty-six zones, each having nine loudspeakers

Figure 44 (page 90) and Figure 45 (page 90) illustrates two sizes of installations with respectively eight and thirty-six zones (72 and 324 loudspeakers). Each installation is layout with both the centralized and distributed amplification topology to be able to compare them.

As seen in Figure 44 (page 90), the combined cable length is only marginally lower for the distributed topology, where the larger installation in Figure 45 (page 90) shows a significant reduction of cable length from 1624 meter down to 1167 meters by using a network based installation. This reduction corresponds to a cable-length-ratio (CLR) between centralized and distributed amplification equal to 1167/1624 = 72% which of course is obtained by eliminating the requirements for multiple homeruns.

The CLR will depend on installation size but is will also be heavily influenced by the geometric shape of the installation. To illustrate this, cable length calculations have been carried out for different layout with same zone count. As calculated above, the CLR for a symmetrical 6 × 6 layout equals 72%, however an 18 × 2 has a CLR as low as 46%, meaning that such an installation using a distributed amplification topology would require less than half the wiring (meters and copper) compared to a centralized amplification topology.

A compilation of different layout sizes is presented in Figure 46. It should be noted that these results of course are only 100% valid for the specific room and hallway sizes, nonetheless the trend is quite clear, showing that larger and particular non-symmetrical installations will benefit from using a network-based approach.

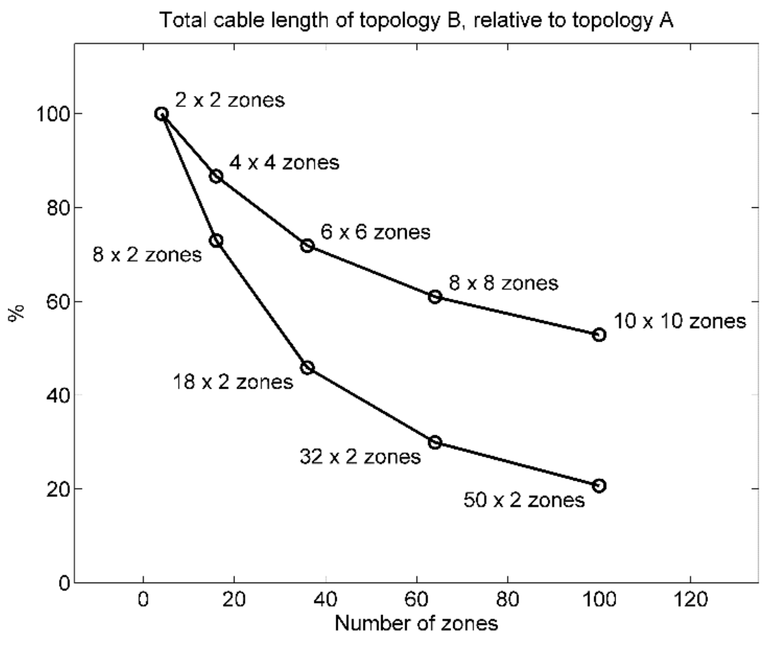


Figure 46. Cable-length-ratio between centralized and distributed amplification layout

9.4.5 Solution space

After having elaborated about the ingredients for audio power distribution, from a source to the loudspeaker, it is now time to see things in a combined perspective. The aim is to visualize the solution space for different (realistic) combinations of technologies of (1) power distribution, (2) audio distribution and (3) physical transport media.

The combinations are mapped into a two-by-two system having divided the solution into the four quadrants:

(A) Data (audio) over power cable / Analog audio path
(B) Data (audio) over power cable / Digital audio path
(C) Power over data cable / Analog audio path
(D) Power over data cable / Digital audio path

	Analog signal path	Digital audio path
Data over power cable (Two-wire cable)	(A) 1. Existing 70/100V systems. 2. Analog (modulated) signal superimposed on supply voltage for remote amplifier. 3. Analog (modulated) signal superimposed on supply voltage for remote amplifier combined with modulated, superimposed digital (bi-directional) control.	(B) 1. MOST/FlexRay combined with "data over power line" (*). 2. Standard digital audio protocol (AES/EBU) combined with "data over power line" (*). 3. HomePlug (Power line communication). 4. Bi-directional (proprietary) digital protocol combined with "data over power line" (*)
Power over data cable (Ethernet cable, CAT5)	(C) 1. Two pairs dedicated to power, remaining two pairs to analog audio and digital control respectively. 2. Power over all four pairs. Analog (modulated) audio superimposed on three pairs, digital (bi-directional control on a single pair).	(D) 1. PoE (power over Ethernet) combined with standardized digital audio over Ethernet (Table 8, page 80). 2. Two pairs dedicated to power, remaining two pairs to digital audio (AES/EBU) and digital control respectively. 3. Power over all four pairs (*). Digital audio (AES/EBU) over three pairs, bidirectional control over fourth pair.

Table 10. Technology combination, solution space.

(*) A general method of sharing a conductor pair for both data and power (Liu, 2013).

To compare the different solutions, the following attributes are assigned scores. These estimated scores do not have equal weight since the weight will depend on the particular application the solution will be a part of. For some applications, the power ability might be much more important than the system complexity and vice versa. Further, the weight will also be affected by personal preferences. The scores presented in Table 11 (page 94) are not exact, but rather an estimate based on the findings in chapters 9.4.1, 9.4.2 and 9.4.3 (pages 77-89) along with the authors own experience. The scores are given in the interval 0-3, corresponding to the adjectives "none", "low", "medium" and "high". A sum is calculated per solution. This sum should not be used to "blindly" compare across solutions, but rather be used as an indicator. Further it should be noted that several of the attribute scores are subject to a large uncertainty. To reduce the uncertainty experiments have to be conducted, both on technical and market levels.

Power level capability equals the amount of power a single line can carry. An example of a technology that can power a vast number of loudspeakers on the same line is the existing 70/100V technology, which is limited only by speaker cabling dimensioning. A technology that has a limited amount of power on a single line is PoE, which has a standard power-rating equal to 15W per port.

Maximum cable length is a measure of the ability to establish long spans from audio source to loudspeaker. A two-wire system with proper copper diameter cabling and a daisy-chained data relaying architecture will enable the option for long cable distances, whereas systems having much higher bandwidth capabilities will suffer from bit errors and/or audio degradation in the case of analog transport, when using long lines.

Data rate capacity is proportional to the number of audio channels that can be transported in the cable. At one extreme, we have the existing 70/100V solution carrying only a single audio channel. Using Ethernet based protocols hundreds of audio stream can be present in a single cable.

Ability to daisy-chain tells if a system can pass on power and audio from one loudspeaker to the next. Simple solutions with audio and DC supply on a CAT5 have this ability, whereas a PoE powered AVB endpoint has not since power is allocated using a point-to-point topology.

Real-time audio ability is a measure of how well real-time audio streaming suits the underlying data exchange mechanism. All analog audio transport systems have this feature inherently, where advanced power-line communication modem technologies have not.

Network node simplicity specifies the level of required amount of electronic circuitry and software required for a given loudspeaker network node. A traditional 70/100V loudspeaker requires a dumb passive transformer and a HomePlug receiver requires supply voltage extraction filters, balanced digital receiver circuitry along with an advanced modem technology established using high speed digital signal processing.

System cost effectiveness is an estimate specifying how well the system performs for a given sales price. Again, this parameter is not based on facts, but it is estimated that a PoE based system (isolating SMPS) with a Dante receiver (requires licence) is more costly than a proprietary “DC+data over CAT5”.

Audio quality potential describes the system’s ability to reproduce audio without degradation. In the average 70/100V loudspeaker installed today, we find an audio power transformer that introduce severe distortion below 100Hz, but in a DC supplied network node supplied with 24bit/48kHz digital audio the quality potential is much higher.

Individual level adjustment ability measures how well the given topology enables individual level control. The traditional 70/100V has a local level selector with 3dB steps, where a true network node has remote and step-less level control.

Network node forward controllable specifies to what extent the network node can be remotely controlled and *Ability to monitor network node* specifies to what extent the network node can be remotely monitored.

Standardization level is a measure for the amount (percentage) of standardized technology used in the solution. The PoE/AVB solution is 100% standardized, where an analog modulated audio transport over a DC bus is not.

Electromagnetic compatibility specifies the expected amount of challenges met, when using a given solution. Existing 70/100V are virtually without EMC challenges, whereas a HomePlug based network has known EMC issues.

Robustness towards network node fail is a number that indicates how well the system will continue to operate even if a single network node will fail. Looking at the 70/100V system it will be unaffected by a loudspeaker/transformer disconnect and it is very unlikely that it will short-circuit the transmission line. In a daisy-chained AES/EBU system the audio and control stream will be cut at the location in the line, where the failing device is positioned, meaning the loudspeakers downstream will be silent.

In Table 11, all fourteen attributes are compared across the twelve solution candidates. The attributes are grouped into four sub groups being (1) attributes relevant for existing technology, (2) attributes relevant for the new technology, (3) a simplicity and cost group, and finally (4) a compatibility group.

Attribute groups	A1	A2	A3	B1	B2	B3	B4	C1	C2	D1	D2	D3
Power level capability	3	3	3	3	3	3	3	1	2	1	1	2
Maximum cable length	3	2	2	1	2	2	2	2	2	2	2	2
Ability to daisy-chain	3	3	3	2	3	3	3	3	3	0	3	3
Individual level adjustment ability	1	0	3	3	3	3	3	3	3	3	3	3
Real-time audio ability	3	3	3	2	3	1	3	3	3	2	3	3
Data rate capacity	1	1	2	3	1	3	2	1	2	3	1	2
Audio quality potential	1	2	2	2	3	3	3	2	2	2	3	3
Network node forward controllable	0	0	3	3	3	3	3	3	3	3	3	3
Ability to monitor network nodes	0	0	3	3	0	3	3	3	3	3	3	3
Network node simplicity (*)	3	2	1	2	3	1	2	3	2	1	3	2
System cost effectiveness (*)	1	2	2	1	3	1	3	3	2	1	3	2
Standardization level	3	1	1	2	1	2	1	2	2	3	3	2
Electromagnetic compatibility (*)	3	3	3	2	2	1	2	3	3	1	2	2
Robustness towards network node fail (*)	3	2	2	2	1	2	2	2	2	3	2	2
Score	28	24	33	31	31	31	35	34	34	28	35	34

Table 11. Solution performance score.
(*) Attribute with high uncertainty.

9.5 Intellectual property rights

This sub-chapter will shortly describe the identified intellectual property rights (IPR). Using the patent search engines *Espacenet* and *Google Patents*, the patents and patent applications described in this sub-chapter have been identified.

Espacenet is a public accessible patent search engine offered by the European Patent Office and Google Patents is Googles free patent search engine. Both services offer search service function across all (no country specific limitation) patents and patent applications also including PCT applications ("world patents"). However, they offer different search options, filter options and result presentations. Based on the authors own experience, the two engines complement each other nicely.

Searches were carried out using a combination of simple text based search, "cascade search" (where patent reference information is used as guidance in the subsequent search) and finally using the hierarchical structural search option offered through the Cooperative Patent Classification system, which places all patents and applications in a structured theme hierarchy. Further details about the patent system and patent search strategies are found to be out of scope for this study.

9.5.1 DE10340104. Efficiently transmitting power when acoustically irradiating rooms.

This patent describes a system that consists of a master device, a transmission bus and a number of loudspeakers that receive both power and data from the master device over that bus. The described system was brought to the market in 2004, in the form of the VariZone system as illustrated in Figure 47.

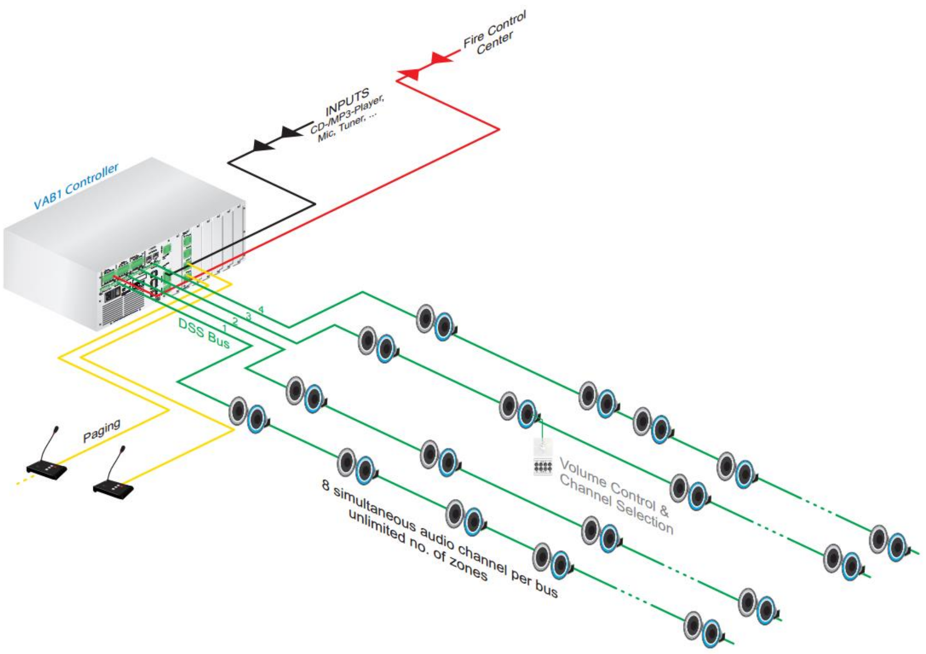


Figure 47. VariZone system.

The DSS bus is a multi-wire conductor (either CAT5 or other suitable twisted pair cables) with at least four pairs. Each bus line carries eight audio streams. The bus powers small amplifiers, one for each set of two loudspeakers. The amplifiers are individual devices sitting outside the loudspeaker enclosure.

The patent application was originally files as a German application, later filed as a PCT (international) application and finally filed as an US application. According to the European Patent Office (INPADOC legal staus), the German patent was actually granted in December 2005, but the IP rights lapsed in June

2011 due to missing payment of the annual patent fee. According to the United States patent office, the US application died in May 2010 due to “Abandonment for Failure to Respond to Office Action”. Transaction history for patent applications is public available through the Patent Application Information Retrieval service (PAIR). From the transaction history, it may be observed that no less than three non-final patent rejections from the US patent office were given before the application was abandoned.

9.5.2 US20030220705. Audio distribution system with remote control

This US patent application describes a system not that different from the Varizone system described in chapter 9.5.1 (page 95) - and is in a similar way based on a multi conductor cable bus supplying small amplifiers with both power and audio data. The system was envisioned as an audio system in a hospital, where patients could control the system using a wireless remote control communicating with electronics located inside the loudspeaker enclose. Further, it was imagined that each loudspeaker held a microphone so the patients could use the system as an intercom system e.g. when help was required – or as a sound monitoring system.

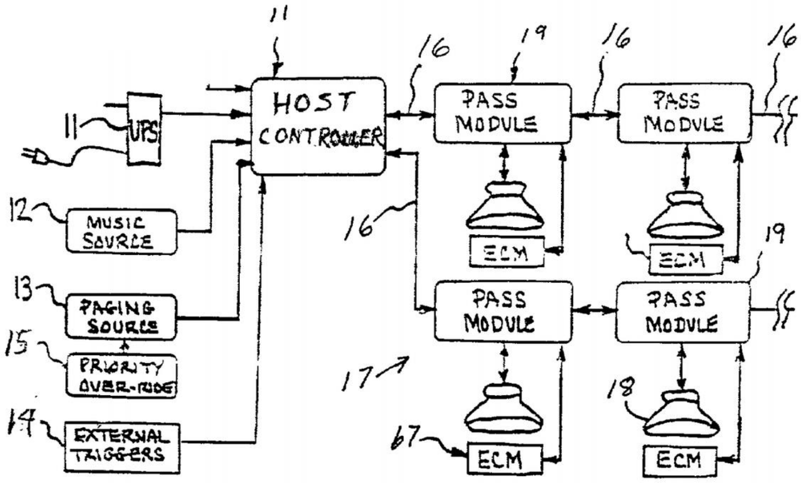


Figure 48. Audio distribution system.

According to the status available on PAIR, the application died in June 2006 due to “Abandonment for Failure to Respond to Office Action” similarly to the case described in chapter 9.5.1 (page 95). However, in this case the application was abandoned after the first non-final patent rejection.

9.5.3 US8879754. Sound reproducing system with superimposed digital signal

This invention relates to a private home HI-FI system. The idea is again that a single cable is shared as a bus, supplying multiple loudspeakers with both power and audio data. However, in this system, the cable is a simple two-wire transport media.

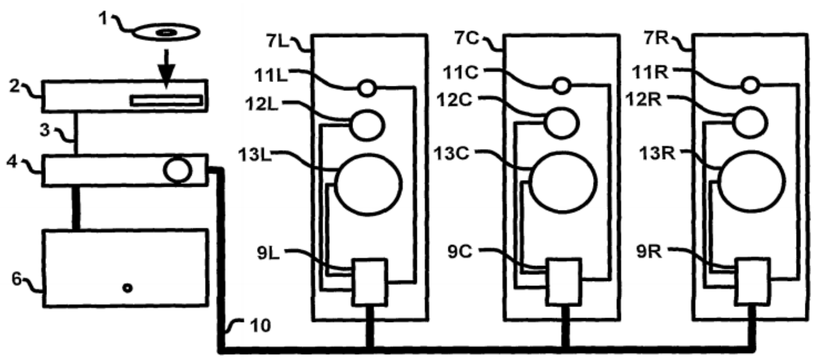


Figure 49. Sound reproducing system with superimposed digital signal (Risberg, 2008).

Status of the patent is that it is granted and valid as of November 2014. Fortunately, seen from a TC Group perspective and others wishing to pursue technology that enables simultaneously power and real-time audio data over a shared bus, the patent has only a single independent claim, that is limited towards a HI-FI reproduction system. Further, the claim has a number of other limiting factors, namely that it:

1. Is a home use sound reproduction system aimed for customer installation.
2. Comprises a user interface including at least one of volume control, bass control, treble control and sound source selection.
3. Includes a control unit, providing digital signal transfer of S/PDIF signals directly from a playback unit.
4. Utilizes a two-lead speaker cable adapted for supplying at least 160 watts continuous power
5. Is adapted to being able to connecting the digital speaker output of the control unit to the active loudspeaker by bare lead ends without any connector.
6. Superimpose the S/PDIF sound signals, received from the playback unit, directly on the power signal without an encoder.

This means that a system missing one or more of these properties will not infringe the patent rights.

9.5.4 US2014247892. System for networking over high impedance cabling

In their United States patent application, Williams & Ware (2011) describes a system where multiple input and output devices are inputting and/or outputting data onto a high impedance cabling network as illustrated in Figure 50. Further, gateway units supply these devices with power, while also receiving and/or transmitting data from and to the network just described.

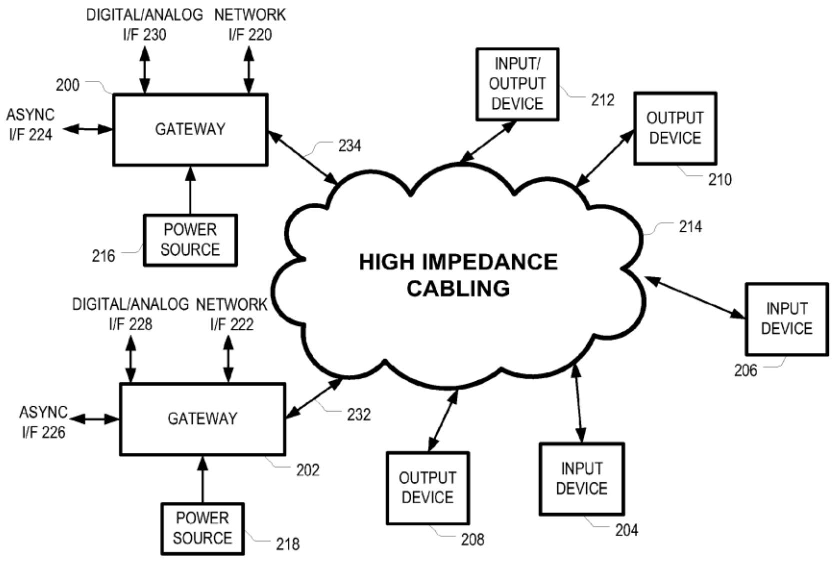


Figure 50. System for networking over high impedance cabling (Williams & Ware, 2011).

The patent application has two very broad independent claims, where the first is formulated as:

A system for distributing digital data and electrical power to a plurality of devices over high-impedance cables comprising:

a) a gateway device connected to a power source;

b) a first device connected to the gateway device by a cable, the cable being a high-impedance cable having at least two conductive paths, and wherein the first device receives electrical power and digital data from the gateway device via the cable over the same conductive path of the cable;

c) *a second device connected to the gateway device by the cable wherein the second device receives power and digital data from the gateway device via the cable over the same conductive path; and*

d) *wherein the power source provides power to the first and second devices via the cable, and wherein the second device is connected to the gateway device through the first device via a daisy-chain topology.*

As it appears, the text reveals no specific limitations and will as such cover many, many technical solutions on the problem.

According to PAIR, the applicant has received the first *Office Action*, from the United States Patent Office (USPTO) and has been given a non-final rejection, meaning that the application is still alive.

9.6 Discussion

This discussion will consist of three parts. The first part is an elaboration on findings, the second part will discuss the technical uncertainties (O'Connor & Rice, 2013) and the third part will discuss identified critical factors.

9.6.1 Solution space

When comparing the columns in Table 11 (page 94), suitable candidates appear to exist in all four categories A, B, C and D, described in Table 10 (page 92). As mentioned earlier, the column sum should not be used as final results without an elaboration. When comparing analog (A+C) with digital (B+D) solutions, the analog solutions is in general simpler and will probably be easier to develop since they require no (or few) software development resources. On the other hand, the analog solutions do not seem to follow the global trend that has been pointing in a digital direction for some years now. Further, the digital solution offers an audio transport mechanism that is free of disturbances like cross-talk issues and hum (50/60Hz) artifacts.

When comparing two-conductor (A+B) with multi-conductor solutions (C+D), the multi-conductor solution appears to offer a simpler approach since individual pairs can be designed to cover only one task (either audio or power) compared to the two-conductor solutions, where audio and control has to be superimposed onto the DC. From another perspective, the simple solutions in the multi-conductor categories do not offer the required power throughput (see Table 11, page 94). Further, it should be added that the market seems to prefer simple two-conductor cables over CAT5, which supports the two-conductor solutions.

Based on the above (with emphasis on digital audio transport and high power capability) the solutions in quadrant B seem most favorable. Among these solutions there seems to be a favorite: B4, which is a solution capable of transporting several digital audio and control channels downstream and multiple channels of status information the opposite direction. The B4 solution shows high scores on all parameters except standardization level. Before choosing B4 as a target technology, the impact of this lack of standardization has to be investigated thoroughly. However, it should be noted that a low score on Standardization level is not necessarily negatively related to all parameters of product development. As an example, specific standards do not need to be complied with, meaning that things like Ethernet and PoE certifications can be avoided.

9.6.2 Technology uncertainties

In the framework presented by O'Connor & Rice (2013), a table holding *Categories of Uncertainty* is presented. This table holds category specific questions identified through their research. As a part of this discussion, these questions (see below) will be discussed in the following.

TQ1. What technical features do this breakthrough innovation enable?
Depending on selection of technology (see Table 10, page 92 and Table 11, page 94), several new technical features potentially exist. Compared to the current technology (70V/100V), several of the solution candidates offers many new features:

a) Remotely (automatically) controlled, loudspeaker individual level control. This enables that a given sound profile in a single zone can be changed dynamically without the need for mechanically adjusting a rotary switch on each individual loudspeaker. This will be an advantage in zones where playback level requirements change over a daily rhythm, like in bars and restaurants. A second feature with this ability is that *mix-minus* can be implemented. Mix-minus is a technique where the audio level in the proximity of a person speaking in a microphone, is reduced. This feature increases the “naturalness” when using microphones. When several microphones exist within a single zone (conference room) it is required that the individual loudspeaker can reduce its level as a function of which microphone is activated.

b) With multiple audio channels existing within a single cable (either as multiple conductors or as multiple digital audio channels within a single conductor pair) installations get more flexible. Since a single cable can carry the audio signal for more than a single zone, the cabling layout can be simplified and thus labor cost can be reduced. A single daisy-chain would potentially supply several loudspeaker zones.

c) With bi-directional data streaming, network node monitoring is now possible. This enables a remote service functionality, where the entire system (including the loudspeaker) can be checked and precise error information is at hand before a service technician is at the location. This feature will also be helpful in the installation phase to verify the installation without the need for manually checking each individual loudspeaker.

d) In the suggested solutions (see Table 10, page 92), where network nodes are supplied with 48VDC, no conduit requirements exist for installations in the United States. This enables a (much) simpler installation process and thus a more cost efficient solution for the installer.

e) With distributed amplification, where each loudspeaker has its own amplifier, the sound quality can be improved. Traditional 70V/100V systems have to pass the audio power signal through in inherent transformer found as a part of the loudspeaker network node. This transformer will cause core saturation effects for low frequency signals (Whitlock, 2001), meaning that a filter is always invoked that attenuates these signal components and thus attenuates the low end of the frequency spectrum. Getting rid of the transformer thus enhances the sound quality with a better and more “tight” bass reproduction.

TQ2. What should the technical specifications be?
When aiming for the existing professional fixed audio installation, with a primary focus on the market in the United States, it is important to aim for systems that have no drawbacks compared to the exiting industry standard. When comparing the existing technology (A1 in Table 11, page 94) with the proposed candidates, the existing technology has some advantages, primarily regarding (1) Maximum cable length, (2) Network node simplicity and (3) Robustness towards network node fail. Regarding the cable length property it is found (see chapter 8.3, pages 60-63) that a majority of zone installations consist of less than 20 loudspeakers with an overall cable length less than 100 meter, meaning that it will be unwise to aim for solutions with less capacity. It is further evaluated that installation simplicity and system robustness should have (much) higher focus compared to an advanced and comprehensive feature set, which is further supported by the market reluctance towards new and advanced system properties (see chapter 8.4, pages 63-65). It is, however, assumed that introduction of a monitoring capability will be valuable, since more and more

installations require this feature, caused by a safety perspective, when using the sound system as a voice alarm system.

TQ3. What additional technical developments are required to implement technical objectives?

As described in chapter 9.4 (page 77), three ingredients exist in a loudspeaker network system: (1) a method of delivering energy to the loudspeaker, (2) a method of transporting the audio information to the loudspeaker and finally (3) a physical connections from the energy source and audio source to the loudspeaker. Regardless of which solution is selected among the candidates in Table 10 (page 92), all three ingredients must be fully understood and mastered using either internal or external resources. To offer the required properties of an audio installation system, the following technology selections and developments should be carried out:

a) Select, develop and mature a DC power distribution technology that supports energy deliverance to at least 20 active loudspeakers sitting on a single daisy-chain.
b) Select, develop and mature a bi-directional protocol that supports multiple audio channels downstream and status information upstream – and has a range of at least 100 meters using standard cables (has to be verified across a large number of different cable types to ensure that any deviation from a target characteristic impedance does not cause bit errors (see chapter 9.4.3.1, pages 86-89). In case of digital communication on the cable media any EMC/EMI related issues has to be solved. Even though the primary market is the United States, the solution also have to comply with stricter radio emission regulation found in e.g. Europe.
c) Investigate the consequences of the low scoring attributes found in the selected technology thoroughly.
d) Optimize the network node electronics with respect to energy consumption to make it comparable or preferably moderate in energy consumption, when comparing to existing technology (seen from a system perspective). Similarly, network node cost should be minimized.

TQ4. What approach will we adopt to achieve these objectives?

To establish a system platform, prototypes of the building blocks must be constructed and debugged. Actually, this process will be very similar to other R&D tasks found within the TC Group Install vertical. Assuming this project passes “Gate 3” in the Stage Gate model, the development process is well known. In case of missing technological knowhow, external resources will be pulled into the development process. It should be noted, that most of the solution candidates require no technologies not already found in the TC Group technology repository.

TQ5. In what form will the product or process be presented to the customer?

In this market vertical, typically specification of products is done as a recursive process in which expected product properties are “probed” using key customers. For this product this process will be very important and relevant since very few similar products exist on the market. Typically, specification and design of a product is done “relative” to existing products. This will be much harder for this product since it is potentially disruptive. It is therefore important that both virtual and real prototypes are shown to key customers to learn if the concepts should be adjusted – or even abandoned.

TQ6. How will the product or process be produced?

It is assumed that the electronic part of the product will be produced using TC Group production standard electronic manufacturing process (SVI, Thailand) - and that the loudspeaker/enclosure and assembly will be handled through Tannoy’s manufacturing process (Meiloon, Taiwan). TC Group has previously had to handle problems with products assembled in mainland China holding electronics (Printed Circuit Boards) manufactured elsewhere, caused by unofficial Chinese trade embargos experienced as unreasonable custom handling processes.

9.6.3 Technology related critical factors

Through the discussion of uncertainties (TQ1-TQ6) several critical factors were identified.

The first and maybe most important critical factor, is the definition of the optimal product regarding features, capabilities and limitations. This definition has to be clear before choosing the technology. If requirements change radically, later in the development process, the technology choice might not be valid anymore. This potential situation can only partly be predicted since a change of company strategy or sudden change of new, competing products on the market is unpredictable and will eventually force a change in direction of the product development.

Second critical factor is the expected challenge in getting the product approved with regards to Electro-Magnetic Interference. If the final solution does not obey regulations found in at least the Unites States, Europe, China and Japan – the product will not make sense, seen as a replacement for the existing 70V/100V technology. This factor can be investigated using early prototypes and can thus be predicted. Third critical factor is spread of cable types. This factor is only relevant for two-wire solutions and can be predicted at an early stage in the development process.

The fourth critical factor identified, is the impact (regarding overall project success) on the low scoring attributes for the selected solution. Assuming B4 (see Table 10, page 92 and Table 11, page 94) will be the selected technology solution; what will it mean for development, sales and marketing that the power and audio distribution does not use a standardized technology for solving this task? This factor will be hard to predict, not least regarding the market impact. Will the customer care at all? Or will they actually expect that a disruptive technology is indeed based on other standardized techniques? These questions can of course be asked in interviews or through a questionnaire toward the target customers, but the precise impact will probably first be experienced when the product hits the market.

A fifth critical factor was identified outside the framework presented by O'Connor & Rice (2013): intellectual property rights. This factor is indeed critical and can potentially be a project showstopper and particularly in the area of development of radical and disruptive products and services, protection of inventions seems relevant. You could argue, though, that this factor belongs among market related critical factors, since it would be possible (and legal) to develop and manufacture a given product, even if it infringed a certain patent. However, you could not bring this product to a market where a third party held IPR covering the product. Nonetheless, the IPR factor is in this study placed among the technical oriented factors since the required actions to circumvent IPR have to be handled through a technical perspective – even if the solution will be that required IPR is acquired from a third party. Taking a more offensive viewpoint, it should also be considered if any patents should be applied for as a function of discoveries made through the product development. Such patents could offer rights to operate on a market, but could also be used to block for competitors.

In this project case (networked amplifiers and loudspeakers), two critical IPR documents have been identified. The first, a granted US patent, describes a bus oriented power and audio distribution systems for installation of a HI-FI system in private homes. This patent has to be analyzed thoroughly, but it seems like several circumventions will be possible. Further, the patent rights only cover applications within a quite narrow scope. Therefore, the required actions regarding this patent can be predicted. The second critical document, is a US patent application that describes a bus distribution principle that allows for multiple network nodes and gateways that share power and data on that bus. This application is very broad and covers basically all of the suggested solutions found in Table 10 (page 92). Fortunately (seen from a TC Group perspective), this application is still in an early phase and a written opposition to the United States Patent

Office has been filed as an attempt to prevent that this patent will ever get issued. This opposition, a so-called *Third Party Concise Description of Relevance*, contains technical descriptions of prior art that invalidates the invention made and is public available through the USPTO (Arknaes & Jeppesen, 2015). However, even in this case with multiple technologies being identical or closes to the topology described by Williams & Ware (2011) it is impossible to predict the final destiny for their patent application. Finally, it should be mentioned that several relevant patent applications might exist in the “patent system pipeline” that has not been published yet. These applications can of course not be predicted either, but it is very important that this area is monitored and that critical applications are dealt with.

9.7 Technical sub-conclusion

In this chapter, loudspeaker network topologies have been looked upon from a technical perspective. Initially the background of professional, fixed audio installations are given followed by a description of an alternative system, where amplification is distributed and that DC power is carried over the cabling instead of the audio power signal. Through this description, it was found that the DC distribution method reduced the cable power loss to approximately only 30% compared to losses in traditional AC topologies (music playback), based on the statistical properties of audio.

The three ingredients (power distribution, audio distribution and transport media) were described and different technologies that could handle the required tasks for each ingredients were elaborated. Using a scalable model of a virtual building space having multiple zones of loudspeakers, the wiring layout advantages in networked and distributed amplification were analyzed. Through a model of a “hundred-zone installation”, it was found that the overall cable length could be reduced significantly. Compared to a centralized topology, the cabling could be reduced to less than 60% for a symmetrical installation and to as little as 20% for an asymmetrical installation. With rising prices of copper (and also labor cost), this parameter is very relevant.

From the technical findings, a solution matrix was presented. This two-by-two matrix divides the twelve solutions into sub groups having an analog signal path or a digital signal path and using a data-over-power cable or a power-over-data cable. All twelve solutions were further compared on 14 parameters (attributes) and scores were given. Based on these scores along with technology trends and market information, it was found that two-wire cabling with a digital transport mechanism would be a viable route to take. Further, IPR was searched for within this specific technical field and four patents or patent applications were found, two of them still active.

As the last part of this technical chapter, technical uncertainties were discussed and five high-critical factors were identified. A compilation of these factors along with their degree of *latency* (O'Connor & Rice, 2013) and the required actions are presented in Table 12 (page 103).

High-critical factor	Latency	Required action
Product definition, capabilities and limitations	Both high and low	Product has to be agreed upon internally inclusive its limitation. Market and technologies has to be continuously monitored.
Electromagnetic Interference	Low	Prototype has to be established and emission levels found and compared to regulations in the important markets.
Compliance to different cable types	Low	Prototype has to be established and impact on cable reflections investigated.
Impact on limitations for a given solution (low score attribute).	Both high and low	Dialogue with the market is required to understand the reduction of perceived value for a given attribute.
Intellectual property	Both high and low	Granted patent claims can often be circumvented by using another technical solution but applications in the pipeline of the patent authorities are difficult to control. Published applications thus have to be monitored and potentially oppositions have to be filed. Further, it should be considered if any established solution or part of that could and should be protected by patents.

Table 12. High critical factors, technology related.

9.8 Reflections

This chapter tried to identify suitable technical candidates for a novel loudspeaker network paradigm, based on distributed amplification. The required basic mechanisms were separated into three groups (1) power distribution, (2) audio distribution, and (3) transport media. From these groups, technologies were found that could handle the required task. From the combined group of technologies, several combinations were formed to system solutions, which were rated on multiple parameters.

A process as described above will always be limited in its scope, since it is restricted to the knowledge of the author and his ability to think out-of-the-box. Many more solutions might exist, which could solve the task in a better or more cost-effective way. However, it is judged that the suggested B4 solution (see Table 10, page 92) will be a very attractive alternative to the existing 70V/100V installation technology. It is further evaluated that factors like defining the right feature set and identifying the optimal installation procedure of the proposed system is of much higher importance compared to the aim for an optimal technical solution (which most costumers do not appreciate anyway).

10. Implications and conclusion

This study set out to explore how TC Group could support the development and commercialization of a product having disruptive potential, being an organization that for the last decade primarily has been doing incremental innovative products and optimizing its procedures for relatively short project time horizons. A vast amount of literature has identified the challenge for established companies trying to engage in disruptive innovation, where such organizations typically are hindered in their ability to be agile, innovative and patient, caused by their heritage, being the values and culture linked to the goal of being successful on the short term, with incremental innovative products or services.

Aiming for a disruptive product within TC Group will pose a big challenge for multiple aspects of the development and commercialization of such a product. This study sought to answer the following questions:

(1) Which organizational properties are required for such a project?

(2) Which market(s) should be addressed with this system and how can the system satisfy the market?

(3) Which technical solution will be optimal for the proposed system?

(4) What resources and competences are required to handle the development and commercialization of the system?

10.1 Implications of the findings

Looking at the organization profile from the organization analysis in sub-chapter 7.6 (page 43), most of the organization attributes belong to the *prospector* archetype. This is a good match, when seeking to engage in disruptive and radical innovation. Such a profile typically means that the organization is agile, effective, autonomous, and seek to explore rather than exploit. However, for TC Group a few of the important attributes are located in non-prospector locations. The most important is the *strategy*, where focus today is put on exploitation rather than exploration. Very much related to that, is the attribute *leadership*, where the uncertainty avoidance parameter received a high score. With such organization values and beliefs, it will be very hard to succeed with a project aiming for a disruptive product. For projects having disruptive character you have to experiment (explore) and accept a larger risk compared to incremental innovative products, since market performance is much harder to predict. Further, you have to be patient for growth, since market penetration (crossing the chasm) takes time and effort. A third important attribute is *knowledge exchange*, where the virtualization parameter received a low score. This means that the organization is reluctant in sharing information both internally and externally, where the latter could be critical, when looking for leading edge technology and/or business models.

The group of people (UA) that are supposed to develop and commercialize the new product, is engaged in different projects in TC Group today. All of these projects belongs to the category of incremental innovative products, which are evaluated using short term KPIs and ROIs. The organization values tied to this evaluation method are not suitable for disruptive innovation. It is paramount that another setup is established for this project, otherwise it will never attain traction, since organization members will be better of working for the existing business. One solution would be to establish an ambidextrous organization, where the group of people working on the new project/business is separated (ideally also physically) from the rest of the organization, as suggested by O'Reilly & Tushman, (2004).

Based on the market survey conducted in this study, it is quite clear that TC Groups current customers are conservative and reluctant towards new technology. This is probably caused by the fact that most audio consultants are using previously designed and now existing installations as templates for future designs, which makes it hard to introduce a new installation paradigm. Further, it was found that the current market for TC Group did not really appreciate the many new features, which are possible with a networked installation topology. These facts, along with a clear customer preference for traditional infrastructure, call for a solution that is simple to install and configure. Further, it would be advantageous if the solution was based on a low-voltage technology, meaning that conduit could be avoided, thus offering a possible reduction of the total price of installation. To satisfy the current market, the solution has to be daisy-chain-able and should be able to drive at least (and preferable more than) 20 loudspeakers on a 100 meters cable, which is slightly larger than the typical installation size.

Aiming for the existing market may not be the best choice for TC Group. It seems like this market belongs to the *late majority* or even the *laggards* (left side of Figure 3, page 15), making it very hard to convince these conservatives customers about the advantages of the new technology. With a new product that is easier to install and configure, and has relaxed requirements regarding safety issues (due to its reduced voltage), means that the product has the potential of being *market disruptive* (Christensen, 1997). With such a product, it will now be possible for other than dedicated audio integrators to carry out audio installations, since the product has relaxed requirement to the skills and certification of the installer. This type of product seems to be very well suited for being mounted by IT installers or electricians – if the product offers a simpler and more self-explanatory install procedure compared to the traditional 70V/100V. Ideally, it would have built-in self-test and self-configuration capabilities.

From the market survey, one of the clear indication for this new technology, was the desire of having a similar infrastructure as 70V/100V. In particular, the two-conductor cable type, Phoenix connectors and the capability of daisy chaining was of high importance. This fact, along with the properties of the identified solution candidates, points at the B4 solution, where power and bi-directional digital data is transported over traditional loudspeaker cables, similar to the system described by Liu, (2013). Compared to traditional 70V/100V technology, this gives the following advantages:

- Cabling may be phase-indifferent. The DC power can simply be rectified in the network nodes, and a proprietary data protocol may be implemented using similar technique as AES/EBU. This eases the job for the installer since he does not have to care about polarity when connecting wires.
- System may contain a self-testing and self-configuration feature, which again eases the job during installation.
- More than one audio channel per cable exists, meaning that a single daisy-chain may supply several zones with (different) audio material (simpler cable-layout).
- Each loudspeaker has an individual level control, which can be remotely controlled.
- Health of individual amplifiers and loudspeakers can be remotely monitored.
- Audio quality may be improved due to the absence of the audio degrading power transformer.
- System may comprise additional sensors or actuators on the network, sitting either as individual nodes or inside the loudspeaker units. Such sensors could be noise detectors, proximity sensors, light detectors or similar.

However, the 70V/100V technology is still superior when it comes to cabling length and network node (loudspeaker) robustness, which of course will be a limitation for some applications.

As part of the technology review, several critical factors were identified (see Table 12, page 103). One of these factors might pose a latent problem for TC Group regarding this new technology, since an uncertainty of the right to operate exists. Several patent applications have been filed close to the B4 solution. A recent patent application by Williams & Ware (2011) describes a technology covering the imagined B4 solution. As a countermeasure, TC Group has filed opposition against this application, with the hope that the patent authorities will invalidate it or at least reduce the claim coverage. As further measures, it is suggested that TC Group themselves file one or more patent application(s) to put themselves in a more favorable position, if any conflict may arise in the future. Further, these patents might also prevent competitors from entering the (hopefully) profitable business of powered digital loudspeaker networks.

To solve the tasks described above, several resources are required that are (seen from the author's perspective) currently missing for TC Group. Firstly, a market research group should be established, which can help in a better understanding of the "work to be done" by this product. This research group should look for other markets than the dedicated professional audio installer market and design business models suitable for these market. Secondly, preferred key partners, having early adopter characteristics, should be identified and addressed. These partners must be presented for the project and contribute to the concept development. Thirdly, product and technology champions should be identified and equipped with a suitable amount of decision power, which would enable them to drive the project forward. These persons have to ensure that the project stays on the top management radar and ensures that sufficient resources are allocated to the project, which is critical for being successful (O'Connor & Rice, 2013).

The above-described implications are a synthesis of the discussions and sub-conclusions belonging to chapter 7, chapter 8, and chapter 9. Special attention should be given to Table 2 (page 51), Table 6 (page 68) and Table 12 (page 103) in these chapters, which list critical factors (and suggested actions) identified for Organization and resources, Market, and Technology respectively.

The work done by O'Connor & Rice (2013) has been an excellent framework for this study, because of its extensive coverage. Judging from the findings in this study, the framework does, however, have room for improvement, since the model does not include the aspect of intellectual property, which for disruptive innovation is of particular importance. Maybe *Strategy* could be added as a fourth dimension to the model, covering intellectual property. This would be an interesting topic for future research. Further, it should be mentioned that the model is based on a retrospective analysis on multiple companies engaged in disruptive innovation. Beside this study, it would be very relevant to see other research, where the model is used proactively.

10.2 Limitations of the study

Since the thesis is a single case study, the results will only apply in the context they were observed, which for this study is the UA (TC Group install) and its current customer. This means that the conclusions drawn in that particular context cannot necessarily be inferred to other contexts. From this perspective, the study has the following limitations. First, the interviewees in the organization analysis were restricted to be middle and top management. Other ratings of the different organization attributes might have been found if a broader group of people had participated. Secondly, the organization analysis interview technique might also introduce a bias, since the interviewer presented his interpretation initially as a discussion starting point. Maybe the discussion had taken a different path if the starting point had had another origin. Thirdly, both the interviewees and questionnaire respondents in the market analysis belong to a group of people primarily representing audio consultants, maybe being over-represented by top managers. Since many of the questions and discussions were related to technical and hands-on matters, maybe that group of people ought to include a larger number of people representing the audio integrators. Finally, it should be mentioned that the technology review (and thus the establishment of solution candidates) is limited to the combination of knowledge available from the author and public sources.

10.3 Conclusion

This chapter describes the implications of the findings with the embracing research question: *How can TCG support the development and commercialization of a networked and distributed amplifier system for fixed loudspeaker installation, which is potentially disruptive?* Through the synthesis of findings and discussion in this study, this thesis provides an answer for the overall research question and the sub-questions pertaining hereto.

In general, several project barriers exist. According to the author's opinion, the most important issue is the apparent lack of will to explore and to take risks. A project that will/may involve new technology, new customers, new business models and in general require a new mindset for a large group of people (both internally and externally), implies increased risk. Further, it has to be expected that the product will have a slower market penetration compared to an incremental innovative product, assuming that the product will not be embraced by the late part of the market until the product has proven its worth in real-world applications. This means that the product has to enter the market slowly, via early adopters. Such a process fits badly with the short term ROI models used currently across all TC Group business units. On the other hand, a successful project, offering the market a cost-effective and feature-rich powered/digital loudspeaker network technology, may be a golden egg for TG Group.

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