EVALUATION OF ELECTRONICS RESEARCH IN FINLAND

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Preface

The Academy of Finland decided in Autumn 1995 to carry out an evaluation of electronics research in Finland. The evaluation, which continues the general evaluation practice of the Academy of Finland, was performed in 1996.

A local committee to plan and organize the assessment was set up by the Research Council of Natural Sciences and Engineering. Head of Electronics Laboratory Kari-Pekka Estola (Nokia Research Center) acted as Chairman of the committee and its members were Professor Olli Martio (University of Helsinki), Professor Pekka Neittaanmäki (University of Jyväskylä) and Scientific Secretary Mirja Vihma-Kaurinkoski (Academy of Finland) as secretary. Also the following people took part in planning the evaluation: Scientific Secretary Jukka Rantala (Academy of Finland), Project Manager Hannu Kemppainen (TEKES), M.Sc. Matti Hosia (Ministry of Education), Secretary General Patrik Floréen (Academy of Finland), and Research Director Jorma Hattula (Academy of Finland).

Because the thorough evaluation of all the groups working in areas related to electronics in Finland would be too large a task, it was decided to limit the evaluation to groups working in the areas of semiconductor processes, manufacturing and packaging, signal processing, design automation and circuits, power electronics, and applied electronics. Smaller groups were also left out from the assessment, even though they worked in the areas otherwise evaluated. After these criteria, altogether 28 research groups from three universities and the Technical Research Center of Finland (VTT) were included in the evaluation.

It was decided that the evaluation would be carried out by two foreign experts with the help of a Finnish project coordinator. Dr. John Barrett, National Microelectronics Research Centre, Cork, and Prof. Franco Maloberti, University of Pavia, were asked to carry out the assessment; and Dr. Jukka Rantala, Academy of Finland, was nominated to act as the project coordinator, accompanying the evaluators during the visits to the groups and editing the evaluation report, written by the evaluators.
2. Background Elements for Evaluation of Electronics Research

Electronics is widely regarded as a key discipline contributing to economic growth and international competitiveness. It is also accepted that for this growth to occur, research must be exploited to produce new product and services. The main benefits produced by research exploitation are:

- competitive advantage;
- increase of market share;
- higher growth rate.

These benefits are very important and if we want to contribute to a real and long term progress in our countries it is necessary to put a big emphasis on the development of electronics and related areas.

Nevertheless, very often it happens that the push for speeding-up exploitation and the need for shortening product-to-market times continuously shifts the focus of many scientific environments toward application driven activities. This seems, at first glance, a good thing but, instead, it is a mistake. The key point is that scientific research and superior education are essential for electronic development but they are not (and can not be) the direct instruments for achieving market competitiveness; instead, scientific research and superior education are the cultivation soil of innovation; therefore, it is fundamental to ensure and guarantee excellent and proper conditions to obtain this special cultivation soil. Moreover, research and superior education are very specific and critical: we can obtain them only with a proper mix of many factors. The most important of them are:

- Global view and international dimension.

Not long ago research activity was based on the particular. Scientists were mainly attracted by specific and unsolved problems. This attitude was mainly originated by the "distance", either cultural and temporal, between discoveries and their practical exploitation. But now, because of the increased speed in evolution, research activities, especially in electronics, have a direct impact on development. Therefore, research can not focus on the particular, but must consider globally all the problems necessary to produce health\(^1\): this means that research will be increasingly driven by a

\(^1\) The words "health" and "healthy" are used frequently in the description of research and technology in this report. This is not health in the medical sense; the word is used to encompass and describe the overall level of energy, cooperation, productivity and dissemination which are essential for a successful research environment. Just as the word
global vision and by long term strategies. Moreover, scientific research continuously expands its dimension over an international scale, and for this reason we have to account for the impacts on social, economic and ethical aspects.

- **Unfettered information flows.**
  Information flow is very important. We are in the information technology era and it is normal to say that information is relevant. But, for research in electronics we have a deeper and critical dependence of results on the information flow. Researchers and scientists are able to do what they do primarily because of the information available to them. Without information, research and development are just not possible.

So, information is important and we have to keep it as wide and free as possible; either at the informal level and at the formal level, where we have a conscious transfer of information, like going to conferences, subscribing to a magazine and submitting scientific papers, or belonging to a professional association. Secretiveness is not a good practice for scientists. When the information flow encounters some constraint, it means that research is changing its fundamental nature and, in some sense, positive or negative, it is becoming "development".

- **Balanced research-industry relationship.**
  The balance which must be achieved nationally and, on the smaller scale, within individual research groups, between research and teaching, between basic and applied research and between research and development is a balance which is currently being debated at the European and national levels. The research-industry relationship is a very controversial issue. A solid link with industry is vital for electronic researchers, it allows them to identify proper topics and to avoid grabbing in the dark. But, an exaggerated link with industry can be responsible for long term damage. Research push and market pull must be properly balanced. We need industry; without industry studies are merely speculative or "good for other" tasks. On the other hand, a strong dependence on industrial aims leads to a subordinate condition that generates a long term cultural impoverishment.

The link between research, invention, innovation and competitiveness is quite complex. The best approach is the following: researchers receive hints,
stimulus for ideas from the industry; these hints are able to trigger the technical curiosity that generates that brain processing which can transform problems into solutions, theories, methodologies. After that, the research products should be properly and quickly transferred to the productive world. The key feature of the approach is the freedom of research investigation; the link with industry is limited to the beginning and the end of the process.

• **Long term perspective and short term objectives.**
Activity in universities and research centres must have "basic targets". Research may not be tied to any immediate product development and must resist short term market pressure. Nevertheless, it is essential to ensure that the created knowledge is the proper one for health generation. This means that having in mind product opportunities must be one of the driving forces of research activity. Moreover, it is necessary to keep under control the path toward "basic" or long term targets. These goals are achieved with short term objectives defined within a long term perspective. Therefore, the key point is the formulation of a long term strategy that foresees by-products and short term measurable results.

• **Co-ordination between scientific organizations.**
Research activity is often supported by different national or transnational organizations; the need for a long term strategy reflects the necessity of a tight co-ordination of efforts. The strategies of various funding bodies should be properly harmonized and should point to a global development vision; moreover, the link between scientific organizations should be such to keep people informed, to empower technology awareness, to stimulate creativity, to favour technical competitiveness, and to produce better decisions.

• **Access to state-of-the-art technologies.**
Advanced research in electronics is mainly achieved with state-of-the-art technologies. It may be that with old technologies we can prove brilliant ideas; but essentially, without advanced technologies progress in electronics is not possible. Therefore, it is necessary to make high-tech available both for researchers and for the industry. The development and the maintenance of many modern technologies are extremely expensive and, often, they must be properly selected and, when necessary, their access can be ensured through transnational efforts. This is a very important political issue: proper arrangements to favour the access to state-of-the-art technologies are the key for achieving a state-of-the-art research.
• **Proper government legislation.**
In all advanced regions it has been established that investment in research correlates well with long term growth. The reverse has also been proven. Nevertheless, the financial market (especially when acting at an international level) looks for short term financial results and, despite far-sighted R&D managers, support to long term projects is difficult to obtain. Cost saved by cutting R&D improves profitability in the short term but tends to have an impact on future products and, thus, future profitability. These kinds of policies can be prevented with proper government legislation.

• **Customer feedback.**
The last factor favouring an health-producing research activity is customer feedback. Electronic designers know very well that any system can not work properly without feedback. In the specific case the feedback must come from people satisfaction, and industrial health and quality of life. The past decade was, for the industry, one of quality and customer service. Future decades must be the decades of quality and customer service for research and innovation.

The above discussion indicates a research policy and funding commitment pointing to:

• an organized approach for monitoring technological and scientific evolution
• good research and development organization to encourage information flow
• accurate knowledge of the nation’s own technological position and capabilities
• efficient organized information on markets and technological trends
5. Final Comments and Conclusions

The previous sections discussed the remarkable level and quality of the electronic research in Finland; only few groups are lagging behind and, in most cases, actions or plans for a quick recovery are in place. Scientific and technological resources are a real wealth for companies that produce high-tech goods. The excellent level of scientific achievements in Finland is reflected by a successful industrial environment capable to contribute significantly to the quality of life of present and future Finnish generations.

5.1 "Science and Technology" Life Cycle

The present status can be viewed in the frame of a "science and technology" life cycle. In the past two-three decades we had in Finland a start-up phase with an heavy cultural investment and production of know-how. The merit of this very successful phase goes to the many scientists, some of them have been met during the reviewing process, that dedicated with enthusiasm their intellectual talent for initiating and consolidating a proper cultural and scientific background. The second phase is the growth phase: the accumulated know-how and competence lead to a significant earning, which is the tangible case of many successful Finnish industries. The second phase is finishing now and Finland is entering the maturity phase. Hopefully, during the present years and in the near future, research will keep high its quantity and quality level; at the same time the industry will undergo a constant improvement of performances. The challenge is to remain in the mature phase and to avoid falling in the last phase of any life cycle: the decline.

With this view in mind, we can revisit the entire process of electronic research evaluation and glue together the many recommendations given in the previous sections. It is obvious that, in order to remain in the mature phase, a proper balance of fundamental studies, applied investigations and development works is necessary. The feeling acquired in the one week of full immersion passed discussing with many Finnish scientists is that, presently, we have a certain tilt toward short-term targets. This is mainly caused by two factors: 1) the rapid expansion of electronic industries that, pressed by development requests, continuously drains lot of human resources; 2) a significant emphasis on applied topics (and the consequent massive use of funding).
The request for short-term activities is motivated by four success factors for high technology companies; they have been identified in a MacKinsey study: successful companies market two to three times as many new products as their competitors; they incorporate two to three times more technological innovations into each new product; they introduce the products to the market two times faster than their competitors; finally, the geographical size of their market is double that of their competitors. We have verified that scientists assert that high-tech developments are important for high-tech companies, but researchers' reaction to a short-term push is dissimilar; it depends on the field of activity, maturity of scientists, and funds availability. In some cases, scientists commit a rigorous cultural independence and are sceptic on the real importance of industrial links; in other cases we have some balance between "basic" and "applied" activity, in other situations the "fund attraction" or the "fund scarcity" are so high that the activity becomes just development. The tendency to short term or long term activities depends also on the phase of the life cycle: in a start-up phase the industrial environment is not capable of providing inputs for researchers: it is the special proclivity of rare scientists that inspires the "good for progress" culture production. In the growth phase the attention is more on the technology transfer: the industry requires to convey know-how and the emphasis shift to applied research; in the mature phase the accent is on marketing and sale increase: what is needed is development.

Since high-tech products reach the peak of their own technological and scientific possibilities, they are inevitably surpassed by competing higher performance products. The same happens, more in general, for scientific achievements and their transformation in health. Therefore, the only way to remain for a long time in a global mature phase, is to favour a continuous generation of new "science and technology" life cycles. This means that, at the same time we need one or more start-up phases, one or more grown phases and many mature phases capable of compensating the negative effects of the decline phases. Therefore, we need, at the same time "good for progress" culture generation, studies on applied issues and technology transfer.

5.2 Motivation in Scientists and Researchers

Many psychologists have stressed the importance of motivation. Their conclusions have important impacts on discoveries for fundamental and applied electronics. Abraham Maslow developed an analysis grid that divides needs in five categories: physiological, safety, social/affiliation,
esteem/recognition and self-actualisation. For scientists and researchers the motivation mainly comes from the last two steps of the needs hierarchy. To satisfy the esteem/recognition needs it is necessary to live and operate in a wide scientific community (internationalisation recommendation) and to aspire to national and international recognition targets like scholarships, special grants, publications, citations, awards, and so on. The self-actualisation needs stems from a personal realisation: it is the need to achieve one's utter personal best in a chosen field of endeavour. In self-actualisation we can have competence-driven and achievement-driven persons. In the first category research equipment is less important than in the second one. Often, the lack of equipment pushes people toward the competence-driven category.

The elements gathered in the evaluation process help us in discussing how to better motivate people. A first relevant component is money. It is obviously important, needed to buy the necessity of life. The level of salaries for initial categories of Finnish researchers is low and should be improved; but the expectation of people is not high, just to bring wages to a reasonable level, the one that correspond to the presumed social value of scientific contributions. Moreover, it appears that at the upper level of the need hierarchy, when one is self-actualised, money in itself is no longer the source of motivation but, perhaps, can be the measure of achievements. Thus, a proper salary policy would help in increasing scientists' motivation. For this, it is worthwhile to remember that, for safety needs, the absolute amount of money is important; when money becomes a measure and not a necessity, the relative amount of money is the important issue. In addition, money for travel and equipments is valuable and must be properly increased. Motivation comes from possibilities for improvement; if they do not exist (as in the case of insufficient equipments or in case of low possibility of foreign contacts), the desire to keep studying and researching vanishes.

Feedback is another element that sustains motivation; the large majority of Finnish research groups considered very positively the present evaluation process and they put lot of effort in showing achievements. The attention and the accuracy that we have found in the visits to research group is a measure of the evaluation importance in itself. Nevertheless, mechanisms for performance-relevant feedback are necessary. Merit-compensation instruments are needed, they can be special grants for new laboratory start-up, young investigator awards, and other. By contrast, privileged situations that don't clearly reflect a real and measurable added value produce negative effects on the motivation of entire scientific environments.
5.3 Attitude Toward Science and Research

The basic element for healthy research is the attitude of people to science and investigation. One possible goal of the Evaluation of Electronic Research in Finland is to comment on the observed status, to discuss a possible dynamic evolution and to suggest, when necessary, correcting actions.

Scientists use different approaches and styles. We can distinguish between five classes of researchers and characterise them using psychological traits; we have:

- **Creative genius**, capable of high quality back-processing that suddenly blossoms in the so called "flashes of genius". A creative genius continuously applies a reflection by A. G. Bell that says: 'Leave the beaten track occasionally, and dive into the wood. You will be certain to find something that you have never seen before'.
- **Forerunner**, able to precursor scientific and cultural evolution, often he is a respected opinion leader being more careful than a creative genius.
- **Innovator** enjoys trying new technical solutions, uses and designs modern tools for facilitating research progress.
- **Follower** that goes along with the majority, sometimes later, and is fascinated by glamorous theme programs.
- **Traditionalist** is conservative, doesn't like risks and prefers security. His guideline approach is the quiet life.

The ideal population distribution of scientists should be centered on innovators. They are the vehicle for ensuring a proper technology transfer essential for a growth phase and for the high level needs of the maturity phase. Nevertheless, to a much more limited extent, creative geniuses and forerunners are vital for long (or forever) mature phases. By contrast, the followers and traditionalists are negative; their number should be kept at a level as low as possible and certainly below the physiological threshold.

Using the above classification, we could state that in Finland the situation for electronic disciplines is very good. The number of people in the last two categories is extremely small and will become, in perspective, much smaller. We have a good percentage of innovators, but we also have people in the first two categories; however, their average age is slightly higher than the optimum. Of course, forerunners accumulate knowledge and are able to build their reputation in time; thus, their age is normally around 50; but in Finland, especially in perspective, the situation is probably critical. The status for the
creative genius category seems to be similar to the one of forerunners. A clear estimation is not easy because of the relatively small scientists' population. However, a need is felt for proper attention to the problem. Creativity is very important for progress. Boundary condition and the necessary time for favouring the five phases of any creative process are essential: preparation, frustration, incubation, insight and working out.

Instead, modern research methodologies foresee a wide use of computer resources. This is imposed by the increasing complexity of systems that, otherwise, could not be managed. Nevertheless, the massive use of tools with a huge processing capability and efficient user interfaces limit the time for thinking and this is dangerous for enhancing creativity. Moreover, the increasing focus on applied issues, the strong request of time-to-market and problems specified too precisely, hinder that kind of intellectual processing that brings images and ideas into existence in our mind and allows us to create.

The problem of fading creativity, especially in young generations, must be carefully considered. Proper directions to research topics and a strong recognition to the few creative studies will alleviate the problem. Moreover, it is recommended to preserve and expand excellent instruments used by the Academy of Finland: Academy Professorship, Senior and Junior Fellowship and associated research positions.

5.4 Internationalisation and European research

We have seen that the internationalisation of research is a fundamental need. This necessity was generally agreed upon during the visit to research groups. However, the level of contacts and the trans-national co-operations are low and restricted to a small fraction of the Finnish research groups.

A few years ago (1989), answering to specific industrial needs an Eureka programme, Jessi (Joint European Submicron Program), was launched. That action connected the major European semiconductor industries and a small number of universities and research centres. The excellent organisation and a strong commitment made the project very successful. However, the Jessi project or its continuation, Medea, will not be capable of properly answering the internationalisation need of Finnish researchers: the goals and strategies of this Eureka project are formulated outside governments' control. This is a more general issue: Eureka frameworks can facilitate European interactions only with proper co-ordination and management.
A significant help to the discussed point would come by enhancing European contacts; this would be facilitated by a more intensive participation to European projects. Unfortunately, the opinion of a number of researchers is a bit critical; scientists feel that projects founded by the European Union are presently losing most of their fundamental nature and they are undergoing a transformation into mere support of conventional industrial products. Using the life cycle discussed above, we can say that Finnish researchers (and ourselves) consider the European supported research near the decline phase.

The implementation of the point J of the recommendations given in section 4.2 will require proper governmental actions capable of favouring renovations and a new life cycle in the European supported programmes for research and development.

5.5 A body for Strategies for Electronic Research and Education

Since science and technology are becoming important factors in the competition between nations, countries are putting increasing attention on science and technology. Strategies for generating, exploiting and protecting advanced knowledge are key issues in many highly evolved countries. Considering research and development as a whole, about 50% of research expenditures in seven major countries (US., Japan, Germany, France, the UK., Italy and Sweden) for the period 1980-1989 came from industry with significantly large percentages in Japan and quite high percentages in Germany and Sweden. Universities are responsible for about 10-30% of all research conducted. The rest is done in public or private research centres. If we consider Japan, the main requirement of the university sector has been to produce highly educated individuals suitable for use in industry rather than research output. The Japanese industry’s share in national R&D expenditures is about 80%, and of the 20% of the government's input only 9% goes to universities. Thus, in the recent past, advanced research was mainly conducted in industrial environments. This ineffective trend is changing now despite the push of some companies in market driven directions.

Any possible strategy for long term health points in the direction of a balanced contribution to science progress and its exploitation; a tight control of policies and actions from a public body is recommended. Feedback and directions from the productive environment is also essential, thus conducting to synergetic benefits. Another important issue concerns the allocation of
resources. It is evident that high-tech industries must be globally healthy and they should generate profits. The use of public money must not subsidise industrial activities but must be inspired on targets that the entire society wishes to reach. Moreover, an unnecessary financial sustenance of actions based on entrepreneurship reduce the motivation for risk. Therefore, as a rule of thumb, public support should be reversal proportional to the evolutionary level in the "life cycle". The issue is, of course, controversial and requires a thoughtful analysis.

The above points disclose the need for a specific body for the conception and the implementation of strategies for electronic research and education. An example (but not a strict model) is the Japanese Ministry of International Trade and Industry (MITI) responsible for the Japanese industrial technology policy. As MITI is doing for the industrial policy, the proposed body should be able to stimulate research topics and educational policies very effectively with a small budget. Policies must not be just formulated by the government but also through open discussion of councils, such as the Academy of Finland and TEKES. The discussions should involve representatives from an additional variety of sources, such as finance, journalism, small business, consumers, general workers and local public authorities. The aim is the solution of national problems such as employment, energy, pollution.

Within the strategies formulated by the new body many of the recommendation given in the previous section should find their execution. Moreover we suggest: situation analysis, target definition, simplification of procedures, and monitoring programs. Evaluation and monitoring are essential for the efforts synchronisation and has become necessary due to the fast changing environment of high technology. Bureaucratic constraints must be minimised since they are against high-tech scientific development.