Electrical Engineering 1999-2004

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FOREWORD

This report is part of the periodic quality assessment of all publicly financed research in the Netherlands. The purpose of this report is to present a reliable picture of the results of the research submitted for this review and to give feedback to the internal quality assessment of the organisations concerned.

This review was initiated and commissioned by the Boards of Delft University of Technology, Eindhoven University of Technology and Twente University.

QANU aims to ensure independent, unbiased, critically constructive assessments using identical quality criteria as far as possible, while taking specific circumstances into account.

We expect the judgements and recommendations will be taken into careful consideration by the researchers, the research directors and the Boards of their Department or Faculty, and by the Boards of the three universities concerned.

We thank the Chairman and Members of the Review Committee for their willingness to participate in this assessment and for the dedication with which they carried out this task.

Dr. Jan G.F. Veldhuis
Chairman of the QANU-Board

Mr. Chris Peels
QANU-Director

PREFACE

This report describes the results of the evaluation of the research in Electrical Engineering carried out in the Netherlands during the six year period of 1999-2004 and contains some observations and views on the cooperation between the departments or faculties in this field. The evaluation was based on the self-assessment reports prepared by the units under review in accordance with the *Standard Evaluation Protocol* (SEP) and interviews that took place during site visits to Delft University of Technology, Eindhoven University of Technology and University of Twente in the week of 30 October till 5 November 2005. In addition the Committee had received a Bibliometric Study of Academic Electrical Engineering Research in the Netherlands 1998-2004 made by CWTS, Leiden University.

The Committee would like to thank the three universities for their efforts in preparing the documentation produced for this evaluation. The self-assessment reports and supplementary material proved to be essential for an objective evaluation of the 37 research programmes. Moreover the SWOT analyses (Strength, Weaknesses, Opportunities, Threats) and the action plans of the 37 programmes were very useful for understanding the key issues involved in the programmes, and for making recommendations wherever these were considered to be needed.

Preliminary evaluations of each programme were prepared independently by two members of the Committee in the Fall of 2005. These evaluations defined the initial state for the evaluation process. During the three site visits, the Committee met with the directors of each of the research programmes and other key staff members, who were interviewed and given an opportunity to present their views and plans for their programmes. In addition, the Committee met with the Rectors of the three universities and representatives of the faculties (usually the Dean and the Research Director). Opportunities were also provided for interaction with representative groups of PhD students at each university. These discussions were most informative and certainly very valuable for the maturation of the opinions within the Committee towards a final state. The Committee appreciates the open discussions with the various representatives on their views, impressions, and concerns.

The Committee gratefully acknowledges the editorial, administrative and organizational support and guidance of Mr Roel Bennink of the QANU. With his extensive experience in research evaluations he has coached the Committee to efficient and productive interactions and to a balanced report.

As chair of the Committee it is a great pleasure to thank wholeheartedly the Committee members for their commitment to the evaluation process and for their thoughtful contributions to this report. I deeply appreciate their willingness to spend time and effort and am pleased to mention that this report reflects the consensus opinions of the Committee.

Joos Vandewalle
Chairman

1. Introduction

1.1. Scope and context of this review

This assessment covers the research in Electrical Engineering (EE) at Delft University of Technology, Eindhoven University of Technology and Twente University in the period 1999-2004. The assessment was commissioned by the Boards of these three universities and organised by QANU.
The self studies submitted by the Departments covered the period 1999-2004, but during the site visits on 31 October till 5 November 2005 updates were provided to the Committee. The Committee has taken all information into account as much as possible.
This assessment is part of the assessment system for all Dutch university research, as organised by the universities in the Netherlands and follows the *Standard Evaluation Protocol 2003-2009 for Public Research Organisations (SEP).*
The aims of the assessment system are:

- improvement of the quality of research through an assessment carried out according to international standards of quality and relevance;
- improvement of research management and leadership;
- accountability to higher levels of the research organisations and funding agencies, government, and society.

The Committee followed the specific requirements of the Discipline Protocol (see Appendix B), prepared by the institutes involved.

The Committee assessed 37 research programmes:

- Delft University of Technology (TUD), Faculty of Electrical Engineering, Mathematics and Computer Science: 14 programmes;
- Eindhoven University of Technology (TUE), Department of Electrical Engineering: 10 programmes;
- University of Twente, Enschede (UT), Faculty of Electrical Engineering, Computer Science and Mathematics: 13 programmes.

The Committee received the following three additional requests for views and opinions:

- to express reflections and recommendations on **critical success factors** for improvements of the research in Electrical Engineering at the three Technical Universities;
- to evaluate the **PhD educational programmes**, their selection procedures and guidance, and the success rates and productivity of their students and to compare these with the international standards;
- to express views on the strengths, weaknesses, opportunities and threats with respect to the **cooperation between the three Faculties of Electrical Engineering**, and to make recommendations for extending the collaboration.

The observations, considerations and recommendations of the Committee on these three additional points were sent to the Boards of the three universities in a confidential management letter. The time schedule of the Committee did not allow for extensive discussions about these topics, so the remarks on these topics should be considered as attention points and recommendations for the management teams.

1.2. The Review Committee

The Review Committee was appointed in September 2005 and consisted of:

- Joos Vandewalle, Katholieke Universiteit Leuven, chairman;
- Piet Demeester, University of Gent;
- Klaus Fröhlich, ETH Zürich;
- Josef A. Nossek, Technische Universität München;
- Carel van der Poel, Philips Semiconductors;
- Willy Sansen, Katholieke Universiteit Leuven;
- Kristian Stubkjaer, Technical University of Denmark;
- Eric van Utteren, Programme for Research in Embedded Systems and Software (PROGRESS).

A short curriculum vitae of each of the members is included in Appendix A. Roel Bennink of the QANU bureau was appointed as secretary of the Review Committee.

Independence
All members of the Committee signed a declaration and disclosure form to safeguard that:

- the panel members judge without bias, personal preference or personal interest, and
- the judgement is made without undue influence from the institute, the programme or other stakeholders.

Any existing professional relationships between Committee members and programmes under review were reported and discussed in the Committee meeting. The Committee concluded that there was no risk in terms of bias or undue influence.

1.3. Data provided to the Committee

The Review Committee has received detailed self-evaluation reports provided by the institutes. For each programme, five key publications were specified in the report and copies of these publications were provided to the Committee.
The documentation included all the information required by the Protocol and the Discipline protocol. The SWOT analyses in the self-evaluations were clear, candid and pertinent in most cases and proved to be very valuable for the evaluation and recommendation work of the Committee. Quite often the Committee could confirm the findings of the programmes in their SWOT analyses, and could endorse the adjusted strategy or actions taken by the staff. Only in some cases the SWOT analyses were formulated rather generically and placed too much emphasis on external factors rather than on internal causes.
A bibliometric analysis produced by the Leiden University Centre for Science and Technology Studies (CWTS) was provided to the Committee in October 2005. This study was commissioned by the three participating universities in order to provide insight in the publication output and international impact of the Electrical Engineering research programmes that are considered in this review. The Committee has used the bibliometric analysis as point of reference in the interviews and in the assessments.
The Bibliometric Study provided valuable insight on the publication output and the international impact of the research on Electrical Engineering using the citation indices databases

(CI). The authors of this study have done a careful analysis of the output and impact indicators of the 37 programmes. Several important indicators are produced for each programme in this review:

- P: the number of CI papers;
- C: the number of citations in CI journals to these papers (excluding self-citations);
- CPP=C/P: the number of citations per paper;
- CPP/FCSm: the impact of the papers of a research programme compared to the average citation rate (FCSm) of the journal set of that research programme.

The use of this ratio CPP/FCSm makes a fair comparison possible between groups that have traditionally different citation culture. It is a well-known fact that lower citation counts are obtained for programmes that are close to technology or industrial applications, while high citation counts are obtained for programmes close to physics or medicine. A value CPP/FCSm = 1 implies that the papers produced in this programme have an average impact that is equal to that of similar groups in the world. A value CPP/FCSm substantially larger than 1 on the other hand implies that the papers of the programme have on average substantially more impact than the counterpart programmes in the world.

The Bibliometric Study contains a number of caveats against deriving the wrong conclusions from the material. First of all the authors have analysed that the CI database only covers about 59% of the citations that are made in Electrical Engineering. This coverage varies greatly from 19% till 85% over the 37 programmes. For programmes with a small number of CI publications and low rates of CI coverage (roughly 30% or less CI coverage) the use of this CI database is considered to be at least problematic if not impossible. The study comes to the conclusion that the analysis of the reference behaviour of Dutch Electrical Engineering researchers suggests that bibliometric analysis solely based on journal output is not necessarily the most suitable method of impact measurement. But since no bibliometric system exists for other types of scientific communication (like conference proceedings, patents, etc.), the current study offers at least some insight in the bibliometric representation of the groups in the field. The overall analyses show that the Dutch academic Electrical Engineering community is publishing more and more scientific journal papers. The impact connnected with this output varies, and is in terms of the field normalised impact score roughly at a world average level.

The Committee is fully aware of the differences in research dynamics (conferences versus journals, CI journals versus other journals) and publication traditions in the different programmes. Hence, the Committee agrees with the authors of the Bibliometric Study that bibliometric indicators cannot be interpreted properly without background knowledge of both the research programmes that are evaluated and the subfields in which the researchers are active. For that reason, the productivity evaluations made by the Committee are not only based on the Bibliometric Study, but also on considerations that are specific to the research programme.

Concerning the cooperation between the three Technical Universities it is important to mention that the three research reports of the three TU's contained an identical section of three pages entitled *Joint note of the Deans of the Faculties of Electrical Engineering, Mathematics, and Computer Science of the three Technical Universities regarding the cooperation on the research in Electrical Engineering and Information and Communication Technology* (December 2003). For the cooperation on electrical energy between TU Delft and TU Eindhoven a joint one page note on the national cooperation on the Energy Academy was also included.

Both these documents were valuable elements for the discussions of the Committee on the plans and prospects for the future cooperation between the three TU's.

1.4. Procedures followed by the Committee

The Committee proceeded according to the *Standard Evaluation Protocol* and the Discipline Protocol (see Appendix B). The assessments are based on the documentation provided by the institute, the key publications of each programme, the interviews and the tours of the facilities. The interviews took place during the site visit on 31 October till 5 November 2005. Time was provided for visits to the facilities and for poster presentations and discussions with PhD students.

The Committee members have all read the Self Evaluation Reports and other documents provided. The first and the second reviewers of each programme independently gave a preliminary assessment, using the form provided in the Protocol (see Appendix C). These preliminary assessments were compiled and sent to the members.
The preliminary assessments were discussed in the Committee meeting on 30 October 2005, preceding the site visits. For each programme the preliminary scores were determined in advance and a number of comments and questions was decided upon. The Committee also agreed upon procedural matters and aspects of the assessment as described in the following paragraphs.

At the start of the site visit the Committee had the opportunity to meet with the rectors of Delft University of Technology, Eindhoven University of Technology and Twente University, who stressed the importance of the research review and the views of the Committee on the 3TU[1] cooperation.

The interviews with the management and programme directors took place during the site visits. For all interviews and discussions the Committee was not split up. Only the tours of the facilities and the interviews with the PhD students were conducted individually or in separate groups where appropriate.
After the interviews, the Committee discussed the scores and comments for each programme and determined the final assessment.

At the end of the site visits the main findings of the Committee were reported in a short presentation by the chairman. A draft version of the report was sent to the institutes in January 2006 for factual corrections and comments. The comments have led to a number of clarifications and changes in the text. The report was subsequently submitted to the Boards of the Universities.

[1] In order to create a single Federative Technical University of the Netherlands by 2010, Delft University of Technology, Eindhoven University of Technology and the University of Twente will be co-ordinating their research, combining their educational programmes and enhancing their activities in the field of knowledge valorisation. This is referred to as the '3TU cooperation' .

1.5. Aspects and Assessment Scale

The Protocol requires the Review Committee to assess the research on four main aspects, namely:

- Quality;
- Productivity;
- Relevance;
- Viability.

The elements taken into account in the assessment are illustrated by the assessment form used by the Committee (see Appendix C).

The Committee points out that the score for Productivity is not completely separate from the score for Quality, because the Committee did not choose to use a purely numerical calculation as an indicator. Wherever possible on the basis of the data provided, the Committee took into account the impact and prominence of the journals and publishers.
The meaning of each score is as follows (SEP page 25):

Excellent • work is at the forefront internationally • work will most likely have an important and substantial impact in the field • institute is considered an international leader	5
Very good • work is internationally competitive, nationally at the forefront in the field • work is expected to make a significant contribution • institute is considered an international player, national leader	4
Good • work is competitive at national level • work will probably make a valuable contribution in the international field • institute is considered internationally visible and a national player	3
Satisfactory • work is solid but not exciting, will add to our understanding and is in principle worthy of support • work is considered of less priority than work in the above categories • institute is nationally visible	2
Unsatisfactory • work is neither solid nor exciting, flawed in the scientific and or technical approach, repetitions of other work, etc. • work not worthy of pursuing	1

Note: The ratings specified in the *Standard Evaluation Protocol* differ from the ratings specified in the VSNU-Protocol that was valid until 2003. From 2003 on a new rating 'Very good' is added between 'Excellent' and 'Good', and the rating 'Poor' is abandoned.
When comparing scores with 'old' scores this must be taken into account!

VSNU 1992-2002		SEP 2003-2009	
5	Excellent	Excellent	5
4	Good	Very good	4
3	Satisfactory	Good	3
2	Unsatisfactory	Satisfactory	2
1	Poor	Unsatisfactory	1

2. General findings and recommendations

In general the Committee is impressed by the quality and the quantity of the research in Electrical Engineering in the Netherlands. It is fair to say that the research makes substantial contributions to the field both in terms of new concepts and methodologies, as in terms of new applications, which are more than proportional to the size of the country.

2.1. General evolution of the field of Electrical Engineering

The field of Electrical Engineering is not perceived by the general public and the youngsters as a very visible and dominant field, even though the products, the services and the contributions of Electrical Engineering are more and more pervasive and prominently present. This blind spot in the public perception is due to the fact that the electrical engineering aspects of many consumer products are hidden from the user, by user friendly designs or by integration into larger systems (such as a car). Another reason is the fact that the electrical power supply is considered an obvious commodity whose dominant role only becomes apparent when a power failure occurs.
The professional organization of the electrical engineers, the Institute of Electrical and Electronics Engineers (IEEE), is one of the largest professional organizations worldwide with about 365.000 members in 150 countries. It is fully aware of this lack of visibility and has set up several initiatives in order to clarifiy the role of Electrical Engineering, such as a Virtual Museum webpage http://www.ieee-virtual-museum.org/ where one can imagine what life would be without telephone, TVs, computers, lasers, the internet.
The Committee considers this lack of visibility an important element in the limited attention and appreciation of the research in Electrical Engineering by the general public, the limited attractivity to high school children and the media.

Since its origin, about 100 years ago, the field of Electrical Engineering has undergone quite a number of gradual as well as abrupt changes. The period under review, 1999-2004, has not been an exception in that respect.

First of all and probably the most dominant factor of change is Moore's law, which states that the computer processing power doubles about every eighteen months. This implies that at the end of the review period the computing power available in chips, computers and various devices is sixteen times larger than at the beginning. This increase in computing power provides new opportunities to design and build new systems or to improve the quality, capacity, intelligence or autonomy of systems. This progress of the chip technology is not achieved without efforts, but an important ingredient of the research in Electrical Engineering is to deliver this progress in computing power along a projected roadmap of IC technology.

The most visible change during the past six years in EE is undoubtedly the collapse of the internet bubble in 2000. While many pessimists thought that the whole ICT field was only hype, it is fair to say that this field is now in more stable waters. This is illustrated by the fact that over the last five years, the broadband access penetration increased by more than a factor 10, reaching today a total of about 200 million lines worldwide. ICT has clear prospects to help society with many of its major problems such as the aging community, traffic congestion, health care, communication, sustainable electrical energy supply and its reliable distribution, disaster prevention, surveillance, prevention of terrorist attacks.

A further fact to be considered is that in the past decades several branches of the electricity and electronics industry have gradually decreased their long-term research efforts. Since such research remains essential for economic growth, this places a special responsibility on universities and public research institutes.
In recent years the globalization of the economy and the explosive expansion of the industrial activity in China has considerably reduced the manufacturing activity of electrical, electronics, consumer and telecom products in Western Europe. It remains to be seen how much this will also affect the design and engineering of these products. These evolutions will continuously require considerable attention.

Finally it must be mentioned that in the past six years the liberalization of the electricity market has had an important effect on the revitalization of the research interest in electrical energy.

Within this context the international research in electrical engineering is presently in rather stable conditions. Typically, the research is organized in teams of eight to twenty researchers with a permanent staff centred around common equipment and/or methodologies. This equipment and infrastructure can be cleanroom IC technology, test equipment, microwave and telecommunication equipment, high voltage equipment, electrical network simulation, etc. The common methodologies can include applied physics, chemistry, mathematics, or material science, or combinations of these in nano. Often the research can also be application driven. In fact, while in our Western European society a large part of the population is employed in services, gradually one can perceive that some research in Electrical Engineering also shifts towards services such as retail, logistics, financial, transportation, etc.

Quite often the research work is centred around complex systems. In fact EE has produced over the years many of the most complex systems made by mankind, such as the electric power grid, the telephone network, complex chips and the like. Typically the research involves the design, control, manipulation, and optimization of such complex systems under varying circumstances. An important aspect of the applied research in EE is that the typical lifecycle of consumer products in ICT is rather short (three to five years), and hence the time to market is quite critical.

2.2. Evolution of Electrical Engineering research in the Netherlands

It is fair to say that the Netherlands currently has an extensive electrical engineering community. The industrial activities in electrical engineering with many smaller and larger companies and with a dominant role of Philips have been a major stimulating force for the research and teaching in Electrical Engineering. During the period under review many structural changes have taken place in the research and teaching at the three universities for good reasons, although not always in the same direction. We can mention here the introduction of the bachelor-master educational system, the faculty and departement reorganization in Delft and Twente, the introduction of research institutes, and several regroupings of programmes within the TU's. Especially in Twente the impact of the Institutes appears to be strong and valuable. Obviously, a steady state has not been reached and perhaps will never be reached in view of the many evolutions in the landscape. With this in mind, the Committee will be reluctant to recommend additional structural changes, unless there is a clear justification.

The Committee has encountered much concern at the three TU's about the **decreasing number of first year students** in Electrical Engineering in the Netherlands. The total influx

is now around 240 new bachelor students per year. Clearly, a decrease in the number of students in Electrical Engineering is a general trend in Western Europe, but the extent of the decrease is certainly more severe in the Netherlands. Apparently there is no shift of interest to neighbouring disciplines, since the reductions are equally severe in neighbouring fields like mathematics and computer science. At a more global level the number of engineering students has decreased in Germany by one third since 1995. In the US the number of students in science and engineering is about 5% of the total number of university students while in China this is 42%.
Many actions have been taken by the three TU's, but the trend has not been reversed. The Committee shares the concern about this problem and recommends even more pronounced strong national concerted action and an intense cooperation between the three TU's on this issue. The three EE's should, in coordination with other efforts from universities and industry (for example JetNet, http://www.jet-net.nl/intro.html), contribute by taking a leading role and be measured and rewarded with the results. This is a long term activity that is essential to the future of the TU's and a consistent effort is advised.
It seems necessary to focus on the early stages of secondary education, where the range of choices with sufficient emphasis on mathematics and physics is already being limited. It is recommended to develop initiatives that involve enthusiastic (high) school teachers and students into attractive introduction programmes. Good examples are found at each TU. Given the major impact of the EE in society, this should be relatively easy to expand on. Cross learning and linkage with other Dutch activities could further strengthen the development. Special attention should be devoted to attract female students to EE. There is no reason at the level of the study programme or the job opportunities why Electrical Engineering should be less attractive to female students than fields like medicine or law.
The recruitment of master students and PhD students is also affected by this reduction in bachelor students in EE. The Committee considers the situation for these students as fragile but reasonably under control, because the TU's have taken actions to attract master and PhD students from abroad, often from China or Eastern Europe. The financial support for the PhD students is considered to be adequate and at an international level comparable to neighbouring countries. From the point of view of the economy in the Netherlands, it would be preferable if the majority of the PhD students could continue their career in this country.

2.3. General findings

The Committee has ascertained that the current status of the research in Electrical Engineering at the three TU's is very good, but there are some points of concern or attention. The Committee was happy to see that the staff and the management at the three EE departments are fully aware of the evolutions that are happening in the world and in the field, and are already taking good actions on many of these issues of concern or attention. But the Committee feels that some recommendations can help to make these actions more effective.
In general the visited Electrical Engineering faculties/departments at the three technical universities have enthusiastic and self-motivated groups with good to excellent research programmes with extensive links to the industry and high-level output. The Committee was pleased to find some excellent programmes at all three TU's that are top players in the world and produce well-cited publications in the best journals and have a convincing comprehensive strategy for further growth and contributions. Besides that, there are many strong programmes that make important well-recognized and appreciated contributions at the international level. A few programmes may need some coaching, reorientation of the research topics or some extra impetus with new staff or some structural changes.

In general there are no 'Unsatisfactory' scores. On the other hand the Committee has been cautious with the score 'Excellent', which is reserved for internationally leading groups with a substantial impact in their field. Among the 148 scores there are 17 Excellent scores and 68 Very good scores.

The five-point scale for the four categories of Quality, Productivity, Relevance and Viability gives a potential maximum of 20 points per programme. The Committee has scored four programmes with 18 points and three programmes with 17 points. The average was 14,4/20. The average score for the four items is: Quality 3,8, Productivity 3,4, Relevance 3,9 and Viability 3,5. So the average score for most items is close to a 'Very Good' (4). On the whole, the Committee considers this to be a very good result. The individual programme evaluations contain detailed assessments and recommendations (see Section 3).

Regarding the general budgetary situation of the research in the Netherlands, it is noticeable that in recent years important investments in infrastructure have been made, thanks to the wise decision of the government to invest income from natural resources in research. Of course as in the neighboring countries in the Netherlands still more efforts are needed in order to meet the Lisbon goals. Also, the balance between the direct funding from the government, the competitive funding from NWO and STW and the contracts with industry and ministeries has been shifting towards the latter two categories, but is still considered to be healthy in general. The financial situations for the three EE's differ, with the TUE being relatively healthy, the other two somewhat less so. However, it must be noted that the different organisational structures and the limited comparability of the data make a full assessment of the financial situation difficult in the course of this review.

The Committee advises to develop ways to assess the financial performances in a more accessable and comparable way. As an example: from the data of the University of Twente it appears that the yearly expenditure and funding budgets have increased between 1999 and 2004 with about 80%, whereas the yearly output (academic publications) has increased by 35%. For the TU Eindhoven these numbers amount to +40% and +35% respectively, and for the TU Delft no data were available for the years 1999 and 2000. The reasons behind the increase of the budget at the University of Twente lie in changes in the financial policy during the review period, such as the research groups having to pay for square meters and ICT. Part is due to an increase of staff on externally funded budgets, mainly PhD students whose productivity takes some years to build up.

Research Input

Based on the self-assessment reports, the Committee calculates that in 2004 the three universities in this review spent 58 million Euros on personnel and other costs for research in electrical engineering. This investment involved 440 FTE dedicated exclusively to research.
The total number of research FTE for the entire six-year period under review, 1999-2004, is 2265 FTE. The amount of money spent on research in electrical engineering in the six-year period is approximately 300 million Euros.[2]

The figure of 440 FTE in 2004 represents an increase of 35% over the review period. Much of the increase was the result of increased funding from external sources (NWO, STW, and others) and has benefited primarily junior researchers in temporary positions. At the same time, the

[2] This is not an exact figure, because TUD has not provided financial data for the years 1999 and 2000.

Committee noted a decrease in the number of senior academic staff. This means that many programmes have to operate under more lean staffing conditions.

Research Output
The Committee counted a total of 339 finished PhD dissertations during this same period (130 at TU Delft, 105 at TU Eindhoven and 104 at University of Twente), or approximately 56 per year. Such PhD qualifications are considered to be proof of proficiency in performing the whole research trajectory from conception at the abstract/fundamental level or the industrial application or society level up to the evaluation of the research results and the publication in international journals or presenting it at international conferences.

There is a slight increase in the number of PhD theses over the period, but the Committee feels that a further increase of this figure is justified in view of the evolution of the field and the capacity of the staff and in view of the overall situation of EE in Europe. Such an increase is in fact projected by many of the programmes.

The standard mechanism for disseminating the results of academic research in Electrical Engineering is either through publications in peer-reviewed journals or through presentations at conferences and workshops. As mentioned before, in certain sub-disciplines such as IC design, computer engineering, etc., it is more customary and more efficient for the interaction with industry to contribute to conference proceedings. Also the degree to which such papers are subject to peer review varies considerably. The Committee counted a total of 2014 international journal papers published during the period of six years (770 at TU Delft, 621 at TU Eindhoven and 623 at University of Twente). So in terms of research output the three EE departments are more or less equal, with a slightly larger volume for TU Delft.

Quality of the Research
Even more important than the quantity is the quality of the research. Here the Committee based its evaluation on the programme descriptions and publication lists, on the key publications supplied with the self-assessment reports and on the reputation of the journals and conferences in which the remaining publications had appeared. The coherence of the programme is an important aspect, together with the prominence of the director and the group as a whole.
The Committee's judgment is reflected in the ratings given for quality of the various programmes. On the average a score of 3,8 was given, with the higher average score of 4,1 for TU Eindhoven, and similar average scores for TU Delft (3,6) and University of Twente (3,7).
We reiterate that care should be taken in making comparisons between the current assessments and those in the 2000 report, because the current Committee had different evaluators, and the scores have a different meaning (see Section 1.5).

On the whole, the Committee judges the quality of the research in Electrical Engineering in the Netherlands to be very good. The best work is at the level of the best research done internationally.

Relevance of the Research
Since the field of Electrical Engineering is a research field with considerable technological, industrial and social relevance, this has been an important element in the evaluation. Nevertheless the importance of the relevance may vary depending on the positioning of the programme on the more fundamental or the more applied side of the spectrum, as expressed in the mission statement. Also the research theme of a programme and the approach taken by its staff can

vary on a scale that ranges from very narrowly targeted and hence often risky, to very generic and hence often lacking cohesion. There are also various ways for the research programmes to interact with industry and society by industrial projects and designs, consulting, patent applications, stimulating spin-offs, contributing to standards, etc. The Committee has based its scoring on the relevance of the research topics tackled, on the effectiveness of the approach taken by the staff to address and solve relevant problems, on the interaction with (future) users (government, agencies, industry, society and others) and on the success in obtaining funding from secondary and tertiary sources. The average score for University of Twente on this aspect is 3,5, for TU Delft 3,9 and for TU Eindhoven 4,3.

Viability of the Research Programmes (prospects)
Even though there are many evolutions in the field, the Committee considers that the major areas and programmes of Electrical Engineering research have stable prospects for the future. However some research groups are considered to have an insecure future, because of retirements or lack of internal vision for the future. Of course the Committee did not score, but only commented in words on the prospects of the programmes that the management has already decided to stop or dismantle.

Research Schools
Much research in Electrical Engineering is carried out under the aegis of research schools. In addition, many research programmes are affiliated with research schools focusing on various disciplines. These research schools were organized to exchange information at the PhD level as well as at the staff level among the TU's. The schools provide research and training opportunities to PhD students and, in general, coordinate research functions in the Netherlands. The Committee did not have the duty nor the intention to review these schools, but from the information it could collect and the interviews it had at various places and levels, it can fully support the important coordination role of these schools.

Infrastructure
On top of the specific experimental, measurement and prototype laboratory equipment that is needed for the various research teams, the computational infrastructure is becoming correspondingly critical, not only for design, verification and virtual prototyping of proofs of concept, but also for reference purposes and access to the electronic digital libraries. Generally, the Committee is convinced that the universities are well equipped to meet the current computing and information access needs.

Valorization and spinoff activities
At the three TU's there is certainly good awareness of the Intellectual Property Rights of the findings and the protection with patents and the valorization of the research by stimulating transfer to companies or the startup by some staff or PhD students of a spinoff. Here Twente has a fairly longstanding reputation and expertise and is stimulating its students rather early. Moreover it is also providing some facilities for the spinoffs, to facilitate the startup. Here again it would be advised to combine and strengthen the experiences by a 3TU approach.

2.4. Findings per subdiscipline

The following paragraphs present the scores and some general remarks along the lines of the domains or subdisciplines.

2.4.1. Microelectronic Technologies

INTEGRATED CIRCUIT AND SYSTEM DESIGN			**Q**	**P**	**R**	**V**	
UT	6	IC Design	**5**	**4**	**4**	**5**	18
TUD	11	Computer Engineering	**4**	**5**	**4**	**5**	18
TUE	8	Mixed-signal Microelectronics	**4**	**4**	**4**	**5**	17
TUE	7	Design Methodology for Electronic Systems	**5**	**4**	**4**	**3**	16
TUD	8	Electronics	**4**	**4**	**4**	**4**	16
UT	5	Computer Architecture, Design and Test for Embedded Systems	**3**	**3**	**3**	**2**	11
		Average scores	4,2	4,0	3,8	4,0	16,0
MICROELECTRONICS TECHNOLOGY			**Q**	**P**	**R**	**V**	
TUE	9	Opto-Electronic Devices	**5**	**3**	**4**	**5**	17
UT	7	Semiconductor Components	**4**	**3**	**3**	**4**	14
TUD	6	Electronic Components, Technology and Materials	**3**	**4**	**4**	**3**	14
UT	8	Systems and Materials for Information Storage	**4**	**3**	**3**	**3**	13
UT	10	Integrated optical Microsystems	**3**	**3**	**3**	**4**	13
TUD	7	High-Frequency Technology and Components (HiTec)	**3**	**3**	**4**	**2**	12
		Average scores	3,7	3,2	3,5	3,5	13,8

In the reporting period, the worldwide activities on Moore's scaling have further accelerated. The associated exploding research costs have led to a strong concentration in a limited number of large centralized research institutes and industrial laboratories such as IMEC (Leuven), CEA-LETI and MINATECH (Grenoble), Fraunhofer, SEMATECH (Austin, USA), while the basic process step research has moved more and more into the realm of the equipment suppliers of the semiconductor industry. The role of (much) smaller-scale process technology research at the universities has consequently become less relevant to the industry. This trend towards further concentration is expected to continue during the coming years.

At the same time, with the nearing of the 'end of the Roadmap', the same centralized research facilities can be expected to extend the scope of their work and their much more advanced and often depreciated 200mm tools into new More-than-Moore arenas. This trend can put the future of small clean-room facilities like those at the three TU's at crossroads. The 3TU's are advised to develop a clear common strategy on how to approach these trends. On the one hand further pioneering into the (physical, chemical, biological) sensors and actuators, Lab-on-a-Chip, Solar Cells, and Optical Communication realms, clearly offer at the three TU's a large number of research topics. For such pioneering, an extremely flexible 'fast-idea-fabrication & tester facility' combined with good experimental reproduction is a challenging target with possible added value for the 3TU facilities. However, while clearly defining focus areas, a certain amount of concentration is probably needed to realize such a facility with sufficient critical mass and synergy between the above-mentioned realms. To subsequently bring the ideas further towards products, additional steps are needed. In this translation, the above-mentioned centralized institutes are expected to play an important role. Thus the two realms (i.e. the large and the extremely flexible facilities) should be strongly connected, and especially in the Netherlands-Belgium arena good opportunities exist to strengthen this linkage. We advise to explore and strengthen these opportunities further, not only with regard to cleanroom facilities, including bonding and thick-film lines, but also with regard to expensive design software and test equipment. When made available to the collective, the infrastructure can be maintained and updated at reasonable costs.

2.4.2. Sensors and Actuators

SENSORS & ACTUATORS			Q	P	R	V	
UT	1	BIOS: Biomedical and Environmental Sensors	**5**	**4**	**5**	**4**	18
TUD	9	EI: Electronic Instrumentation	**4**	**5**	**4**	**4**	17
UT	2	BSS: Biomedical Signals and Systems	**4**	**4**	**4**	**3**	15
UT	9	TST: Transducer Science and Technology	**4**	**3**	**4**	**3**	14
UT	3	MI: Measurement and Instrumentation	**3**	**2**	**3**	**NA**	
		Average scores	4,0	3,6	4,0	3,5	16,0

Sensors have come a long way. Since decades they have been products of physics-oriented developments for the measurement of physical quantities such as pressure, temperature, etc. and later of chemical concentrations such as oxygen, glucose, etc. Their development has benefited greatly of the availability of semiconductor processing. The deposition and etching of layers of a wide variety of exotic materials has been made possible, yielding CMOS compatible devices for numerous applications. At this moment sensor systems are being produced consisting of sensors, drivers and interface circuits (ADC's, ..) all on the same substrate. All the universities of the Netherlands have played a role in this development albeit with different accents. Twente is famous for its chemical sensors whereas Delft is more into physical sensors. All of them have created a need for clean rooms with dedicated processing equipment, for micromachining, layer deposition, etching, etc.
In addition biomedical applications have exploited the growing availability of sensors. They can be classified into two categories. The first one aims at a more direct contact between living tissue (cells, neurons, muscle, ..) and the measurement electronics. The other category aims at the development of signal processing software to separate signals from noise. Both categories have received more attention for funding because of the aging population in Western Europe.
Contact with living tissue is only possible by use of specific so-called bio-compatible materials and deposition techniques, which is only possible in clean rooms. A concentration of this clean-room equipment would thus lead to the availability of a larger variety of equipment for these purposes. Medical signal processing software on the other hand is easily developed in different laboratories. Knowledge is required however of the physiology involved. Custom courses are thus required to provide sufficient background to such developments.
Twente is certainly closest to the physics of the (bio)sensors because of their long tradition. Delft on the other hand has a longer tradition in the development of sensor interface circuits. Twente, Eindhoven and Delft have a close link with the medical hospitals in which the problems are actually defined. A concerted action in both sensors systems and in the biomedical applications could thus be envisaged.

2.4.3. Electrical Power

ELECTRICAL POWER			Q	P	R	V	
TUD	12	EPS: Electrical Power Systems	**4**	**3**	**4**	**5**	16
TUD	14	HTM: High-voltage Technology & Management	**4**	**3**	**4**	**4**	15
TUE	6	EPS: Electrical Power Systems	**4**	**3**	**4**	**3**	14
TUD	13	EPP: Electrical Power Processing	**3**	**4**	**3**	**4**	14
TUE	5	EPE: Electromechanics and Power Electronics	**3**	**3**	**4**	**4**	14
		Average scores	3,6	3,2	3,8	4	14,6

During the last decade the liberalisation of the electricity market in most European countries has been taking place. Utilities focussed very much on the task of re-organisation and restructuring which was essentially connected with significant attempts to save costs. The consequence was that the utilities cut funds and investments down to a very low level. Thus orders for manufacturers decreased significantly leaving the latter much less flexibility to spend money for research as this was usual in the past. Also utilities cut their staff numbers drastically. Most of the research groups in electric power ran into a depression due to less attention by utilities and manufacturers as well. Financial resources went low and the image of the power sector faded in the view of the people and of course of potential students for the field. Thus, the research groups suffered by lack of money and of attractiveness for the students.

A change in this trend became visible in the last two years. Utilities face rising problems with their ageing equipment and many of their staff are due for retirement without having suitable replacements. Thus a need for electric power engineers becomes visible. Also the entire energy discussion on the need for sustainable replacement of conventional generation in context with the greenhouse problems and the increase of demand in electric power became a hot topic. In view of this situation it is not surprizing that a significant increase on the number of students is observed in most of the power groups of the universities in Europe, so it is at TUD and TUE. Electric power is again attractive for the students, as also can be witnessed from the significant increase in general of the number of the PhD's during 2005.

Productivity, viability and relevance of the power groups have hence to be seen in view of this temporary depression which seems to be over now. Productivity can be expected to improve. Viability and relevance are very good.

2.4.4. Telecommunication

ELECTROMAGNETICS AND TELECOMMUNICATION			**Q**	**P**	**R**	**V**	
TUE	2	ECO: Electro-Optical Communications	**4**	**3**	**5**	**4**	16
TUD	3	NAS: Network Architectures and Services	**4**	**3**	**4**	**4**	15
TUE	4	EM: Electromagnetics	**4**	**2**	**4**	**4**	14
TUD	2	MRT: Microwave Transmission, Radar and Remote Sensing Technology	**3**	**4**	**4**	**3**	14
TUD	4	WMC: Wireless and Mobile Communications	**3**	**3**	**4**	**4**	14
TUE	3	ECR: Radiocommunication	**3**	**4**	**4**	**2**	13
UT	12	DACS: Design and Analysis of Communication Systems	**3**	**3**	**4**	**3**	13
TUD	1	EM: Electromagnetic Research	**3**	**4**	**3**	**2**	12
TUD	5	P&N: Positioning and Navigation	**4**	**3**	**4**	**NA**	
UT	13	TE: Telecommunication Engineering	**3**	**3**	**3**	**2**	11
		Average scores	3,4	3,2	3,9	3,1	13,5

Over the last five years, a remarkable change has occurred in the development of telecommunication networks. The internet protocol (IP) has become the preferred networking technology (as illustrated by Voice over IP) and this trend will continue in future. In addition fast internet access for consumers has increased rapidly making use of twisted pair DSL networks or cable modem networks. In certain countries, optical fiber is also penetrating in the home. Mobil-

ity became a part of our daily life and this was supported by second generation technology (GSM). Also the local area networks showed a drastic change with the move towards 100 and 1000 Mbit/s Ethernet and the increased usage of Wireless LAN (IEEE 802.11).

In the future we can expect the need for network access at any time, any place and with any device. Bandwidth to the home will increase further, based on the use of improved twisted pair or coax networks or on the deployment of new optical access networks. Wireless access may form a viable alternative in some specific cases. Inside the home, networks will play an equally important role requiring fixed and wireless access to support the necessary bandwidth and Quality of Service. Due to the proliferation of wirelessly connected devices, many more than there are PCs today, novel networking techniques need to be developed. One of the key technologies will be ad hoc networks, where devices are interconnected to and through each other in an ad-hoc fashion (without the use of fixed infrastructure). Problems ranging from radio technology up to the service layer need to be tackled in a coordinated effort. Not only the access network will require special attention, also changes in the core network will be required to support end-to-end Quality of Service. Since the network will become more and more user-centric, generic approaches are required in order to support the user in a seamless way. This includes research in areas such as self-configuration, context awareness, automatic adaptation, etc.

With the strong focus on wireless systems and networks the interest in radio communication, antennas and electromagnetic theory has been revived, as also emphasised by activities in the three TU's. In the case of electromagnetic theory the availability of stronger computers and new software has revolutionized the visualization and understanding of complex problems. The availability of new materials (including meta-materials) and new array techniques will lead to new and smart antenna designs that will impact radio communication systems. Another dominant trend is towards higher carrier frequencies and ultra wideband systems that open up new application areas. The developments within radio systems will also impact areas like remote sensing, which is also part of the research at the TU's.

The work of the different programmes has covered a number of important topics during the reporting period. Problems were tackled from different angles resulting in many cases in complementary approaches. Today it is observed that collaboration between the different groups is increasing. This should result in a better focus and complementarity of the research and as a direct outcome, results will be obtained in a more efficient way.
The networking activities in Delft have been boosted in recent years by setting up two new research programmes with a clear and complementary research focus. In Twente the situation is different, because some key people left or are about to leave the networking research field. This will need special attention in the coming years in order to keep the strong position of Twente in the networking area.

The commitee finds that special attention must also be given to the areas of Electromagnetic Research in Delft and Radiocommunication in Eindhoven since they are presently without a permanent chair.

It is recognized that together the areas of Electromagnetic and Microwave Techniques as well as Radiocommunication represent a considerable effort at the three TU's as a whole. We strongly encourage the TU's to make a closer coordination to increase the impact of Dutch efforts on a world scale.

2.4.5. Signals, Systems and Control

SIGNALS, SYSTEMS & CONTROL			Q	P	R	V	
TUE	10	Signal Processing Systems	**5**	**4**	**5**	**4**	18
TUE	1	Control Systems	**4**	**3**	**5**	**4**	16
TUD	10	Circuits and Systems	**5**	**3**	**4**	**3**	15
UT	4	Control Engineering	**4**	**3**	**4**	**4**	15
UT	11	Signals and Systems	**3**	**3**	**3**	**2**	11
		Average scores	4,2	3,2	4,2	3,4	15,0

There are a few very basic concepts stemming from classical circuit theory which play a central role in the field of signals, systems and control. These are passivity and losslessness, which occur with different names in different fields such as contractivity and orthogonality. These concepts are important for the insensitivity and stability of signal processing algorithms. Another important trend is the increasing role that information theory is playing for signal processing and control systems, because estimation and decision making is encompassed in such systems. A major driving force for signals, systems and control is the increase in computer power that allows to design and implement more advanced algorithms and more performant systems. From the applications point of view the scope is extremely broad, as these theories have demonstrated their practical relevance in speech processing, image processing, communication systems, security systems, instrumentation, automation and control.

The future is very bright for this field, as on the one hand the applications become more and more diverse and on the other hand much theoretical progress is still ahead of us in the merger of previously separated basic theories. This becomes apparent by looking at e.g. wireless multiple input multiple output (MIMO) systems, where information theoretic investigations about capacity limits taking into account fading correlations, basic influence of quantization, robustness and numerical efficiency, are in the focal point, to name a few. The opportunities are especially in research and developments crossing the border between previously separated theories and technologies. It is important to keep this global interdisciplinary view, because otherwise there is the danger of fragmentation according to the different application areas.

The three TU's have all taken this challenge in different ways. In Delft Control is not part of the EE programmes, but is in mechanical engineering. Signal processing work is done there on a very high level in the Circuits and Systems group, with strong emphasis on the theory (array processing, computational systems theory). In Eindhoven the Signal Processing Systems group is also doing excellent research leading to highly relevant implementations and applications. Control Systems in Eindhoven is also very successful and with their modelling expertise they are opening up new application areas. The Signals and Systems group in Twente is more implementations oriented, but can benefit from cooperation e.g. with Circuits and Systems in Delft. The Measurement and Instrumentation group in Twente has been terminated and its residuals have been merged with Signals and Systems and Control Engineering respectively.

Generally speaking, the field of Signals, Systems and Control is a truly generic one, which should remain present at each of the TU's.

2.5. General recommendations

Here the major general recommendations that can be drawn from the findings, are briefly summarized.

- Recruiting more EE bachelor students: Concerted national action towards the high school students and their teachers is needed for attracting more incoming bachelor students to EE. Attracting female students deserves special attention.

- Women in the EE workforce: Although some progress has been made in hiring and promoting women in the electrical engineering research community during the reporting period, there is still a long way to go. Further changes are needed, because the country cannot afford to ignore one half of the population.

- Number of full professors in a programme: The ideal size of the staff of a programme depends to a certain extent on the research topic. But it was felt that there are quite a few programmes that consist of only one full professor (who is the chairholder) and a few UD or UHD. This model is not considered to be the optimal one, since it heavily depends on the existence of a chair expounding a certain research interest. The retirement or transfer of the present chair and the subsequent introduction of a new chair then often creates unproductive shifts or turbulence. Another problem with such small research teams is their difficulty to store expertise of the technical field at hand. In fact, the Committee observed that programmes that are larger and have several full professors and that defined their research missions based on the synergetic cooperation of their full professors are likely to have an advantage in comparison with international standards.

- Role of the UD and UHD in the programmes: In the Netherlands, only a full professor (*hoogleraar*) has the formal right to grant a PhD (Ius Promovendi). In practice, other permanent academic staff (UHD, UD) are often *de facto* the advisors of PhD students. This makes the number of PhD students less sensitive to the presence of a particular full professor. In view of this, the role of the UHD or UD who has the expertise and has done most of the advising, should be more explicitly recognized. This model works successfully in several other countries.

- Recruitment of full professors: The Committee noted a certain difficulty in filling certain full professor positions. It recommends early actions ahead of the retirement of the former full professor and supports the present flexibility and openness in hiring procedures. The best talent needs to be attracted and rewarded appropriately. This proactive approach should also avoid negative transient effects in the research quality and productivity due to retirements of programme directors.

- Recruitment of master and PhD students: Besides the importance of local recruitment, complementary actions are required to attract students from abroad. Several research programmes established very good contacts with foreign universities resulting in a high inflow of master and PhD students. Because of the large demand for electrical engineers in industry, special actions are required to convince a relevant fraction of these foreign students to develop a professional career in the Netherlands. Also, it is important to maintain a balance between the student populations from the Netherlands and from

abroad – especially the Far East. An unbalance will have an adverse effect on the motivation of the students and may accellerate the export of vital industries.

- Administrative overhead: At several occasions it was pointed out that the administrative overhead is detracting the attention of scientists from their research. It is recommended on the one hand to reduce the administrative overhead as much as possible (at a university, national and European level) and on the other hand to provide appropriate and efficient central and ICT support.

- Develop programmes for inter-TU mobility.

The three Departments have formulated a joint reply to these recommendations, which is included in this report as Appendix A.

3. Assessments per Faculty and per Programme

3.1. Assessment at the level of the Faculty/Department

As required by SEP, the self studies contained information on the level of the 'Institute'. Since the word 'Institute' is used in a different context by the three TU's, we will not use this word here, but rather the word 'Faculty/Department', which is the management structure responsible for the overall research in Electrical Engineering.

The information in the self studies at this level describes the leadership, mission and goals, strategy and policy, resources, funding policies, facilities, academic reputation, societal relevance, and includes a SWOT-analysis. The interviews and discussions with the management provided additional focus on this information.

In the following sections, the specific observations of the Committee for the Faculty/Department level are followed by the assessments per programme in that Faculty/Department.

3.2. General remarks about Electrical Engineering at TU Delft

The TUD has restructured its faculties just before the start of the review period 1999-2004, by making a Faculty of Electrical Engineering, Mathematics, and Computer Science. This restructuring has already resulted in some positive effects during the review period. Also the faculty is aware of its weaknesses and threats and is overall taking convincing measures to solve the weaknesses and to counter the threats.

The Committee would like to make some additional observations, and mention special points of attention:

- The TUD in particular seems to struggle with the mobility of their staff and filling in some full professorship positions and mobility threats. Hence a thorough resource and career planning is urgently advised.
- The Committee understands the necessity to attract master students from China and other countries outside the EU. This is urgently needed in view of the low intake of Dutch students.
- It is a wise action to set up a special budget for speculative visionary PhD's.
- The personal Van Leeuwenhoek professorships are highly appreciated as an important instrument for strengthening the programmes and for building programmes that have a better structure.
- Good efforts to set up a matrix organization where the institutes (Delft Research Centers, DRC) link the different programmes that had been working too independently over the years. The operation of the research centers gains a lot in momentum when they bring in money for the programmes or pool some expensive infrastructure. Such Centers can also build a strategy and programmes for Intellectual Property valorization of the research and spinoff and prototyping actions (e.g. IRCTR, DIMES).

The Committee assessed the following research programmes of the TU Delft:

Delft University of Technology		
TUD	1	EM: Electromagnetic Research
TUD	2	MRT: Microwave Transmission, Radar and Remote Sensing Technology
TUD	3	NAS: Network Architectures and Services
TUD	4	WMC: Wireless and Mobile Communications
TUD	5	P&N: Positioning and Navigation
TUD	6	ECTM: Electronic Components, Technology and Materials
TUD	7	HiTEC: High-Frequency Technology and Components
TUD	8	ELCA: Electronics
TUD	9	EI: Electronic Instrumentation
TUD	10	CAS: Circuits and Systems
TUD	11	CE: Computer Engineering
TUD	12	EPS: Electrical Power Systems
TUD	13	EPP: Electrical Power Processing
TUD	14	HTM: High-Voltage Technology and Management

3.3. Assessments per programme: TUD

TUD 1
Programme: **EM: Electromagnetic Research**
Director: Prof. dr. ir. H. Blok, prof. dr. ir. P.M. van den Berg

Assessment:	Quality	3
	Productivity	4
	Relevance	3
	Viability	2

The group currently awaits the appointment of a new chair that can assure stable leadership in the future. The group addresses a number of topics centred on computational and mathematical modelling of fields and waves in electrical, electronics and telecommunication engineering. It is mentioned in the written report that the activities are subdivided into nine research topics, which is probably too many considering the number of staff listed. Even though the individual research topics may be sub critical it is acknowledged that the application areas are very interesting. They include biomedical modelling, ablation of tissue and ground penetrating radar for geophysical imaging, tracing of landmines as well as oil and gold exploration.

The quality of the work is good considering the many changes on the personnel side that have been experienced over the last years. The productivity is very good with a relatively high number of PhD graduates and also a relatively large number of journal papers over the reporting period. It is noticed, however, that the group at present has only one PhD student and that the number of publications is decreasing.

The group has a number of collaborative efforts within TU Delft and also with companies. This is appreciated, but it is clear that more external funding should be generated. The group differentiates itself from the activities at TU Eindhoven by being more focused on computational methods. We strongly encourage the two groups to form a closer coordination of activities since we believe they could mutually inspire each other and benefit e.g. in student intake.

The central challenge in the near future is to find a chair who can boost the activities. The idea of putting focus on the telecommunication area is fine, also considering the synergy that may be obtained with other activities at TU Delft. If this effort is not successful we encourage the university to consider a merger with relevant groups into a stronger unit. As mentioned above it might be a good idea to coordinate activities, e.g., with the similar activities at TU Eindhoven.

TUD 2
Programme: **MRT: Microwave Transmission, Radar and Remote Sensing Technology**
Director: Prof. dr. ir. L.P. Ligthart

Assessment:		
	Quality	3
	Productivity	4
	Relevance	4
	Viability	3

The focus of the MRT-group is on four areas: Radar, Remote Sensing, Antennas and Radio Transmission. Comparing the size of the programme in terms of 10 FTE the number of areas addressed is perhaps too high for world-class impact. Judgement is, however, difficult because of extra resources outside this programme via the IRCTR and the close collaboration with Russian research institutions. Given the information that the extra manpower corresponds to approximately 30 FTE, sufficient manpower seems ensured.

The director provides very good leadership. It is appreciated that the programme with its multidisciplinary systems approach has good collaboration with other programmes at TUD, but a clear strategy for the collaboration would be appreciated.

It is greatly acknowledged that comments from the last review regarding methodology were taken onboard. It is also acknowledged and appreciated that the group has focused some of its research areas.

It is recognised that the group has built up world-class facilities for its experimental work. The contacts with industry are wider when the extra activities through IRCTR are taken into account.

The programme has good prospects for the future with a fair influx of young students to the area (about half of the EE students at TUD go to this area).

It should be noted that the P&N programme is now merged into the MRT programme, but evaluated independently in this report.

TUD 3
Programme: **NAS: Network Architectures and Services**
Director: Prof. dr. ir. P.F.A. Van Mieghem

Assessment:		
	Quality	4
	Productivity	3
	Relevance	4
	Viability	4

This programme seeks to design a rigorous network methodology for end-to-end, secure and quality of service (QoS) aware communications by employing network/graph theory, stochastic processes, algorithms and network measurements.

The programme has a clear mission and has built up a very good international visibility over the last five years. The chair has a long tradition in QoS based routing and became one of the worldwide experts in this area. Work was extended towards understanding the fundamental operation of the internet using advanced modelling and comparison with extended measurements. Work is further expanded to ad hoc networking and robustness. So far a coherent programme was developed under the active guidance of the programme chair.

The programme developed a nice project portfolio and the PhD students over tenured staff ratio reached a healthy proportion (although the recent further increase in PhD students requires special attention). Basic infrastructure is available, and where necessary, good contacts have been established with external organisation (e.g. RIPE) in order to have access to necessary information (e.g. measurement data).

The programme has a high academic value in trying to resolve some fundamental questions in networking in a rigorous and original way. This resulted in high quality scientific output, as can be observed from the well received publications that are cited frequently. The number of publications is very good with a good balance between journal papers and conference papers. The number of finished PhD's is acceptable but could clearly increase in future.

The research has a high scientific relevance, but more emphasis should be on the valorisation of the results (e.g. through collaboration with industry, patenting and eventually the creation of spin-off). In addition it is recommended to expand the participation in EU funded projects. This may require performing some shorter term research (but still keeping the right balance between fundamental and applied research).

The NAS group is a young and dynamic research group that has gained a good research profile in a short timeframe. From past performance and plans for the future it is expected that the group has a good growth potential. Care should be taken to keep the focus of the research, by choosing future research topics that are mutually reinforcing with the actual items rather than too diverging.

TUD 4
Programme: **WMC: Wireless and Mobile Communications**
Director: Prof. dr. ir. I.G.M.M. Niemegeers

Assessment:	Quality	3
	Productivity	3
	Relevance	4
	Viability	4

The programme is focusing on ubiquitous wireless communication, in particular to support personal networks and ambient intelligence. This requires a cross-layer approach which covers all layers from the physical layer (radio) to the layers that provide generic services to applications, including the control and management levels. Wireless and mobile applications are not included in the programme.

There is a clear view on the research direction and the chair (appointed in 2002) has obtained international recognition with its vision on personal networking and by putting this theme on the FP6 EC research agenda. Specific research themes include: radio link techniques (UWB, cognitive radio), mobility support, self organization, cognitive network techniques, QoS support and security, cross-layer optimization. All these topics are important for finding feasible solutions for personal networks.

The research funding has increased drastically over recent years (especially the number of EC funded projects is remarkable) resulting in a fast increase in PhD students. There is enough tenured staff to guide the PhD students (taking into account the planned appointment of a part-time professor). The research infrastructure is currently focused on the physical layer and the necessary expansion into the higher layers is planned.

The scientific output during the reported period is still limited (making a bibliometric evaluation difficult) but a steep increase is observed recently.

The research is highly relevant and received a lot of international attention. The combination of radio link knowledge with higher layer knowledge gives the group a strong position, because interaction between the different layers becomes more and more an issue for resolving some specific problems. The planned appointment of a part-time professor from industry is important to bring in the necessary know-how of the application layer (especially related to security) and at the same time it will strengthen the link with industry.

The WMC group was formed in 2002 and could build on a solid knowledge base in the area of radio communications. The appointment of a new chair brought in a new research field and resulted in a rapid expansion of the research group. The group has a very good chance to become a leading research group in the international arena. The set-up of a strong interdisciplinary team (with several research groups inside and outside the TUD) may put the Netherlands at the forefront in the development of personal networking.

TUD 5
Programme: **P&N: Positioning and Navigation**
Director: Prof. dr. ir. L.P. Ligthart

Assessment:	Quality	4
	Productivity	3
	Relevance	4
	Viability	not applicable

The P&N group is in a transition period after key personnel left the programme. Emphasis has now shifted from positioning towards navigation. The mission of the group is clear and the working area is clearly defined.

The group is now integrated into the MRT group, but it has been without leadership for a while before this merger. The group has in spite of its size been able to become an attractive partner for big organisations such as NASA that has made facilities available for the testing of ideas and developed systems.

Fusion of various data sources and their reliability is a main focus. The Committee has some reservations as to the extent in which this research portfolio fits that of the MRT group with which it will be merged.

The group is now ramping up on staff including PhD students. We welcome this development. It could also be envisioned that the group has potential to grow into a larger group. Such growth is encouraged to achieve critical mass since the group has a fair chance to become one of the world-leading groups in its field. In this context it is appreciated that the group has a very clear picture of world wide competition to benchmark up against.

The merger into the MRT group is probably a good idea. Attempts to find a chairholder for Positioning and Navigation (vacant since 2000) were unsuccessful.

It is the impression of the evaluation Committee that 'prospects' for this group should be rated 'very good' given the fact that it is the strongest in its field in the Netherlands and the fact that it has potential to become outstanding also on a world scale.

TUD 6

Programme	**ECTM: Electronic Components, Technology and Materials**
Director	Prof. dr. ir. P.M. Sarro

Assessment:	Quality	3
	Productivity	4
	Relevance	4
	Viability	3

A key strength is the very positive spirit that is maintained on group level and the motivated PhD staff. The ratio of tenured staff to PhD is somewhat skewed; self-bootstrapping of the PhD's is promoted. The number of PhD and postdoc candidates in the evaluation period is high (36). Innovative silicon device integration, MST, MEMS, Solar cells and TFT programmes are executed. In addition to the maintenance of a clean room for other users, this group carries out its own research on CMOS-compatible technologies such as thin-film devices, solar cells, etc. The recommendation of the previous review regarding patents has recently resulted in a growing patent output of the group.

The ambition to enable the manifold of device functions and devices to function in a SiP will need incorporating appropriate design tools and methods into the research activities.

The scope of the group is very wide and the idea level and output are very high, but the longer term roadmap is less clear and needs work. It is recommended to retain the wide customer base, but also to reconsider and adjust the very wide focus of the programme, possibly adding a number of new pioneering initiatives in the G1 funding range. The cooperation opportunities as well as the balanced focus area choices among the groups of Sarro, Burghartz and French and Schmitz (LT processing) could be further identified and implemented.

Finally it is noted that the group provides a welcome opportunity to demonstrate to the public how women can excel in key lead roles in technology in EE research in the Netherlands.

TUD 7
Programme: **HiTEC: High-Frequency Technology and Components**
Director: Prof. dr. ir. J.N. Burghartz

Assessment	Quality	3
	Productivity	3
	Relevance	4
	Viability	2

Just like the other groups centred around DIMES, the key strength of the programme lies in the enthusiastic PhD and student community and the strong linkage into the industry, made visible, among others, in the strong PACD programme. The linkage to the RF design group (Long) has its main focus along the RF characterization axis and less along the process technology linkage.

The focus RF-research field is highly actual and well-chosen, well constructed along Mixed Level Design Materials & Processes, Devices & Components, cleverly leveraging internationally well recognized Compact Models, RF-Circuit Block design and Characterization and Packaging.

The recommendation of the previous review with respect to patents has not yet resulted in a substantial increase in the patent output of the group. It is recommended to reconsider the single customer risk and extend the programme by adding a number of new initiatives in the G1 funding range.

The ratio of tenured staff to PhD is skewed. The number of PhD candidates in the evaluation period is growing rapidly, whereas a relatively low number of PhD's have been successfully completed up till now. This is due to a steep ramp-up in the PhD intake during the last period. A comprehensive PhD education programme is being implemented. A higher PhD thesis output and publication rate should be strived for.

The programme leader has now moved to another university. In combination with the retirement of a key (industrial) professor in the programme of Sarro this puts a challenging burden on the vitality and prospects of the group.

Given the ambition to expand towards medical and sensor areas, the 3TU cooperation opportunities among the groups of Sarro, Burghartz and French and Smit, Van den Berg and Schmitz could be further explored.

TUD 8
Programme: **ELCA: Electronics**
Director: Prof. dr. J.R. Long

Assessment : Quality4
Productivity 4
Relevance 4
Viability 4

With its new director (since 2002) this programme has re-established Delft as a major centre for research on analogue integrated circuits. The programme has gained considerable strength on the international level in the discipline of RF design for communications applications. The director has recently become chair of the ISSCC subcommittee on Analog/RF. Such position has hitherto been given to a European only twice. This International Solid-State Circuits Conference is the foremost one on solid-state circuits.

The other staff members of this group have a long tradition in analogue design as well. One of them has produced a well-known book on Systematic Analogue Design, for example.

Since the change in leadership the number of PhD's in progress has increased. It is limited rather by the availability of good candidates than by positions. The number of publications has also risen. Several publications are found in the ISSCC Conference and in the IEEE Journal of Solid-State Circuits, the most important ones in this field.

This research group has strong relationships with other groups such as ECTM for technology and with HiTEC for high-frequency measurements. This is why they are involved in several Research Centres. For example they can use the high-frequency measurement equipment available in DIMES. Also wire bonding and packaging is available in DIMES.

The biomedical activities are limited to the circuit level. Real interaction with medical staff in hospitals (as is done in the EI group) is not pursued here.

The overall opinion of the Committee is that this group has very good prospects.

TUD 9
Programme: **EI: Electronic Instrumentation**
Director: Prof. dr. P.J. French

Assessment :	Quality	4
	Productivity	5
	Relevance	4
	Viability	4

The Electronic Instrumentation group has grown considerably in scope and application range. Their activities are largely based on their vision that 'sensorization' is the next wave in society and industry. The programme scope is rather broad and ranges from sensor technologies and packaging, over circuit design to software development (computer engineering). The activities fit well with ECTM, ELCA and HiTEC. The work overlaps most with the ECTM group as sensors require custom technologies. In addition this group is strongly entrenched in biomedical engineering. Research assistants attend real-life surgery in the medical hospital to learn about the actual needs and possible solutions.

The spectrum of 'tricks on silicon' is very wide, and still expanding. An interesting question is whether the EI devices can be grouped on Standardized Platforms. The differentiating claim with regard to the other TU's is to limit the work to CMOS compatible technologies. The differention or complementarity towards the work at Twente is not really clear. Further cooperation with UT and the Holst Centre are foreseen.

The new director has taken up the responsibility for this group with dynamism and enthusiasm. The result is a very impressive list of PhD's and publications in the top sensor journals.

The group contains acknowledged experts on analog processing circuits, temperature sensors and imagers. They have already had circuits at ISSCC, which clearly shows their quality.

Their approach to attract and hire PhD's can serve as a reference example to the other groups. They invite candidates for thorough evaluation, in order to guarantee a sufficiently high level.

The group was very successful in acquiring new projects and money through national spearhead programmes like MicroNed and NanoNed.

TUD 10
Programme: **CAS: Circuits and Systems**
Director: Prof. dr. ir. P. Dewilde

Assessment:		
	Quality	5
	Productivity	3
	Relevance	4
	Viability	3

The programme has two tracks: 'Fundamental methods in circuits, systems and signal processing' and 'VLSI design and verification'. After 2001 the fundamental methods track is clearly dominating. The reputation of the group is excellent and the director is highly visible through quite a number of prestigious positions he is holding. Their work is of extremely high quality, it is published in the best journals in the respective fields and is practically very relevant. They are continually building on a sound theoretical basis stemming from classical circuit theory and expanding these basic principles into a wider context in new application areas. In doing so they had quite an impact in the areas of array signal processing, computational system theory and physical modelling and verification of VLSI systems. The real-life applications of these contributions are in the field of wireless communications (e.g. 3GB, UWB), in radio astronomy and in modelling and verification of submicron VLSI circuits (e.g. interconnects, substrate related parasitics). But the VLSI system design activities should be strengthened, especially to complement the signal processing research with sound VLSI architectures research to support the implementation of algorithms and the transfer to industry.

The output of the group, especially the number of PhD theses, has experienced a dip, which coincides with the departure of two professors in 2000 and 2001.

Much of the drive and the richness in quality and content in the group is in its leadership, which is a key strength and a challenge in view of the near retirement of the director. From May 1, 2006, prof.dr.ir. A.J. van der Veen will be the new programme director. There is a vacancy for a chairholder oriented towards VLSI system design.

Developing the VLSI track of the programme in view of the overwhelming worldwide effort in this field and keeping up the fundamental track at its present high standard will be an important challenge and opportunity for this group.

TUD 11
Programme: CE: **Computer Engineering**
Director Prof. dr. S. Vassiliadis

Assessment	Quality	4
	Productivity	5
	Relevance	4
	Viability	5

The Computer Engineering group is relatively large and spans the whole range of CE problems from multi-processor networks, via high speed professional and consumer-oriented processors to computer arithmetic, and from hardware/software co-design and optimization tools to backend compilers for reconfigurable architectures. To financially safeguard speculative and fundamental research (like e.g. nanocomputing), special measures have been taken. The whole work package is well structured and each part has been placed under the responsibility of a staff member.

The group maintained its global top-level position in academic CE research through scientific achievements on paper and via prototype hard- and software designs. Qualitative assessment of the output through the citation index appears very difficult (if not impossible) because of the mismatch of the group's output channels with the ISI publications database.

The productivity of the group is outstanding, also relative to its size. During the previous assessment recommendations were given to increase the number of reviewed academic papers and of PhD graduations. In the period under review the first challenge was followed up by an 80% increase (nine to sixteen PhD's) and the second one by a 70% increase (32 to 54 papers), among which eight best paper awards and one outstanding dissertation award.

The future-proofness and the industrial relevance of the group are underlined through a well-filled list of funded projects.

TUD 12
Programme: EPS: **Electrical Power Systems**
Director: Prof. ir. L. van der Sluis

Assessment:		
	Quality	4
	Productivity	3
	Relevance	4
	Viability	5

This programme addresses precisely the problems that arise in the electric power systems including an increasing number of new renewable and decentralised power sources. Connected with that, novel unconventional principles and solutions for the electric energy network are aimed at. In particular, implementation of the fast growing wind power in the northern parts of middle Europe is a major topic for the next decade. Studies on stability problems and transient phenomena are part of that activity.

On the equipment side the digital testing approach of vacuum circuit breakers is a very actual topic in the field. The necessary experiments are carried out at TUE which underlines the close coordination and collaboration with the EPS group there. Dealing with the implementation of high power electronics as a mean for short circuit limitation and phase shifting are good examples for an innovative dynamic group.

The programme takes into account the key long term aspects of a future power system, that are expected to make a significant contribution to sustainability in electric power supply. At the same time the actual needs of today's system are not neglected, in order to serve the needs of industry and utilities. The rather unique 'Renewable Energy Laboratory' and the world's second largest digital real time network simulator are of extreme value for the work.

Being significantly involved with CIGRE (the most important international association in the field) and with standardising bodies such as IEC, the programme director has firm connections to the practical international world. Generally spoken, the group improved the quality of the programme during the evaluation period to a very good level.

The group responded well to the upcoming lack of electric power engineers and actions were taken with success. A significant increase of the number of students interested in the topic on the master and the PhD level can be observed. In general the group has set a very good strategy and policy utilizing their resources and excellent facilities adequately.

External funding from industry is sufficient although the group deserves a stronger financial involvement of the Dutch utilities. Close cooperation and sharing of resources with the EPS group at TUE and HTM, EPP at TUD is to be very much appreciated. Synergies are used giving all groups an additional momentum. Sharing a professor as well as facilities with TUE underlines that fact.

The number of publications and PhD theses during the evaluation period is, relatively speaking, on the lower side, but in view of the depression that affected all power groups during the last decade (see chapter 2.4.3) the productivity is still good. Clear indication is given that significant improvement is to be expected in the following years, as they have managed to increase the number of PhD students significantly already in 2005.

The group is unique in the Netherlands and only a few programmes worldwide have such a clear future oriented aim. As a consequence the prospects of this dynamic and very stable group are excellent and their work is very relevant for society.

TUD 13
Programme: **EPP: Electrical Power Processing**
Director: Prof. dr. ir. J.A. Ferreira

Assessment:	Quality	3
	Productivity	4
	Relevance	3
	Viability	4

The engineering quality level of the programme is high, addressing thermal, material and multidisciplinary advanced application areas such as: Power Electronic Converters, Machines and Actuators, Power Electronics in Power Systems, Pulse and Burst Power.

This programme is split into two key activities. In a fundamental part new limits in the capability of power electronic converters are aimed at, whereas in an application part industrial applications such as integration, machines and actuators, pulse and burst power and apparatus for high power systems up to the transmission level are the goals. Substantial cooperation with groups at TUD (EPS, HTM) has been established.

To be appreciated is the coordination with the according group in TUE (EPE), as overlaps in the research programmes are avoided. EPP at TUD focuses primarily on high power devices in the kW range up to the highest levels in electric power transmission, while at TUE devices at power levels below this range are dealt with.

The group responded actively and positively to the previous review comments. The funding base has been significantly widened towards the industry. The publication output has increased, and the number of PhD's has been growing at a rapid rate. The quality of the programme improved visibly during the evaluation period. The group, in particular the programme leader, has a very good academic reputation, which fact certainly contributed to an improvement in general. The prospects for the future of the programme are very good as the group is dynamic and has a high growth potential.

It is important that the programme can take a leading role in the future developments in the area of integration of high power electronics, where the microelectronic technology is expected to fail. For the future, suitable strategic actions are also needed in view of the strong developments in China.

TUD 14
Programme: **HTM: High-Voltage Technology and Management**
Director: Prof. dr. J.J. Smit

Assessment:		
	Quality	4
	Productivity	3
	Relevance	4
	Viability	4

With their mission and goals the group responds to the actual needs in the systems of electrical power transmission and distribution. One part of the programme deals with the increasing problem of the electric power suppliers how to manage their aging equipment and to keep it in service without risking catastrophic failures and blackouts of the system. Intelligent diagnosis and asset management of the various apparatus in the system are therefore given a considerable focus. Another part of this programme aims at innovation in the search for novel materials/ design for HV equipment in the electric power system. Remarkable is the research on a direct conversion of wind energy into electric energy without rotating parts. Overall, the programme has improved quality to a very good level. Being a past chairman of CIGRE Study Committee D1 (Materials and Emerging Technologies), the programme director has an excellent international reputation, which certainly contributes to the success of the group. The laboratory facilities, in particular the high voltage laboratory, are excellent and match the needs.

Considering that the group (as all other electric power groups in Europe) suffered from the depression in this discipline during the last years caused by the liberalisation of the electricity market (see chapter 2.4.3), the output in number of publications and PhD theses can be stated to be good. A significant increase in number of PhD students for 2005 is stated, which certainly will improve the productivity in the coming years.

In view of the number of external financial sources and the various problems that the electric power systems will face in future, the relevance of the programme is very good, in particular as the research on sustainable solutions for electricity generation enhances the attraction of the programme. Prospects for the future are therefore also very good, emphasised by the general trend of students to favour this discipline more than in the past.

3.4. General remarks about Electrical Engineering at TU Eindhoven

The same restructuring as at the other two TU's has not been performed here, but the staff and the management is confident that the present structure is suitable for the current situation of the field.

The self assessment estimates that the weaknesses and threats are not so severe. The management proposes good action plans.

This is in line with the opinions of the Committee, but some points of appreciation, attention or focus can be mentioned:

- TU Eindhoven has one of the better situations concerning the number of incoming EE students, because of many valuable and effective actions towards high school students and their teachers. (This argument must not be overemphasized since the geographic location of Eindhoven is probably also an important factor in this.)
- The Committee is positively impressed by the remarkable stimulating decision to leave the overhead to the programmes/groups that perform the research.
- There is a positive attitude and commitment to the 3TU cooperation that can build on many successful actions in the past for transfer of professors and joint use of equipment.
- Good geographic location and links with Holst Centre.
- The department has obtained a considerable number of patents over the review period (more than twenty per year), and several actions are under way for more valorization efforts, yet the Committee feels that a more proactive role could still be taken on this issue.
- For the review of some programmes with a recently appointed chair the assessments are obviously based on relatively limited information.

The Committee assessed the following programmes of the TU Eindhoven:

Eindhoven University of Technology		
TUE	1	CS: Control Systems
TUE	2	ECO: Electro-Optical Communications
TUE	3	ECR: Radio Communication
TUE	4	EM: Electromagnetics
TUE	5	EPE: Electromechanics and Power Electronics
TUE	6	EPS: Electrical Power Systems
TUE	7	ES: Design Methodology for Electronic Systems
TUE	8	MsM: Mixed-Signal Microelectronics
TUE	9	OED: Opto-Electronic Devices
TUE	10	SPS: Signal Processing Systems

3.5. Assessments per programme: TUE

TUE 1
Programme: **CS: Control Systems**
Director: Prof. dr. ir. P.P.J. van den Bosch

Assessment	Quality	4
	Productivity	3
	Relevance	5
	Viability	4

The group concentrates on modern topics in control system design, and mainly the hybrid systems, which are combinations of dynamical systems with switching. In this way they can make conceptual bridges between classical continuous time systems and switching methods, thereby linking the physical and technical systems of various applications such as chemical processes, automotive systems, autonomous vehicles, biomedical systems with computer controllers. This approach bridges the more classical fields (electrical, mechanical and chemical engineering) with the computer science and is adequate for many modern applications where computers are abundantly present and where these computers should perform intelligent control actions on the systems (embedded controllers).

The strength of the group is in the combination of systems and control concepts with a solid understanding of the generic system aspects of the specific applications. They have developed a highly adequate strategy of extracting appropriate hybrid system models through interaction with the process engineers or specialists and operators in the field. This has allowed them to perform very impressive projects in very diverse application fields like automotives, batteries, engines and biomedicine through cooperation in industry as well as in academia. These are very relevant contributions to the scientific knowledge, the industrial and social environment, and at the same time can be very appealing to the education of engineering students. Typically, the staff members and PhD students should be able to make the bridge between the mathematical study of systems and the reality of one or more application topics. This also leads to a sound intellectual balance for the researchers and a solid budgetary situation for the group. Often creative methods of model reduction and system identification of nonlinear models are developed, that are crucial for the application.

They have excellent cooperation with the application fields within the faculty and through the DISC research school with the three TU's, and with industry.

The output of the group, especially the number of PhD's and publications, is good but not completely up to benchmark, mainly because of an unbalanced spread over the staff members. However, they have strong publications in highly ranked journals.

In view of its unique role and high impact it is justified that the team can replace the retiring staff members with new members that can bridge the hybrid system and control theory with certain new applications. This can have a very stimulating effect in the future and consolidate the role and the strategy of the group.

TUE 2
Programme: **ECO: Electro-Optical Communications**
Director: Prof. ir. A.M.J. Koonen

Assessment:		
	Quality	4
	Productivity	3
	Relevance	5
	Viability	4

This programme addresses mainly optical communication techniques with focus on three topics: 1) high capacity networks, 2) telecom nodes, and 3) local networks. The focus of the group is fine and its considerable size allows more than critical mass within the different subgroups.

The overall strategy is fine and we appreciate the ambition to have a high fraction of externally funded staff. The group has extensive collaboration with other universities and industries both domestically and internationally. Moreover, the aspiration to be a key player in the field generally is achieved. The programme leader is a well known player in the field since many years. The experimental facilities are very good and allow for very competitive experimental work. The quality of work performed is very good, but the group could strive for higher impact of publications.

The productivity of the group is generally good, but should also be seen relative to the large number of staff. We recognise that the number of PhD students is increasing now, holding promise for a larger number of PhD graduates. We also recognise that the number of publications increases steeply. We urge the group to maintain this trend while also keeping focus on prominent conferences and journals. The external funding level of 2-3 million Euro per year is very fine.

The relevance of the activities is excellent. The results are significant for industry and also recognised in the international research community through projects and publications. The group is a central player in organising high profile collaboration, e.g., broadband experiments, international university collaboration, and also in collaboration with other Dutch universities (NIRICT on ICT with TUD and UT). The idea of concentrating on the physical layer, while having contacts with network specialists (e.g., Niemegeers TUD) is probably wise. It is important to ensure that the topics studied are relevant for the network groups.

The Committee emphasises the importance of the activities carried out in this area in Eindhoven. The group is definitely the strongest of its kind in the Netherlands and also a key player on the European scene. The prospects and vitality of the group are considered very good, but we encourage the group to keep the pressure on continued collaboration with industry, and at all time consider how a unique international position can be obtained while maintaining value to local industry. It is important to maintain a clear strategy of focusing on the system work, without going too much into detail on component modelling.

TUE 3
Programme: **ECR: Radio Communication**
Director: Prof. dr. ir. E.M. Fledderus (a.i.)

Assessment:		
	Quality	3
	Productivity	4
	Relevance	4
	Viability	2

The Radio Communication group at TUE is in a transition period since the retirement in 2002 of its chair. The group still does not have a permanent chair. In this interim period the present leadership has done a fine job in reshaping the research programme also with consideration to the relatively small size of the group.

The group has chosen to focus its activities along two lines: 'Antennas and propagation' and 'Digital Radio Systems'. The first area addresses the 'classical' topics of antenna design and channel evaluation, while the latter focuses on wireless ATM LANs in connection with MIMO systems and the possibilities to correct for RF stage impairments in the digital stages of the receiver. It is the aim also to induce system oriented thinking into the work of the group, which is already evidenced by the work carried out in the recent year.

With the small size of the group it could be questioned if focus on two different areas is obvious. On the other hand it is also recognised that the group should not become too narrow in its scope. Consequently, it is important that the group obtains more support to allow expansion to about the double of its present size.

The quality of the work in the past is good, but we recommend that an eye is kept on the coherence of the work to ensure high impact in selected areas. Especially, the group should carefully consider the coherence between the two lines of work, since it is not entirely obvious how they fit together.

The productivity of the group is good considering its size and other obligations.

We consider the group's working areas highly relevant, which is also emphasized by the by the interest shown by external partners such as KPN that will finance two to three PhD students in the future. It is also noted that the group has a considerable collaboration with other groups at TUE and TUD. In the latter case collaboration is on network issues.

Given the present situation the prospects for the group are satisfactory, but can be greatly improved by the appointment of a permanent chair who can boost on a full time basis the group's activities. If resources for the group are not increased substantially, it should be considered to merge the activities into other groups or to coordinate closer with the other TU's where similar activities also tend to be too small.

TUE 4
Programme: **EM: Electromagnetics**
Director: Prof. dr. A.G. Tijhuis

Assessment:	Quality	4
	Productivity	2
	Relevance	4
	Viability	4

The Electromagnetics group is doing more fundamental research while also paying some attention to possible applications. The group is very methodology driven and focused on ways to shorten the computation time for complex electromagnetic problems. Scattering, photonic crystal circuit design and antenna design are examples of work carried out using the simulation tools developed. It is the impression that the application areas addressed are selected among those 'just showing up on the scene'. We do encourage that a strategic line is implemented for selection and development of application areas.

The group has a very good collaboration with the Mathematics Department at TUE and also collaboration with other groups such as the Opto-Electronics Device group. Collaboration with TNO is also extensive, while collaboration with, e.g., TUD and its group on Electromagnetics is missing. The possibility for closer collaboration with TUD should be explored. The group is popular with the TUE students evidenced by graduating about 15% of the candidates in electrical engineering.

We encourage that the group disseminates its fine results also by making software packages available. Moreover, we could also recommend that the group makes these nice results available and known to research groups outside the relatively narrow field of electromagnetism.

We acknowledge that the group has ramped up the number of PhD students during the last couple of years. We could also recommend expansion with a couple of postdocs to allow for more 'blue sky' research.

It would be desirable to have higher second money stream. The productivity in the past has been relatively low in terms of the number of PhD graduates as well as the number of papers. It is recognised that the number of PhD students has increased taking care of our first concern, but we strongly urge the group to implement a more aggressive strategy on publishing, while maintaining the fine quality.

TUE 5
Programme: **EPE: Electromechanics and Power Electronics**
Director: Prof. dr. ir. A.J.A. Vandenput

Assessment:		
	Quality	3
	Productivity	3
	Relevance	4
	Viability	4

Two major fields are aimed for by this programme, i.e. electro mechanics and power electronics. Specifically linear, planar and multi degree of freedom permanent-magnet type electromagnetic actuators are in the focus. Soft switched, high bandwidth power converters with emphasis on enhanced functionality are major topics in power electronic research. In general the group aims for low power applications, thus their topics are very much complimentary to the research done by the EPP group at TUD. This is a good example how coordination and collaboration between the EE faculties of both universities may work out.

The programme is of good quality containing mid- and long term perspectives resulting in a considerable number of external financial sources – in particular industry. Visions on a long term scale indicate a clear concept for the far future. Subjects such as interface management, multiport DC-DC converters and high temperature devices are envisaged on the power electronic part, whereas automotive actuators and a flying robot are examples for electromechanical visions.

Concerning the packaging and integration of low power electronic devices it is recommended to search closer contacts with the electronic groups.

Productivity is rather low, explainable by an emphasised focus on the quality of papers submitted to refereed journals. However, redirection of the research programme during the evaluation period became already effective showing a significant increase of PhD students and a considerable series of submitted contributions to refereed journals in 2005 thus an increase in the productivity is clearly visible.

Considering the portfolio and the dynamics, the prospects of the group are very good.

TUE 6

Programme:	**EPS: Electrical Power Systems**	
Director:	Prof. dr. ir. J.H. Blom	
Assessment:	Quality	4
	Productivity	3
	Relevance	4
	Viability	3

Mission and goal of this programme are well set towards the needs of today's and future electric power systems. The activities are well coordinated with the electric power groups at TUD. In a common vision on a new sustainable electric power system, the 'Intelligent Network' the group at TUE concentrates on the so called low voltage distribution side on topics such as: Power Quality, Electromagnetic Disturbance, Control and Diagnosis. A further strategic key activity is the research on pulsed power discharge generation with a typical pulse width in the nanosecond range for purification, catalysis and disinfection of fluids and gases. The former high voltage laboratory was adapted accordingly for the pulsed power activity, which, considering the excellent HV laboratory at TUD, was certainly a smart decision.

It is to be appreciated that the programme has established synergetic coordination, collaboration and sharing of facilities with the corresponding groups (EPS/HTM) at TUD. The openness for collaboration is underlined by the shared professor with TUD. Although the programme is of very good quality and the research topics chosen are of very good relevance, there is room for improvement by a sharper focus and a clearer strategy.

The remarkable success of the group is also measurable by a very good funding situation with sufficient external funding.

In terms of number of PhD thesis and number of publications the productivity of the group is good. Such a result has to be seen in view of the depression of the discipline during the evaluation period (see chapter 2.4.3). Improvement on the productivity is to be expected as the number of PhD students increased significantly in 2005.

The prospects of the programme are good as the group was stable even over the difficult years. However, as prof. Blom is due to retire in about three years, an early decision on his successor would help to improve the prospects of the chair significantly.

TUE 7
Programme: **ES: Design Methodology for Electronic Systems**
Director: Prof. dr. ir. R. Otten

Assessment	Quality	5
	Productivity	4
	Relevance	4
	Viability	3

The mission of the ES programme is to provide a scientific basis for design flows of integrated electronic systems. The group has clearly chosen for a methodological programme aimed at complete design environments and based on a formal algebraic approach (design algebras and optimization c.q. minimization based on Pareto frontiers). The ultimate goal is to provide integrated system designers with a predictable design trajectory. In order to keep contact with the IC and application communities the group has at least four staff members with the required skills. Very recently a new part-time staff member with yield and testing expertise was attracted. The group has an extensive professional network (both industrial and academic). The funding situation is good with a very well filled project portfolio.

The group is a clear frontrunner on integrated system design methodologies with both formal and practical virtues. It is definitely on par with top institutes like UC Berkeley, CMU and MIT. The group has significant output, which is valued as very good given the staff size. The relevance of the research is also clear, given the complexity of the designs and the technologies of the future.

The Committee likes to make some remarks with respect to the long-term prospects of the group. The prime concern is the relative isolation in which it operates. It is true that the group develops most needed skills, but it does so via people acquisitions and development of own staff members. Genuine cooperation with design and/or application groups seems more appropriate since that may alleviate the challenge of transferring methodologies.

Another remark is related to the absence of mixed-signal and analogue design expertise in the programme. This is not only because of the important front-end functionalities, but also because of analogue aspects of digital deep sub-micron and nanotechnologies.

TUE 8
Programme: **MsM: Mixed-Signal Microelectronics**
Director : Prof. dr. ir. A. van Roermund

Assessment:		
	Quality	4
	Productivity	4
	Relevance	4
	Viability	5

This research group is aimed at the design of front-end circuits for digital communication systems. Specifically they want to design transceiver circuits and Analogue-to-Digital and Digital-to-Analogue converters in silicon for communications applications. Although they have become very good at that, there is still room for improvement.

The group made a fresh start in 1999, with the advent of the new chairholder. All activities before have been discontinued, including the 1/f noise research. As a result of the change, the number of PhD's finished is still limited, but it is growing. Also this group has concentrated on presentations at conferences, including the prestigious ISSCC, but has failed to submit as many papers to the IEEE Journal of Solid-State Circuits. As a result it will take them somewhat more time to really make a breakthrough on the international scene. Nevertheless, the director is one of the three programme chairs of the workshop on Advances in Analogue Circuit Design. This is one of the best-known analogue-design workshops in the world.

The group has many relationships with other groups at the university, such as ECR, EM, EPS, CS, SPS and OED, but not with ES, which is somewhat surprising. The MsM group is really at the heart of communications systems, yielding all these relationships. The ES group apparently fails to provide design software on a level that can be used by mixed-signal system designers.

As the MsM group is heavily solicited by industry (among which Philips), they strive at a better balance between science and industry. Better support on G1 level would make it a lot easier for them to safeguard fundamental and frontier research.

The main difference with a similar group in Delft (ELCA, Long) is that the Delft group is more oriented towards devices and technologies. This Eindhoven group is more oriented towards communications systems. There is thus considerable difference in application focus.

It can be concluded that this group has much potential. It was formed fairly recently, but has already shown high quality in research. Its output can only grow in time.

TUE 9
Programme: **OED: Opto-Electronic Devices**
Director: Prof. dr. ir. M.K. Smit

Assessment:		
	Quality	5
	Productivity	3
	Relevance	4
	Viability	5

The mission of the Opto-Electronic Devices group is to play a leading role in the further development of semiconductor-based photonic integrated circuits for application in Broadband Telecommunications.

The chair was appointed in 2000 and has developed a very coherent and visionary research programme. This implied the ending of the GaN/GaAs based programme. The major focus today is the further development of photonic integrated circuits based on the use of three basic building blocks: waveguides, phase controllers and amplitude controllers. This work is currently extended towards digital photonics and it will be based on the recent development of a photonic flip-flop. Work on digital photonics is very advanced and speculative, requiring a clear roadmap view (taking into account competing technologies and possible application fields). This is important to keep a high relevance level.

The group is performing excellent research and is worldwide recognized as one of the leading groups in the area of photonic integrated InP based circuits. They have demonstrated a number of important breakthroughs in this area. The research group has also been very active and successful in attracting national and EC funded projects. The successful set-up of bilateral projects with local and international industry will form an important and challenging measure for the relevance of the future research and will to a large extent determine the prospects of the group.

There is very good research infrastructure available (the COBRA clean-room) that was built during the evaluation period. Because of the strategic importance of the programme, future support of this infrastructure, including the running cost, will be an important point of attention by the management. It might be interesting to put this in a European infrastructure perspective.

The photonic activities in the OED group started at the beginning of the review period. The group could build on the transfer of technology and key people (a.o. the chair) from Delft to Eindhoven. This transfer is a good example of concentration of expertise and it opened new opportunities that will be further exploited in future. The group is at the forefront of the field and has an excellent prospect to keep this position in future. It is expected that the productivity will ramp up in the near future.

TUE 10
Programme: **SPS: Signal Processing Systems**
Director: Prof. dr. ir. J.W.M. Bergmans

Assessment:	Quality	5
	Productivity	4
	Relevance	5
	Viability	4

The programme consists of four subprogrammes all aiming at advancing signal processing technology at the level of basic theory as well as in prominent application areas. This group is the outcome of a merger of the former signal processing and the medical engineering group. This merger has been implemented successfully through the following two actions: 1) the basic theory part has been expanded to encompass not only signal theory but also information and communication theory and 2) the incorporation of expertise in important application domains such as media signal processing, medical signal processing, and signal processing for communications.

During the period covered by the report, the group has been growing from approximately ten to almost twentyFTE of total research staff. There is solid evidence that the group has a quite high international reputation: several members are Fellows in their respective professional societies. They have also been able to get substantial external funding and they have produced a high number of PhD theses, publications and international patents. The quality and relevance of their research is excellent. It has contributed to several important industrial products and a successful spin-off company in the field of medical decision support systems has been set up.

Due to the size of the group, management issues have become an important topic for the group leader. The general trend that PhD research has to be funded on second or third money stream may be a problem in the future. In order to maintain and further develop the basic theory side of the research – which is vital in the long run – a certain amount of direct funding is desirable or even necessary.

The future prospects of the group are very good, due to their balanced mixture of theory and applications and their strong industrial contributions.

3.6. General remarks about Electrical Engineering at the University of Twente

The SWOT analysis is honest and valuable. It should however be complemented by action plans to remedy the weaknesses and to counter the threats. A proactive strategic approach is needed to avoid an overload of short term actions and lack of control, and to solve some structural issues.

The Committee appreciates the efforts that have been made for setting up a stimulating and workable structure, and estimates that the full effect still remains to be seen.

The Committee would like to express some points of appreciation, attention or focus:

- For seven out of the thirteen programmes the publication impact score is better than the world subfield average[4]. This is proving the high scientific quality of the research that the Committee witnessed during the site visit.
- University of Twente has a long tradition of an entrepreneurial university and of stimulating the students to start a spinoff company. The spirit of starting a spinoff is supported by the staff and has indeed penetrated the masters and PhD researchers community.
- The operation of the whole university is very business oriented, with costs charged for the space used and people allocated in the different programmes and services used by the programmes. So the programmes have to work with a budget in order to cover all these costs. The administrative load for such an approach is not negligible.
- Good cooperation with universities in China, and India, and cooperation in the national research schools.
- Although the 3TU Federation is supported fully by the management, the staff of some programmes is considering it more as a threat than as an opportunity. The management has a duty here to work on a model whereby the programmes can win in the Federation.
- There are strong and justified feelings of burocratic overload along the whole path from financial source in the ministery or in the EU administration until the workfloor.
- More than at other TU's it was sometimes difficult to evaluate the research of some programmes, because important parts of these programmes were outside this review.
- The review of a programme with a recently appointed chair can of course not be based on an extensive past record in the job and hence is somewhat limited and cautious.

The Committee encourages any action to reduce the number of programmes, which is thirteen now, and is considered to be too large.

Also the merger of the three faculties is not so evident here as at TU Delft, since many programmes here operate closer to physics.

The Committee assessed the following programmes of the University of Twente:

[4] See the Bibliometric Study, table 3, page 29.

University of Twente		
UT	1	BIOS: Biomedical and Environmental Sensors
UT	2	BSS: Biomedical Signals and Systems
UT	3	MI: Measurement and Instrumentation
UT	4	CE: Control Engineering
UT	5	TDT: Testable Design and Testing
UT	6	ICD: IC Design
UT	7	SC: Semiconductor Components
UT	8	SMI: Systems and Materials for Information Storage
UT	9	TST: Transducer Science and Technology
UT	10	IOMS: Integrated Optical Microsystems
UT	11	SAS: Signals and Systems
UT	12	DACS: Design and Analysis of Communication Systems
UT	13	TE: Telecommunication Engineering

3.7. Assessments per programme: UT

UT 1
Programme: **BIOS: Biomedical and Environmental Sensors**
Director: Prof. dr. ir. A. van den Berg

Assessment:	Quality	5
	Productivity	4
	Relevance	5
	Viability	4

A well-established group with international reputation that benefits greatly from the MESA+ facilities in fabricating Lab-on-Chip systems and in finding potential applications. During the reporting period the programme was strongly developed further and thoroughly anchored into the educational programme.

Chemical sensors appear a key strength and unique area of expertise. Although much of the expertise started in nanofluidics, interesting developments into the bio-area are being pioneered. The research area will have to be strengthened by adding Bio expertise to the competencies of the group. Further linkage to System aspects can lead to possibly more intimately connecting the work to the Bio Signals & Systems group.

In the opinion of the Committee, it would be beneficial to establish collaboration with a strong Biological institute to enhance the access to bio-expertise. A good connection to a local hospital is an important addition to the programme. We expect these pioneering activities to grow in the coming period. These trends should also help in increasing the PhD output of the group.

It is expected that the fields like Sensors and Actuators will synergistically overlap with the Lab-on-Chip arena. Thus it is advised that joint projects between this group and the Electronic Instrumentation group in Delft will become important. It is noted that also outside the Netherlands interesting cooperation possibilities can be identified.

Stronger linkage to the Industry should be targeted for, including validating the ambition to initiate spin-off businesses.

UT 2
Programme: **BSS: Biomedical Signals and Systems**
Director: Prof. dr. ir. P.H. Veltink

Assessment:	Quality	4
	Productivity	4
	Relevance	4
	Viability	3

The central theme of this programme is the field of Neural Engineering. According to the definition of the IEEE society Engineering in Medicine and Biology (EMBS) this is an emerging field that links engineering, physics, chemistry, mathematics and computer sciences with molecular, cellular, systems, cognitive and behavioral neuroscience.

The research themes covered by the group are:

- neurotechnology and cellular engineering;
- electrical stimulation of the nervous system;
- biomechatronics and human function technology;
- central mechanisms underlying chronic pain.

All these themes are highly relevant for our society.

The publication activity (especially in refereed journals) is very good. Direct funding is still high (approximately 2/3) and competitive research funding (second money stream) is low. The number of PhD theses was not high in the review period, but after the appointment of new professors in 2000 and 2003 the number of active PhD students has increased considerably and the number of finished PhD's is expected to increase in the next few years.

The group has set up two new curricula: Biomedical Engineering and Technical Medicine. Graduates of the latter are intended to treat patients, although it is unclear to what extent this will be possible.

The long term prospects of the group strongly depend on their success in bridging the gap between the engineering solid state part and the biological cellular tissue part.

UT 3
Programme: **MI: Measurement and Instrumentation**
Director: Prof. dr. ir. P.P.L. Regtien

Assessment:	Quality	3
	Productivity	2
	Relevance	3
	Viability	not applicable

The group is small and heavily involved in teaching, which means that the resources for research are limited. Despite this fact, quite diverse topics are addressed in the research. The number of finished PhD theses has been good in the beginning of the evaluation period, but has been going down. Among the five key publications in that period there are two textbooks, which are quite good for students. This again is a sign of the emphasis on teaching.

The programme is facing the general problem that measurement and instrumentation was originally a coherent area of electrical engineering but is now evolving into different directions: sensor systems on the one hand and signal processing for the instrumentation part on the other.

Since the EWI Faculty management has decided to terminate this programme, the main challenge is to find an appropriate research assignment for the programme staff. Depending on their respective specialities, either the signals and systems group or the control engineering group could be a new home, where they could actively contribute.

UT 4
Programme: **CE: Control Engineering**
Director: Prof. dr. ir. J. van Amerongen

Assessment:		
	Quality	4
	Productivity	3
	Relevance	4
	Viability	4

The team has a unique position in the Netherlands for a comprehensive systems approach to dynamic mechatronic systems, which is internationally recognized. They are integrated in the Drebbel Institute on Mechatronics at UT and in the embedded systems cooperation through their work on hardware in the loop. They have attractive research activities for modelling and simulation using bond graphs that has wide applicability. Hence the research has a very high quality.

The research productivity went through a dip over the past review period with a rather low average number of PhD defenses, but this trend is reversed from 2005 on with an expected average of three PhD's finished per year and a current team of ten to twelve PhD students. Part of this dip may be due to the responsibility of the programme chairman as department chairman. The weak financial situation as mentioned in the SWOT analysis in the report has also improved since.

The group has a solid strategy of performing relevant research for industry and society. Moreover their results are transferred to industry like ASML via projects, cooperations and several successful spin-offs and regional companies in the Mechatronics Valley Twente. They also have excellent cooperation with the application fields within the UT and through the DISC research school with the two other TU's.

In view of the generic nature of the system methods, the scope of applications of the group is very wide but attractive. For the future an increased focus on the very valuable topics of robotics, micro and nanomechatronics is projected.

UT 5
Programme: **TDT: Testable Design and Testing**
Director Prof. dr.ir. Th. Krol

Assessment	Quality	3
	Productivity	3
	Relevance	3
	Viability	2

The TDT group operating inside MESA+ is the 'EE part' of the CADTES research group. The other part of the group belongs to the Computer Science department and operated inside CTIT. That subgroup is therefore not assessed in this framework.

The TDT subgroup investigates Design for Test and Testing of a large variety of circuits and systems. Recently this variety has even been extended with rather esoteric vehicles like mems (with fluidics) and super-conductive devices. Another extension relates to hardware/software co-testing or system debugging.

From the industrial point of view testing is generally seen as a very relevant activity. Not only is it a necessity to distinguish at the end of the fabrication line the bad chips from the good ones, also the difficulty and the cost of testing is increasing enormously over time.

TDT is presently the only dedicated academic test group in the Netherlands and dr. Kerkhoff is the only test guru. This places some responsibility of the group in terms of quality and prospects.

The overall quality of the subgroup is rated good. For further improvement the Committee suggests: 1) to shift the test of esoteric devices to another MESA+ party or to the originating research groups and to concentrate on the various kinds of VLSI test and 2) to extend the subgroup with an expert on mixed-signal testing.

Also the productivity is the subgroup is good. Five PhD's in six years is nice, and 22 papers in refereed journals and 58 in conference proceedings is also good output. The score of the group in the citation index is poor, however.

As mentioned above the industrial relevance of the subject is very high. However, by looking at the list of present and future industrial projects, the industrial relevance is not matched by the relevance of the group in this field.

The viability of the group is insufficient. With the present crew and the present industrial project portfolio the group can perform only marginally. Also the fact that the TDT group has no real and substantial link to Philips Research and Philips Semiconductors is striking.

The Committee likes to suggest that dr. Kerkhoff writes together with one or two people from the relevant Philips organizations a white paper on the importance of academic education and research in the theory and practice of integrated chip and system testing, together with a solid realization plan.

UT 6

Programme	**ICD: IC Design**	
Director	Prof. dr. ir. B. Nauta	
Assessment	Quality	5
	Productivity	4
	Relevance	4
	Viability	5

The mission of the ICD group is to become leaders in analogue, RF, and mixed-signal circuit design under the ambition to obtain 'Fundamental solutions for practical problems', to publish in leading conferences and journals, and to deliver three PhD's per year.

The group is operational since 1998 and has become an established research partner for many academic and industrial design departments. It is most self-supporting. The considerable teaching activities constitute an important strategic role in the programme. First they bring in enough resources to pay for the technical support for a full-fledged test and characterization laboratory. Next it is a solid basis for recruitment of PhD students. In fact all PhD's students are recruited from their own master students and the number of twelve PhD's (good for an average turnover of three per year) has been reached in the mean time.

A clear research policy has been carried out with dedication and efficiency, and has developed a team with excellent status and results. The quality and the prospects of the group are accordingly. The productivity is very good, given the size of the group and the fact that a considerable amount of IC design work has to be done before most papers can be issued. The dip in the patent output is temporary. The relevance of the field is without question, the relevance of the group is very good, given the list of industrial partners and projects.

The Committee likes to point out that the position of the group in its field can still be improved by becoming slightly more outward looking (cooperation with sister programmes at other TU's, future topics like power, digital for analogue, analogue for digital, different technologies). We are confident, however, that this will be achieved over time.

UT 7
Programme: **SC: Semiconductor Components**
Director: Prof. dr. J. Schmitz

Assessment:		
	Quality	4
	Productivity	3
	Relevance	3
	Viability	4

Since the last reporting period, the group has evolved strongly. The transition, caused by the departure of eight experts, has been managed very well. The prime goal for the group is to educate top researchers and to successfully accomplish the PhD research.

The research programme is geared towards CMOS technology, with strong linkage to Industrial Partners. The challenge is however not to follow the ITRS Roadmap, but rather to find the 'key niche' in this broad field and the best combinations of overlapping expertise, and – where needed – employ the MESA+ facility. The aim of the group is to explore ultra low temperature processing (< 200° C) and realize 'Above Silicon' devices added to the base Si. When successful this research could be expected to lead to increased Patent output (strategy needed!), as well as transfers to industry.

To execute the experimental tasks, including 'home built equipment', almost the full suite of equipment available in the MESA cleanroom is needed and therefore an up-to-date cleanroom infrastructure (and competitive cost level) is of key importance – and a key challenge – to this group

After finishing their PhD's the researchers easily find relevant jobs in Nijmegen, Eindhoven and Leuven on Si specific topics. There are fourteen PhD relevant positions defined. The top journal output has been retargeted and has been rising as is needed with respect to the 2004 output level.

The customer base for this research is with the international supplier community, with new contacts to Alcatel and ASMI. It is advised to strongly connect to the 'large facilities community' (such as IMEC) in this domain. It is also advised to actively broaden up the scope of customer base beyond Philips. Increased synergy with the sensor and transducer groups is expected, including those at Delft and at the Holst Institute.

UT 8
Programme: **SMI: Systems and Materials for Information Storage**
Director: Dr. ir. L. Abelmann

Assessment:		
	Quality	4
	Productivity	3
	Relevance	3
	Viability	3

The group Systems and Materials for Information Storage explores new materials and devices for magnetic storage, which means that they are heavily involved in physics. Most publications are thus in Applied Physics and journals on magnetism. This group has generated many papers and has received many citations. The output (number of PhD's, international conference proceedings) in the reporting period has been low, but the publication quality and number of citations is high.

The initiative towards explaining the work for the general public is well recognized and should be continued.

Magnetic Storage research is performed on the full range of fundamental science to systems. The tape recording programme is being ramped down, which is well recognized and in line with worldwide trends. The magnetic probe recording (as executed in four UHV scanning probe systems) is very similar to the IBM approach and the Committee wonders whether there is sufficient differentiation.

The work on spintronics is being enhanced. In this effort, strong links with the UT TST, CE and IOMS groups are formed.

The group is losing its link with the physics department and therefore with the students in that department. This seems a clear handicap for the future, because the number of students in electrical engineering that are interested in this kind of physics research might not be sufficient.

The SMI group is a very frequent user of the MESA+ facility, which gives the opportunity to share expensive processing. The group does not actually need the highest possible cleanroom quality; deep submicron capability is not needed.

Positions for eleven PhD's have been defined with as funding base STW and FOM/EU. More direct cont(r)acts to the industry are advised.

Of all presentations seen, this group is closest to a Physics curriculum. It is to be debated whether the linkage to Bio application of magnetics should become part of the programme. The chair position issue has to be resolved rapidly.

UT 9
Programme: **TST: Transducer Science and Technology**
Director: Prof. dr. M.C. Elwenspoek

Assessment	Quality	4
	Productivity	3
	Relevance	4
	Viability	3

The Transducer Science and Technology group at University of Twente has been in existence for a number of years and is one of the largest users of the university's clean room facility. The programme leader is well known in the areas addressed by the group: Sensors, Actuators, Fluid handling, Micro fabrication and Nanotechnology. The number members of the staff is adequate to address the number of topics, but an increase in staff would help to further increase the impact in this important area of technology. It is appreciated that the group has collaboration with other groups in the Netherlands as well as internationally. It is, however, the feeling that an effort should be made to establish formal collaboration, e.g. with the other TU's.

The quality of the work is considered to be very good and at the level of the international competition. We do, however, encourage the group to increase its number of publications and also to consider taking more PhD's onboard. Especially the number of conference publications should be higher, considering the publication practice within the field. Even though the group is known to have more conference publications than those listed in the report, there is still room for more conference publications.

The relevance of the group's work is high, with activities within a field offering many new opportunities. The relevance is clearly emphasised by the impressive number of spin-offs from the group. We appreciate the clear strategy of the group to transfer knowledge to either existing industry or to new start-ups.

We encourage the group to pay attention to reliability issues and in that context also to packaging, since both are highly relevant for the further dissemination of the group's work. This could be achieved either by introducing the activities directly in the group's own research portfolio or by strategic alliances with university-industry consortia. Another issue (and opportunity) that needs careful reflection is the position of the group in Twente relative to the activities at the Holst Centre in Eindhoven. We urge the group and the university to carefully consider this issue.

UT 10
Programme: **IOMS: Integrated Optical Microsystems**
Director: Prof. dr. M. Pollnau

Assessment:		
	Quality	3
	Productivity	3
	Relevance	3
	Viability	4

The Integrated Optics Microsystems group at University of Twente has been in existence for a number of years addressing areas of integrated optics for telecommunications and for sensor applications. With the appointment of professor Pollnau as the new chair just one year ago the group is now in a transition period. The projects of the group are being reshaped. As a first step this has implied the addition of one new activity regarding active optical waveguides in new materials (such as KY(WO4)2). One application is new types of light sources for sensors. At the same time the old activities are continued at least until the external projects expire. It is anticipated that a concentration will be achieved within a couple of years. So, the approach taken for the reshaping is a soft bottom-up process. Our advise is to execute the rebuilding as rapidly as possible.

The quality of the work carried out in the past period is good, but in no way unique. The productivity of the group is acceptable. We notice that the new chair in his previous position had publications with a relatively high citation impact for some of the research that is now brought to Twente.

Relevance of the work carried out in the group is good with work disseminated in publications and through knowledge transferred to industry. It could be questioned, however, if the group in the future can make unique contributions to the telecom components area. Certainly it will be necessary to closely look into how the work compares with the competition. Relevance for the new work that is brought into the group could be high, but it will take time to fully assess the potential.

We encourage the concentration that the group plans, also considering the present number of people and the resources. We see the new ideas of the chair as having very interesting prospects. We also recognise that the ideas do involve new technology representing a relatively high risk. The next couple of years should be used to create a solid funding base and also to establish extensive contacts to industry and collaborators that can benefit from the new research areas. We do encourage further collaboration with the optics community in the Netherlands including the other TU's.

UT 11
Programme: **SAS: Signals and Systems**
Director: Prof. dr. ir. C.H. Slump

Assessment:		
	Quality	3
	Productivity	3
	Relevance	3
	Viability	2

The programme encompasses a large variety of topics (signal processing for wireless, in acoustics, in biometrics), including some biomedical signal processing, although a separate strong group is devoted to this field.

The work concentrates on the implementation of signal processing systems. The topics seem to be chosen based on opportunities rather than on a visionary strategy. In order to excel it is necessary to focus on fewer topics, which rely on a set of common methodologies.

The publications of the group are spread over a wide variety of journals and conferences, which is not enhancing the visibility and reputation of the group. This again is due to the lack of focus.

There is a need for a strategic orientation of the group, defining the specific area of excellence they are aiming at. In that area not only the implementation issues but also the basic theories and their advancement must be addressed. The Committee notes that these comments are already reflected in the SWOT analysis of the group. The two actions that are proposed in the SWOT analysis are to ask for a permanent staff anchor in biometrics, and to aim at more papers in journals in certain specific clusters. The Committee does not consider these actions adequate or sufficient. More specific strategies, goals and actions are necessary to remedy the current situation. Careful choices must be made to avoid spreading the resources too widely and action must be taken to build on strengths and competitive advantages, both on the fundamental level and on the level of the applications.

UT 12
Programme: **DACS: Design an Analysis of Communication Systems**
Director: Prof. dr. ir. B.H.R.M. Haverkort

Assessment:		
	Quality	3
	Productivity	3
	Relevance	4
	Viability	3

The research of DACS is centred around the design, implementation, evaluation and management of wireless and wire line communication systems, thereby focusing on the data link, the network and the transport layer, with excursions to the physical layer (optical access networks) and the application layers (web-servers, web-services and network management). The incorporation of quantitative evaluation techniques in the design and capacity planning process is a key ingredient in the work.

The group started in 2003 and was only two years active during the evaluation period. This makes the judgment on quality and productivity of scientific output rather difficult.

In 2003 a chair was appointed and a number of new staff members were attracted. Amongst the staff members there are part-time professors from industry who will bring in very valuable knowledge in the group and who will contribute to the necessary industrial links.

The chair and his staff have developed a programme based on the following research themes: mobile and wireless BB access networks, QoS support in the internet (NSIS, IPv6), security and QoS in ad hoc networks, network security impact for P2P applications and self-management/self-configuration of networks. From a more fundamental point of view, work will focus on model-checking/verification, algorithms for performance and dependability studies, rare-event simulation. It is clear that these are very relevant topics but at the same time they are rather diverse.

External funding was attracted successfully and a number of PhD students and temporary staff started in the group to work on these subjects. So far the productivity and quality is good (for a young research group) and further improvement is expected in the future.

The group has a good prospect, but special attention is required in order to focus the research. In the current programme, many topics are tackled at the same time which may result in a lack of critical mass in the future.

UT 13
Programme: **TE: Telecommunication Engineering**
Director: Prof. dr. ir. W.C. van Etten

Assessment:	Quality	3
	Productivity	3
	Relevance	3
	Viability	2

The mission of the TE Group is to develop and carry out a high-quality programme of contemporary research in the theoretical and practical aspects of telecommunications with special relevance to optical and wireless communications, and radar systems. The principal research areas are optical signal processing and networks, wireless communication techniques, statistical signal processing and detection, microwave techniques, and electromagnetic compatibility.

The group is building on a longstanding tradition in telecommunications (especially in optical fibre communication) and the chair has obtained worldwide recognition for his important contributions in the field of telecommunications. During the review period a number of subjects were added, broadening largely the scope of the research, resulting however in a lack of focus and critical mass and reducing the chances to obtain highly relevant scientific contributions. The group has a small and constant size with a large number of professors (full-time and part-time) compared to the number of PhD students. The group was able to produce a number of very high quality publications in specialised fields. The overall quality of the research strategy is however rather low, and a great opportunity was missed during the review period to build a very coherent and focused programme by attracting new permanent staff.

The output (e.g. number of PhD's obtained compared to the number of professors) was fairly low. It is expected that this will rise because a number of new PhD students have started recently.

The group has appointed during the review period a number of new professors in different research fields. This broadened the scope of the small group, but at the same time reduced the focus. It is strongly recommended to have a more focused research strategy and to increase the number of PhD students in order to build up enough critical mass in some focused areas. In addition, the current chair will retire soon, which is a concern regarding the continuation of the group. The score for prospects should be interpreted as a warning concerning the focus of the programme and the fact that a vacuum may be left when the chair will retire. The area of telecommunication engineering will remain however a very important field in the future and therefore appropriate action is required from the management. It is also recommended to line up with other related research programmes in Twente and Delft.

Appendix A: Reply of the three EE departments to the recommendations of the review committee

First of all we like to acknowledge the high value of the report which has been produced by the review committee. Both the detailed comments at the level of the programmes as well as the general findings and recommendations give practical guidelines for the strategy of the future. We are glad with the observation that the committee "is impressed by the quality and the quantity of the research in Electrical Engineering in the Netherlands" and "on the whole, considers the outcome of the review to be a very good result".

Our reply to the General Recommendations in paragraph 2.5 is as follows:

Ad 2.5 General Recommendations

a) Recruiting more EE Bachelor students

The three faculties acknowledge the concern about the decreasing number of first year Bachelor students. The analysis made in the report is correct. A joint 3TU effort will be initiated. Next to an already existing large number of public relations and recruiting activities, focusing on the recruitment of more female students will be an essential part of this activity. We will attempt to present electrical engineering in a more thematic manner (energy, environment, health, safety, biomedical and automotive). The presence of female students and staff at the promotion activities will be stimulated. More attention will be directed towards the staff and high-school teachers who are a prime source for motivating students to choose a technical study. On the other hand we should consider to make the transfer between high school and university more smooth and delay the selection point for EE at the university by introducing a broad bachelor.

A concrete plan of action will be formulated before the end of 2006.

b) Women in the EE workforce

The three faculties acknowledge the remarks on the need to attract more women in the EE workforce. This issue is being addressed on a 3TU level. A number of actions to promote a women friendly environment is envisaged (although our environment is not necessarily woman unfriendly, but insufficiently friendly to attract more than a proportional amount of women).

We continue to attract women on scientific positions and will pay attention to the composition of selection committees that should at least have one female member to ensure the involvement of networks of female scientists within the procedure. Further on an additional check is required on the availability of women, e.g. through the Web of Science. We also offer special coaching programmes for female scientists and, as long as the ratio men/women is unbalanced, create networks of female scientists.

c) Number of full professors in a programme

The three faculties appreciate the comment that more than one full professor in one programme strengthens the research performance in most cases and reduces the vulnerability of

the programmes. Furthermore the managerial tasks can be delegated to the professor with the appropriate skills, while the others can concentrate on their research topics. The faculties will adopt this policy for future appointments of full professors.

d) Role of the UD and UHD in the programmes

The increasing role of UD and UHD staff members in the PhD guidance has been noticed in several Boards of Promotions who decide on the admission of PhD's for promotion. The faculties feel this issue should be resolved at this level, which goes beyond the faculty level.

e) Recruitment of full professors

All faculties support the recommendation to start the recruitment of new professors at an early stage. On a selected number of positions, we attract a successor long before the professor retires ('dakpanbeleid'). This is already an established policy in all faculties.

f) Recruitment of master and PhD students

All faculties support this recommendation. However, the remark on the adverse effect of an unbalance between students from the Netherlands and abroad is not recognized. Generally speaking the students from abroad like to develop a professional career in the Netherlands and many of them get a job here indeed. To maintain a balance is important, but it is worthwhile to note that the international character of a curriculum also attracts Dutch students eager to develop their network of the future. Within several groups substantial numbers of foreign students are employed by Dutch companies after graduation. It is important that the industries hiring students from abroad offer them a career perspective, that bonds them to the company.
We feel the Dutch Universities are part of the global community as are the industries in need for the students.

g) Administrative overhead

We appreciate the recommendation to reduce the overhead at a University, national and European level. We also like to point out these overheads are created at a level which is beyond the control of the three faculties.

h) Develop programmes for inter-TU mobility

The recently created Centers of Excellence are an excellent tool to promote this issue.

Appendix B: Curricula vitae of the Committee members

Prof. dr. ir. Joos Vandewalle obtained the degree of MSc in Electrical Engineering, a doctoral degree and a special doctoral degree respectively in 1971, 1976 and 1984 at the K.U.Leuven. He was a postdoctoral researcher during 1976-1978 and visiting assistant Professor during 1978-1979 at the Electrical Engineering and Computer Science Department of the University of California, Berkeley. Since 1979 he is appointed at the Electrical Engineering Department of the K.U.Leuven, where he is Full Professor since 1986. His main research interests are in system theory and its applications in circuit theory, signal processing, cryptography and neural networks. He is an Academic Consultant since 1984 at IMEC (Interuniversity Microelectronics Center). From August 1996 to August 1999 and from August 2003 till February 2005 he was Chairman of the Department of Electrical Engineering. From August 1999 till July 2002 he was the Vice-Dean of the Faculty of Engineering at the Katholieke Universiteit Leuven. In the Spring of 2003 he was on sabbatical leave at the I3S laboratory of CNRS Sophia Antipolis, France. From February 2005 on he is a member of the Governing Board of Exact Sciences at the K.U.Leuven. He teaches courses in linear algebra, linear and nonlinear system and circuit theory, signal processing and neural networks. His research interests are mainly in mathematical system theory and its applications in circuit theory, control, signal processing, cryptography and neural networks. He has authored or coauthored more than 300 international journal papers in these areas. He is the co-author of four books and co-editor of five books. He is a member of the editorial board of several journals (Int. Journal of Circuit Theory and its Applications, Neurocomputing, Neural Networks, Journal of Circuits Systems and Computers, IEEE Transactions on Circuits and Systems, International Journal on Information Security). He was programme chairman or chairman of several international conferences (ISCAS 2000, Geneva, IJCNN 2004, Budapest, NOLTA 2005, Bruges). He was elected fellow of IEEE in 1992 for contributions to nonlinear circuits and systems and in 2005 as Vice-President Technical Activities of the IEEE CAS Society. In 1991-1992 he held the Francqui chair on Artificial Neural Networks at the University of Liège and in 2001-2002 he held this chair on Advanced Data Processing techniques at the Free University of Brussels. He is also Fellow of the IEE (UK). He received several best paper awards and research awards. He is a member of the Academia Europaea and of the Belgian Academy of Sciences and of a committee of the Research Foundation Flanders (Fonds voor Wetenschappelijk Onderzoek Vlaanderen).

Prof. dr. ir. Piet Demeester received his MSc and doctoral degree in Electrical Engineering from Ghent University in 1984 and 1988 respectively. He became full time professor in 1998. His research focused initially on the development of epitaxial growth techniques for the realisation of novel opto-electronic devices in GaAs based materials. This research further expanded to other materials including InP and GaN based systems. He was heading the research group on epitaxial growth till 1995 and this work resulted in about 250 international journal and conference papers. In 1992 he started a new research group on broadband communications networks, which is his current field of research. Work on multilayer networks, QoS and IP based networks, mobile networking, access networks, grid computing, network and service management, distributed software and software applications resulted in about 500 international journal and conference papers. More information is available at www.ibcn.intec.ugent.be.

Prof. dr. Klaus Fröhlich received a master of Electrical Engineering and a PhD in Technical Science from the Vienna University of Technology, Austria. After eleven years in Switchgear

and High Voltage Technology with Brown Bovery & Cie (later ABB) in Switzerland he became a full professor at the Vienna University of Technology in 1990. Since 1997 he has been a full professor of High Voltage Technology at the Swiss Federal Institute of Technology Zurich, Switzerland. Klaus Fröhlich is a fellow member of IEEE and chairman of CIGRE Study Committee A3 (High Voltage Equipment).

Prof. dr. techn. Josef A. Nossek received the Dipl.-Ing. and the Dr. techn. degrees in electrical engineering from the University of Technology in Vienna, Austria. In 1974 he joined Siemens AG in Munich and from 1980 he was head of the department responsible for electromechanical, microwave and digital filter design activities. In 1987 he became head of all radio systems design. Since 1989 he has been Full Professor for circuit theory and signal processing at the Munich University of Technology, where he teaches undergraduate and graduate courses on circuit and systems theory and signal processing and leads research on signal processing algorithms for communications systems, theory of linear systems and VLSI architectures. From 1999 to 2002 he was Dean of the Department of Electrical Engineering and Information Technology and from 2002 to 2005 Dean of Academic Affairs of the same department.
Josef Nossek served as Guest Editor for the IEEE Transactions on Circuits and Systems in 1993, as Associate Editor from 1991 to 1993 and as Editor-in-Chief from 1995 to 1997. He has been a Fellow of IEEE since 1993. He is on the Editorial Board of a number of scientific and technical journals. He was programme co-chairman of the IEEE International Conference on Acoustics, Speech and Signal Processing in Munich in 1997. He was a member of the Board of Governors of the IEEE Circuits and Systems Society from 1998 to 2000. He was President Elect, President and Past President of the IEEE Circuits and Systems Society in 2001, 2002 and 2003 respectively. He is Vicepresident of VDE (Verband der Elektrotechnik, Elektronik und Informationstechnik e.V.) 2005-2006.
His awards include the ITG Best Paper Award 1988, the Mannesmann Mobilfunk (now Vodafone) Innovations Award 1998, the Award for Excellence in Teaching from the Bavarian Ministry for Science, Research and Art in 1998 and the Golden Jubilee Medal of the IEEE Circuits and Systems Society for 'Outstanding Contributions to the Society' in 1999.

Dr. ir. Carel van der Poel completed a PhD on Nuclear Physics in 1982 and joined the Philips Research Labs., starting research in the Optics group on erasable Compact Disc via reversible phase transitions in thin film materials. Subsequently, in 1987, he initiated a project on non-linear optics to attain efficient frequency doubling of red light for high-density optical storage. This period included a one-year stay at Dupont Cental Research (USA). Thereafter, in 1990 he returned at the Philips Opto-electronics Center, participating in experimental research and development of short wavelength III-V semiconductor diode lasers. In 1995 he became sector-head of the Semiconductor Process Architecture research group, executing a research programme on Process Integration aspects of advanced Si-IC related process technologies, with subjects ranging from Special and Discrete devices, Bipolar devices, BiCMOS, embedded Flash memory to advanced CMOS technologies and embedded options thereof. In recognition of the above work he was awarded the Philips Research Invention Award in 1997. In 2001 he was appointed Senior Vice President of Philips Research, and in this function built the Philips Research Leuven organization. From 2005 onwards, he is responsible for the Process and Library Sector of Philips Semiconductors.
He authored and co-authored more than fifty international publications, has participated in a number of conferences and ITRS committees and holds several patents in the research fields mentioned above.

Prof. dr. Willy Sansen received the masters degree in Electrical Engineering from the Katholieke Universiteit Leuven in 1967 and the PhD degree in Electronics from the University of California, Berkeley in 1972.
In 1968 he was employed as a research assistant at the K.U.Leuven. In 1971 he was employed as a teaching fellow at the U.C.Berkeley. In 1972 he was appointed by the National Fund of Scientific Research (Belgium) as a Research Associate at the ESAT laboratory of the K.U.Leuven, where he has been a full professor since 1981. During the period 1984-1990 he was the head of the Electrical Engineering Department.
In 1978 he spent the winter quarter at Stanford University as a visiting assistant professor. In 1981 he was a visiting professor at the Federal Technical University Lausanne, in 1985 at the University of Pennsylvania, Philadelphia, and in 1994 at the University of Ulm. Willy Sansen was General Programme Chair of the ISSCC in 2002 and is now Vice-President of the IEEE Solid-State Circuits Society.

Prof.dr. Kristian Stubkjaer is Dean of Research at the Technical University of Denmark (DTU) since 2004. After research experience at the Tokyo Institute of Technology, Japan, and the IBM TJ Watson Research Center, United States, he became a faculty member at the Technical University of Denmark in 1983. His research has been in the field of active components for optical systems and networks. From 1985 to 1990 he was head of the Electromagnetics Institute. He served on the Danish Technical Research Council (Danish Ministry for Research) from 1991 to 1997. From 1997 he has been Danish member of the management committee for the European Research Programmes ESPRIT and IST. From 1998 to 2004 he was director of the Research Center COM. Kristian Stubkjaer has been active in several European research projects and been on the programme committees of ECOC, OFC, CLEO and many other conferences within optical communication. He is also an elected member of the IEEE LEOS Board of Governors.

Drs. Eric P.C. van Utteren worked for over 32 years at Philips Research in Eindhoven. He was manager of the VLSI Design Automation & Test department and later director for Information & Software Technology. After his retirement in 2003 he became Chairman of PROGRESS, the Dutch research platform on Embedded Systems & Software. PROGRESS manages presently 23 research projects with about 60 FTE combined from academia and industry.

Appendix C: Preliminary Assessment Form

Preliminary assessment for Programmenr.:

(only for internal use by the Committee) Reviewer:

Programme title (short): .....

5 = excellent, 4 = very good, 3 = good, 2 = satisfactory, 1 = unsatisfactory

Research Programme

How do you evaluate the programme with respect to:		5	4	3	2	1
1.	leadership					
2.	mission and goals					
3.	strategy and policy					
4.	adequacy of the resources					
5.	funding policies					
6.	facilities					
7.	academic reputation					
8.	societal relevance					
9.	balance of the strengths and weaknesses					
Overall						

Quality

How do you evaluate the quality with respect to:		5	4	3	2	1
1.	originality of the approach and ideas					
2.	significance of the contribution to the field					
3.	coherence of the programme					
4.	publication strategy					
5.	prominence of the programme director					
6.	prominence of the other members of the research group					
7.	quality of scientific publications (scientific impact)					
8.	quality of other results					
Overall assessment of quality						

Productivity

Considering the number of staff, how do you evaluate the productivity with respect to:		5	4	3	2	1
1.	number of PhD theses					
2.	number of scientific publications					
3.	number of professional publications					
4.	other results (if applicable)					
4.	distribution of published output within the group					
Overall assessment of productivity						

Relevance

Considering the stated mission of this programme, how do you evaluate the relevance of the research with respect to		5	4	3	2	1
1.	the advancement of knowledge					
2.	the dissemination of knowledge					
3.	the implementation of knowledge					
Overall assessment of relevance						

Vitality and feasibility

Considering the present status and future developments (if known) of staff and facilities, how do you evaluate the long-term viability of the programme		5	4	3	2	1
1.	in view of the past scientific performance					
2.	in view of future plans and ideas					
3.	in view of staff age and mobility					
Overall assessment of vitality						