European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 15 May 2014

COST 041/14

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action IC1401: Memristors - Devices, Models, Circuits, Systems and Applications (MemoCiS)

Delegations will find attached the Memorandum of Understanding for COST Action IC1401 as approved by the COST Committee of Senior Officials (CSO) at its 190th meeting on 14 May 2014.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action IC1401
MEMRISTORS - DEVICES, MODELS, CIRCUITS, SYSTEMS AND APPLICATIONS (MemoCIS)

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4114/13 "COST Action Management" and document COST 4112/13 "Rules for Participation in and Implementation of COST Activities" , or in any new document amending or replacing them, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to create a run a European-wide scientific and technology knowledge platform, in order to instigate interdisciplinary interaction for the development of innovative memristor technology and methods, for future self-learning hardware systems.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 52 million in 2014 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of section *2. Changes to a COST Action* in the document COST 4114/13.

TECHNICAL ANNEX

A. ABSTRACT AND KEYWORDS

The invention of the “transfer resistor”, or “transistor” as it is know today, is considered to be the greatest invention of the 20th century, as it forms the basis of all electronic systems. The next technological revolution will come through self-organizing and self-programming circuits and systems, which are similar to biological brains in that they can learn to perform tasks.

The recently rediscovered Memristor offers a computational substrate with plasticity, in which adaptive circuits can be efficiently implemented. This COST Action is aimed at bringing together researchers of different backgrounds to work in unison so as to overcome multidisciplinary barriers in the area of memristors. Bringing together device designers, device modelers, circuit theorists, analogue and digital designers, neuromorphic engineers and computation scientists will enable the defragmentation of current research efforts and is likely the to bring then next technological revolution. The creation of the hardware basis for future self-organizing/self-programming systems will really open up a wide range of application areas and new industries, e.g. humanoid robots to look after the elderly, self-driven vehicles etc.

Keywords: Memristor, memristive systems, memristor modeling, adaptive circuits, bioinspired circuits, non-linear circuits, memristor device simulation, memristor simulation, state-dependent resistance, self-organising/self-programmable circuits.

B. BACKGROUND

B.1 General background

The Memristor is a device that has recently become the focus of seemingly divergent research activities. In 1971 Leon Chua published his seminal paper on the theoretical prediction of a fourth fundamental circuit device. The paper postulated that besides the resistor, inductor and capacitor, a fourth fundamental circuit element would relate charge (time integral of current) with flux (time integral of voltage) through the device. This element, which he called a memory resistor, or memristor, would in effect have a resistance that depended on prior inputs. Though in the past the functionality of a memristor had been emulated in circuits using opamps and capacitors or with FPGAs etc., it had really never took off, until in 2008 researchers at Hewlett-Packard fabricated a single-device, man-made, memristor through a Pt/TiO_2/Pt structure, which was compact enough to make memristor elements practical. The creation of this memristive device has spurred research in this area and has led to the creation of other memristive devices, intended for a broad scope of applications, such as digital memory, digital logic and analog circuits. More importantly it seems that the adaptive properties of memristors are ideal for use in neural network and neuromorphic engineering applications. It is envisaged that memristive elements will lead to the next major technological revolution, enabling computational systems to overcome the current obstacles that have limited the use of self-organising/self-programming intelligent computational systems.

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The current research effort in this direction is highly fragmented and poses many challenges given that this area is highly multi-disciplinary. Researchers working on memristor device technology may disregard a device that is unsuitable for long-term memory storage, due to the memory being partially volatile. However, this device might be perfectly suited for creating bioinspired circuits. Furthermore, there is a great need for circuit theorists to “enlighten” device fabricators and circuit designers with respect to memristors; Hewlett Packard was not aware of the theoretical existence of memristors when they developed their first Memristor. Though not currently offered as part of standard semiconductor processes a number of companies are working towards integrating memristors with standard CMOS processes, including one of the project partners.

The COST Action is ideal for bringing together researchers working in the aforementioned fields, in order to enable the cross-fertilization between related but different research areas and by bringing together scientific communities that share similar problems but are currently lacking of a common network in order to share ideas and solutions. Furthermore by coordinating the research efforts it is possible to avoid inefficiencies due to duplication. Finally this COST Action can aid the transfer between Academia and Industry, given that a number of industrial players have expressed interest in joining the Action in this critical field of research.

B.2 Current state of knowledge

Memristor related research is currently distributed under various disciplines requiring very different skill sets. Firstly the theoretical framework that was extrapolated to predict their existence in the 70's, by Chua, is in the process of being refined and expanded so as to create the basis for categorizing and modeling of new devices. The non-linear properties and dependence on prior inputs or internal states make this area of memristor research quite challenging. Minimising the measurements required to determine the parameters of the model is one of the aspects under investigation. Device simulators that can deal with ionic movement in solids have yet to become available.

The discovery and fabrication of new memristive devices is currently proceeding at a phenomenal rate with memristive behavior being demonstrated on silicon nanowires, organic substrates, graphene, polymers, various metal oxides, metal alloys such as NiTi, metal-insulator-metal structures etc. This research is predominantly being driven by the need for faster, denser and more reliable memory technologies in digital circuits. However, the analogue memristive characteristics of these devices is often overlooked, since short-term profitability of purely digital devices is currently more promising, as they can be directly used with current computational paradigms. Analogue memristive devices promise to revolutionize the way that we compute, however they are expected to make their impact in the medium to long-term, since the tools for designing bioinspired circuits are still quite primitive in comparison to those available for digital circuits.

The design of circuits that utilize memristors in the past made use of transistors and capacitors e.g. the *Bernoulli cell*, to get block-level memristive properties. Such circuits required large chip areas thus making it unfeasible to build bioinspired systems that could outperform the conventional digital technology. With the opportunities opened by the latest generation of memristive devices, bioinspired systems are promising to change the computational fabric of today.

Currently there are various initiatives in Europe to learn about how the brain works, with intent to design a new generation of computational systems, e.g. The Human Brain Project and The annual CapoCaccia Conginitive Neuromorphic Engineering Workshop. Furthermore it seems that a further push will come from the Horizon 2020 EU research programme for ICT. EU investments in ICT are due to increase by 46% in comparison to the FP7 programme and topics to be supported amongst others are “ a new generation of components and systems”, “Next generation computing systems and technologies” and “advanced interfaces and robots”. In the United States a prominent related project is the SyNAPSE (*Systems of Neuromorphic Adaptive Plastic Scalable Electronics)* project, which aims to develop electronic neuromorphic machine technology that scales to biological levels, which has received over US $75million.

Memristors are expected to also impact more conventional circuit design, such as oscillators in addition to memory.

The COST Action is necessary in order to bring together the very diverse research communities and to exchange information on their needs and capabilities, thus coordinating future directions

B.3 Reasons for the Action

There is a great need for a new computational paradigm in order to overcome various approaching obstacles in computing, such as the end of “Moore’s Law”, due to current transistors approaching the atomic level and the “power wall” due to high thermal power density. Also the many-core computational paradigm has its limitations, since the complexity of programming and heat dissipation issues limit the scalability of such circuits. Self-organizing/self-programming circuitry is one way of overcoming the programming issues related to ultra-parallel hardware, whilst the sparse nature of neural computations is likely enable the creation scalable, high-complexity systems while using the high density of integration without the power issues. The advent of 3D semiconductor technologies is a step forward in reaching device densities similar to those found in biology, but which also require a shift in computational paradigm.

Self-learning future robotic companions, or stationary systems, designed to recognize if an elderly person is in distress, will have a crucial role in the social and economic well-being of the current and future generations. What is missing in the current state-of-the-art technology are devices like memristors that can store information in a compact and continuous manner, much like biological synapses. Such a technological advancement will have an immense impact of most application areas.

An experts network in the area of memristors is very important to facilitate the interaction between the different disciplines required to understand and utilize potential memristor technology. The network will make 'research-effort duplication' less likely. By working in sync it is possible to make more of an impact with less resources, much like a 1W laser can burn a hole in a material whilst a 1W light bulb barely lights it up. A diverse network of experts will avoid 'wastage' of research results, which may be considered to be useless by one community but are very useful for another.

Once such example could be leaky memories, which are not good for the digital world but which have their place in biological systems. Perception of speech relies on such leaky biological devices to filter particular spatio-temporal patterns in neuronal activity.

B.4 Complementarity with other research programmes

This COST Action is complementary to a multitude of European research projects and networks, some of which are HiPEAC, EUCog, PNEUMA, RAMP etc (see Section E.3). The topics of existing research networks are focused on broader aspects of future computing and lack the focus of this initiative. Typically, semiconductor device designers, the computer architects, digital and analogue circuit designers, circuit theorists, and computational neuroscientists work independently, thus inhibiting fast diffusion of information between the areas.

This COST Action brings these research communities together, not only to accelerate information flow and allow cross-fertilization of ideas but also to help develop a common framework for modeling, measurement, fabrication and utilization of Memristors in future computational infrastructure. The Action combines application domain expertise with knowledge stemming from various research areas. The already available knowledge obtained through national and EU-wide research projects will help in establishing MemoCIS as a focal point for launching the next big leap in bioinspired computational technology.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The main objective of the Action is to form a European-wide scientific and technology knowledge platform, in order to instigate interdisciplinary interaction for the development of innovative memristor technology and methods, which are required for future self-learning hardware systems.

C.2 Objectives

The main secondary objectives of the Action are:

1. To consolidate knowledge on existing device technology and highlight the advantages and disadvantages of the various memristor devices fabricated to date.

2. To stimulate the generation of new memristor technologies by highlighting the need for such devices and their properties.
3. To solve reliability issues related to large-scale manufacturing of memristors on classical semiconductor technologies.
4. To consolidate, to improve upon and to disseminate memristor theory to device and circuit designers
5. To consolidate models and simulation tools and to disseminate know-how for a fast adoption of memristor technology.
6. To encourage the design of new circuits and systems which are not necessarily bioinspired, e.g. oscillators, chaotic encryption systems etc.
7. To encourage the design of self-learning bioinspired circuit primitives and to demonstrate their potential, e.g. various synapses, neurons etc.
8. To encourage fabs to incorporate memristors as optional devices in mainstream semiconductor technologies.
9. To create semiconductor intellectual property cores/cells containing memristors to enable design reuse and faster system integration.
10. To develop complex memristor based systems, which include the demonstration of self-organising structures.
11. To contribute to the training of early-stage researchers and the establishment of a network of young researchers on the topics covered by MemoCIS.
12. To stimulate and promote collaborative research by structuring and developing concept reports for future research proposals on the national and European level.
13. To strengthen/establish links with industrial partners and promote academic and industrial collaboration, eventually resulting in commercial applications.
14. To identify and promote grand challenges pertinent to memristive technologies.

The following quantitative indicators will be used to evaluate these specific objectives:

1. Number of researchers, groups and companies participating actively in the Action activities

2. Number of joint papers in journals and conference proceedings
3. Number of transnational collaborative research proposals prepared
4. Number of training activities and number of people trained
5. Number of researcher exchanges and scientific missions supported by the Action
6. Number of new devices, software and hardware tools developed
7. Number of scientific achievements generated in this COST Action.

The suggested quantitative evaluation criteria are listed in Section C.3.

C.3 How networking within the Action will yield the objectives?

The above objectives will be achieved through a close collaboration between the partners of this Action, which will bring together researchers working in various different fields, to enable cross-fertilization between research areas, knowledge transfer and technology transfer between areas and between Academia and Industry. An important way to achieve the Actions objectives is by research exchange visits between different organizations. In these short-term scientific missions new valuable knowledge is gathered with regards to the theory and the applications of the methods and tools investigated, and the foundations for future collaborations are set. The expertise and knowledge of leading European experts in the scientific fields of the Action will be infused through networking to other Action participants. The exchange of the latest scientific results both from academia, industry and research organizations will be instrumental in achieving the Action objectives.
The means to achieve these objectives are summarized below, providing quantitative figures for evaluation:

1. Networking will reach at least 60 partners in 18 countries (50 partners in 13 countries have already signed up for this Action)
2. Networking will be extended to at least 10 companies (4 companies, of which 3 are large semiconductor corporations have already signed up for this Action)
3. Minimum 10 collaborative, transnational projects on specific topics will be submitted to national and European level programs

4. Management Committee meetings will take place 2 times a year to facilitate better and more intense communication among members
5. A project website listing upcoming and past activities, paper abstracts and presentations will be prepared by the Action participants
6. Four annual workshops/training schools
7. Two meetings per year
8. A total of 100 publications in international peer reviewed journals and conference proceedings as a result of the scientific projects and yearly conferences of the Action
9. 20 scientific achievements created by Action participants in collaborative work within the Action
10. 20 short term scientific missions and research exchanges within the Action
11. Annual progress reports by each Working Group
12. A final report describing the project outcomes and successes
13. Organization of at least 4 special sessions at international conferences.

C.4 Potential Impact of the Action

The Action has both technological and societal benefits. It supports cutting edge research in memristor technology and applications, through collaborative work and provides a practical viewpoint due to the participation of the industry. The main benefit is the exchange of expertise and knowledge, the development of a scientific community that may be active in promoting other actions at the European level, and the training of young scientists with a multi-disciplinary curriculum. The networking dimension of the Action will have immediate benefits in preventing unnecessary duplication of research work between different groups. It will coordinate the existing efforts and set goals and directions for future work. In this way it will help the community to optimally distribute research tasks, time and person-power.

In particular, the benefits of the Action are:

- Creates the critical mass for a strong interdisciplinary research team that can tackle challenging engineering problems related to self-learning hardware

- Promotes the technology transfer from academia to the industry
- Promotes knowledge transfer between organizations and researchers, as well as between research areas through cross-fertilization of ideas
- Facilitates collaboration between researchers with diverse backgrounds and expertise to create synergies
- Provides the opportunity to initiate conferences/symposia on memristive technologies
- Creates future computational foundations for solutions to a wide range of real life problems that have a direct effect to the safety, well-being and prosperity of society
- Ensures that the consortium partners have a high level of up-to-date expertise of the latest science and technology developments in the areas of the Action

This COST Action will be an effective way to close the gap between European industry and academia, and the technology gap between the USA and Europe, by making faster and more efficient use of the scientific know-how in Europe through increased networking at the top level. The next leap in electronic technology is of crucial importance to the European well-being and economy, as well as an enormous scientific and commercial growth potential; an Action on these topics is therefore a timely and much-needed contribution to Europe to gain a technological edge over the USA which is also investing heavily in these areas.

C.5 Target groups/end users

There are two main target groups in this Action:
(a) Researchers in academia and research organizations
Research in the fabrication, the modeling and the application of memristors is a vital and crucial scientific area. A large number of European researchers are searching for ways to overcome the obstacles presented by the end of 'Moore’s Law' and the 'Power wall' and are expected to participate in the Action activities through their Universities and research laboratories/organizations. Basic research work in the fields of the Action can be generalized in other related research areas, thus targeting a wider scientific audience. Many of the key academics in this area have been involved in the preparation of the proposal.

(b) Researchers in industry and government organizations

Self-programmable hardware is the future of electronic systems and thus is likely to attract the attention of a multitude of industries, government organizations, SMEs, start-ups and spin-off companies. They will be the end users of the generated knowledge, the research results and the regulatory or scientific methodologies developed by the Action researchers through the collaborative activity. Some of the key industrial players have been consulted whilst writing the proposal and whilst others will be invited to the meetings of the Action.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The activities of this Action will concentrate on four essential research areas, all of which are encompassed under the general umbrella of the MemoCIS proposal. These are: “Memristor Device Technology”, “Memristor Theory, Modeling and Simulation”, “Memristor-based Circuits” and “Memristor-based Systems”. A particular aim of this Action will be to make sure that scientists and engineers learn at least the basics of other constituent parts and understand how it all ties together so that they can better focus their efforts in their particular specialization. Furthermore this will lead to the cross-fertilization of ideas between the areas and will assist in achieving one of the fundamental objectives of this Action, which is to bring together researchers from different research fields to enlighten each other and collectively overcome common problems.

The area themes are chosen so as to allow inclusion of new members to join at a later stage, or members to join more than one theme. This Action is open and flexible and welcomes the participation of new members.

In the area of Memristive Device Technology the most important research tasks relate to increasing the reliability of existing devices and finding ways to integrate them into mainstream semiconductor technologies in a seamless manner. Founding members of this consortium include world-renowned universities, with state-of-the art fabrication facilities, as well as key commercial semiconductor fabs. The industrial partners have research experience and commercial fabrication of non-volatile memories, some of which have been identified to have memristive properties. A key facilitator to creating new devices is the development of modules that can handle ionic movement in solids in physics based simulators such as TCAD.

In the area of Memristor Theory and Modelling it is envisaged that the further development of computationally efficient models and open source libraries, e.g. in VerilogA, are of paramount importance, since without these it will be difficult for circuit and system designers to integrate

memristors into their design flows.
In the area of Memristor based circuits the most important research task is to create a selection of basic circuits to be utilized in many application areas. These will form the basis of many adaptive systems to come, both in classical electronics as well as in bioinspired electronics. Adaptive amplifiers and filters are very important for future sensory systems whilst biocomputational primitives, such as STDP synapses will form the underlying computational fabric of future self-learning systems.
The final area of "Memristor based systems" will utilize the knowledge framework developed in the other three areas and develop new architectures and solutions for particular applications. This area is also expected to contribute information on requirements to other areas at the start of the project. E.g. state that needs/specifications for various degrees of memristive volatility, depending on which part of a bioinspired system the components will be used in.
Though the emphasis of this proposal is on Memristors, less mature devices of the same family, such as that Mem-capacitors and Meminductors, are also within the scope of these activities.

D.2 Scientific work plan methods and means

The activities of this Action will be organized in four Working Groups (WG). Three WGs will promote research specifically dealing with the creation of a knowledge platform on which future systems can be built upon, whilst the fourth will have a more applied system approach. Each workgroup will prepare an overview of their subject area to be presented to the other workgroups. This measure is designed to enhance cross-fertilization of ideas between the areas and will assist in achieving one of the fundamental objectives of this Action, which is to bring together researchers from different research fields with common problems.
The Working Group themes are chosen so as to allow inclusion of new members to join at a later stage, or members to join more than one Working Group. The objectives of the four Working Groups are:

WG 1: Memristor Device Technology

- Existing device technology consolidation
- Development of new memristor devices
- Development of device simulators that can handle ionic movement simulation in solids (TCAD)
- Solving issues of robustness, reliability and large scale manufacturing

- Solving issues related to non-homogeneous technology integration.

WG 2: Memristor Theory, Modelling and Simulation

- Development of Memristor theory and educating circuit designers
- Development of computationally efficient models
- Creating an open source libraries e.g. VerilogA, of models

WG 3: Memristor-based Circuits

- Development of nonlinear circuits and oscillators
- Development of adaptive amplifiers and filters
- Memristor-based digital logic
- Bio-computational primitives e.g. STDP synapses, axon-like transmission paths etc.

WG 4: Memristor-based Systems

- Self-organising architectures
- Sensory platforms
- Non-homogeneous technology simulation and integration
- Other unconventional applications, e.g. memristor biosensing systems

The COST Action will facilitate the coordination and concentration of the efforts of the individual participating entities, as well as it will initiate a number of additional research projects which will be carried out by the participants. The projects will be arranged in such a way that they will enable interdisciplinarity and maximum interaction between the Working Groups.

E. ORGANISATION

E.1 Coordination and organisation

The COST Action will be coordinated by a Management Committee (MC). The Chair and the vice-Chair of the MC will be elected at the kick-off meeting to be held at the start of the Action. Each signatory country will have two representatives in the MC. In addition, Chairs and vice-Chairs for the Working Groups, a web site Coordinator and Transfer of Knowledge Coordinator will be appointed at the kick-off meeting. A Secretariat for the MC will also be appointed that will be supporting the Chair in administrative matters.

Following the kick-off meeting, MC meetings will take place twice a year. These meetings will deal with all strategic issues concerning the Action such as the approval of new Working Groups, the termination of existing Working Groups, organization of workshops, approval of Short Term Scientific Missions (STSMs), ways to improve communication between consortium partners, ways to improve dissemination of the results of the Action, etc. The MC will also be in charge of coordinating the editorial production of the Annual Reports of each WG, which are due at the end of each year that the Action is running. For each WG the first Annual Report will contain an extensive state-of-art review, the next two Annual Reports will contain the progress of the Action, and the last Annual Report will contain the conclusions of the Action. The MC will decide on urgent matters by electronic communication (e-mail).

The research associated with the Action will be coordinated by the Working Groups (WG), through their Chairs and Vice-Chairs. In order to promote collaboration among the researchers (and thus fulfilling the overall objective of the Action), the partners will also be encouraged to additionally form Focus Areas (FA) targeting specific applications and research problems within or across WGs. Furthermore, FAs allow additional flexibility to the Action, in order to accommodate new members and new applications. To encourage participation and initiatives of early-stage researchers, the Vice-Chair of each WG will be an early stage-researcher.

Four annual workshops/training schools will be organized in parallel with the MC meeting. The workshop/training schools will be open to the entire scientific community and can potentially be held jointly with some other conference or workshop. The goal of the workshop would be to summarize the current status and future trends of the research field. Participants and invited speakers from European and non-European countries, such as Japan and the USA, will update the members of the COST Action on the most recent results, as well as on general trends within the device, modeling, circuits, computational neuroscience and neuromorphic engineering communities.

Short Term Scientific Missions (STSMs) for exchange of students, as well as senior scientists, between the participating research groups will be promoted by the MC. Young researchers and women scientists in particular will be encouraged to participate in such exchanges. A website for the Action will also be set-up at the start of the Action. This website will assist in the exploitation and dissemination of the results of the Action, both externally and internally. Through this site, the partners will be provided with access to the various technical reports, related projects, STSMs, etc. The WG chairs will be responsible for maintaining the website.

E.2 Working Groups

The activities of this Action will concentrate on four main research areas, three of which promote research dealing with the creation of a knowledge platform on which future systems can be built upon, whilst the remaining research area develops a system level framework for bringing together the various application domains. This will lead to the cross-fertilization of ideas between the areas and will assist in achieving one of the fundamental objectives of this Action, which is to bring together researchers from different research fields with common problems. The area themes are chosen so as to allow inclusion of new members to join at a later stage, or members to join more than one theme.

Based on these research areas, this Action will establish four Working Groups (WGs) that will be responsible to complete all the scientific goals set forth by this Action. Working Group Chairs will be elected and their responsibility would be to coordinate the activities of the Working Groups, lead the scientific discussions, and provide the Management Committee with an annual report on the progress of the Working Group. A WG vice-Chair will also be elected. All researchers participating in this Action will be invited to join one or more Working Groups, depending on their research interests and activities. In the course of the Action, new Working Groups can also be established depending on the needs of the consortium. The contents of the four Working Groups are:

- WG 1: Memristor Device Technology
- WG 2: Memristor Theory, Modelling and Simulation
- WG 3: Memristor-based Circuits
- WG 4: Memristor-based Systems

E.3 Liaison and interaction with other research programmes

This Action will establish liaisons with other complimentary COST Actions, e.g. COST Action MP0805 (Novel Gain Materials and Device Based on III-V-N Compounds), COST Action TD1003 (Bio-inspired nanotechnologies from concepts to applications), and interact with existing FP7 Networks of Excellence, e.g. HiPEAC Compilation Architecture, which is in the area of high-performance computing and embedded computing systems. Furthermore we will actively plug into relevant multidisciplinary workshops with joint seminars or special sessions, such as the annual CapoCaccia Cognitive Neuromorphic Engineering Workshop, where experts in neuroscience, neuromorphic engineering, cognitive science and robotics discuss about open problems in these

fields and form workgroups for some hands-on work.
Interactions with other COST Actions and FP7 European research programs, e.g. the FP7 “Real Neurons-nanoelectronics Architecture with Memristive Plasticity” (RAMP), can be established by joint meetings, for example as part of a commonly organized Conference. The outcome of such interactions will be joint publications as well as product development between partners of this Action and researchers external to the Action.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and will also be committed to considerably involve early stage researchers. Both these items will be placed as standard items on all MC agendas. To promote gender diversity and balance of the researchers involved in this Action, the Management Committee will be responsible in building and maintaining diversity in all teams by nationality and race. Furthermore, every effort will be made to maintain a good gender balance in the elected leaders of this Action (Chair, Deputy-Chair, MC members, WG leaders) that are responsible for all coordination, organizational and other related responsibilities. In addition, early stage researchers are also invited to participate to MC meetings as auditors.
To promote gender diversity this Action will promote enhanced involvement and visibility of distinguished women senior researchers in co-advising and cross-training exchanges, seminars, tutorials and conferences. Similarly, women team members and postgraduate students in this Action will be specifically supported to participate in exchange visits abroad, conference presentations of their work, leading and peer-mentoring of undergraduates in team projects etc, to provide live examples of success in postgraduate education.
This Action will also encourage the participation of early stage researchers (MS, PhD students and young postdoctoral scientists) and in particular, young faculty in the research projects that will be carried out within the WGs. Four of the initiators of this Action are young faculty, including one female young faculty. Moreover, each WG will have a vice-Chair, who will be an early-stage researcher. Finally, as part of the Action the consortium will encourage and promote short-term scientific exchanges and visits for young researchers on a competitive basis.

F. TIMETABLE

The Action will have a total duration of four years. Every year there will be two (2) Management

Committee (MC) Meetings. Furthermore there will be an annual workshop/training school (WTS) as shown in the following table.

Month	Year 1	Year 2	Year 3	Year 4
1-3	Kickoff Meeting Website Operative	STSM planning	STSM planning	STSM planning
3-6	MC Meeting WTS	MC Meeting WTS	MC Meeting WTS	MC Meeting WTS
8-10	MC Meeting	MC Meeting	MC Meeting	MC Meeting
12	Annual Report 1	Annual Report 2	Annual Report 3	Final Report

The Action will start with the Kickoff Meeting where the Working Group (WG) leaders will be elected. Furthermore, within the first 3 months of the Action, the Action website will become operative.

The Action will organize four multi-day events that combine a workshop with a PhD training school. During these events various Management Committee meetings will be scheduled. The remaining MC meetings will be two day events where half day will be devoted to the MC meeting and the remaining time will involve technical meetings typically organized by the Working Groups (WG). During the Workshops/Training Schools and MC Meetings, renowned experts from Academia and Industry will be invited to give presentations. Additional technical meetings can be organized ad-hoc outside the MC meetings if necessary. Each MC meeting will take place in a different participating Member State in order to allocate organization responsibilities among each partner and promote collaboration. Finally, it is expected that after the Kickoff meeting and for the duration of the Action, there will be several Short Term Scientific Missions (STSM) among the different research groups. In the first months of each year, calls for tentative planning of Short Term Scientific Missions will be undertaken via email, in order to give the MC time to evaluate and prioritise these missions and to take the final decisions at the next MC meeting. The annual reports will analyse the progress made on each of the 14 objectives stated in section C2, and describe any corrective actions undertaken (or planned) so as to ensure the attainment of the Action's objectives.

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: CH, CY, CZ, DE, EL, ES, FR, HU, IL, IT, NL, NO, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 52 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The intended target audience for the dissemination of the Action results and findings is the following:

- The COST Action Members
- The international research community in the areas of devices, analog and digital circuits, computational neuroscience, neuromorphic engineers etc.
- International and regional industry in related fields (with a strong focus on SMEs)
- Policy makers and planners (such as research foundations and government bodies in the EU and the USA)
- Standardization bodies, (such as the European Committee for Standardization and ITU-T (International Telecommunications Union))
- Professional bodies, such as the IEEE.
- Trade/professional magazines
- The general public

H.2 What?

The intended methods of dissemination are the following:

- Action website/database listing: upcoming and past activities, annual reports from the Action, paper abstracts and presentations prepared by the Action partners, technical information of developed tools (software and hardware), abstracts of joined research proposals initiated by the Action partners, Action progress reports (the website will include both public and private password protected sections for working and coordinating documents)
- Electronic discussion forum, hosted by the Action website, for interactive communication and support between the Action partners and other partners and individuals interested in the Actions activities (with a special focus on PhD-students, post-doctoral fellows and other young researchers)
- Two meetings of the Action partners per year, for internal dissemination
- Annual workshops/training school, with public proceedings
- Publications: joint papers in international peer-reviewed journals and conference proceedings, technical reports
- Organization of special sessions at international conferences
- Dissemination of the results to the Industry will be mainly carried out via personal contacts of the Action partners as well as during international and regional conferences
- Contributions to standardization bodies and invitation to such bodies to participate in scheduled standardization meetings
- Distribution of the Action findings and recommendations to the general public.

H.3 How?

Dissemination methods are classified as internal and external. The internal dissemination activities target all Action partners, in order to make all research results, findings, and recommendations available to them. The outline of the Action website will be presented and finalized at the kick-off meeting, so that it can be launched as early as possible. The website will act as an on-line database and communication and support tool (through the electronic forum) among the partners, allowing efficient and quick dissemination of research results. Website accesses, and other related statistics, will be collected and analyzed on an annual basis, so that the websites impact (in terms of format and content) can be evaluated and updated as needed during the course of the Action. Internal dissemination will also be enhanced through the scientific exchanges of researchers, the periodic

scheduled meetings between the Action partners, and the workshops/training schools, which will target young researchers and the industry for science and technology transfer purposes.
External dissemination activities target audiences beyond the Action network and intend to make public the results of the research efforts related to the Action through participation in International Conferences, joint publications in international peer-reviewed journals, organization of special sessions in the field, and the creation of liaisons with other COST Actions and Networks of Excellence. The Action website will also play an important role in the external dissemination activities. Dissemination to the general public will be achieved via popular science articles, seminars, and audio and television broadcasts. Finally, it is emphasized that the Action will participate in platforms and coordinating actions, and will focus on the Industry University collaboration by allowing the Industry Members to take on a consulting role especially towards young researchers and shape the research efforts.
Other dissemination efforts will focus towards the enlargement of the Actions size by attracting and including additional important partners from the European research community in fields related to Memristors, as well as smaller groups and upcoming young researchers from EU Member states. Besides the website which will include invitations to join the Action, recruitment of new collaborators and open research positions related to the Actions activities will be announced in the academic press, at international and regional conferences, as well as other on-line services (such as the website ERACARREERS, the Pan-European ResearchERs Mobility Portal). Furthermore, specially appointed Action members will act as contact persons to the external scientific community for recruiting new Action partners, supporting researchers outside the Action interested in integrating the Action scientific results and tools in their research (with special focus on graduate students, post-doctoral fellows, and other young researchers), and communication with industry representatives. These outreach activities will be collected and analyzed on an annual basis, and included in the yearly Action progress report.