INTRODUCING CIRCUITS AND SYSTEMS

Bruno Riccò and **Paolo Bellavista**
University of Bologna – DEIS, Viale del Risorgimento, 2, 40136 Bologna, Italy

Keywords: Information Society, Information and Communication Technologies, Analog Signals, Digital Signals, (Electronic) Circuits, (Electronic) Systems, Computers, Microelectronics

Contents

1. The Purpose of this Introduction
2. The Importance of CAS
3. Circuits and Systems
4. Integrated Electronics
5. Digital, Analog, and Mixed Circuits
6. The Great Convergence of Telecom and Computers
7. CAS Technologies
8. CAS Design
9. The Future of CAS
10. Conclusive Remarks and Theme Organization
Glossary
Bibliography
Biographical Sketches

Summary

This chapter, introducing the theme “Circuits and Systems”, has two main goals: i) attracting the readers’ interest and ii) putting all specialized subjects targeted in the following topic-level contributions in the proper general context. To this purpose, first the extraordinary importance of the subject for the modern "information society" is discussed from different points of view. Then, the difference (largely arbitrary and context-related) and the relationships between “circuits” and “systems” are clarified. Successively, the founding pillars of the theme are briefly illustrated in order to clarify: i) the nature of (electronic) signals, which are essential elements in processing, transmitting, and receiving “information”; ii) the basic differences between analog and digital signals, with the latter now largely dominant and having enabled the convergence of computer and telecommunication worlds that represents a major factor in the current phase of social, industrial, and cultural development; iii) the role and complexity of microelectronics, which is the real technological engine of the "information society". Some glimpses about the future of “circuits and systems” are then finally described.

1. The Purpose of this Introduction

The subject of this volume, Circuits And Systems (CAS), is very important, even “central” to our modern society, often called “Information Society” to indicate its characteristic feature. In particular, this means that nowadays production, distribution, and treatment of “information” (e.g., data, news, and music) represent the most important human activities in the present phase of development, from an economic, social, and cultural point of view.

Presenting the volume dedicated to such a subject, this theme-level Introduction offers a general overview dedicated to a vast public with a general technical background, particularly, but not exclusively, students at the beginning of their university studies, with two main aims: attracting the readers’ interest; putting in the right general context all specialized subjects targeted in the volume. For these reasons, the treatment intends to be easily comprehensible to a large number of people, while more technical discussions are left to the various chapters of the volume.

To give a fresh and hopefully intriguing introduction to the volume, this theme-level chapter goes rapidly through all main aspects of the subject. First, of course, the CAS central relevance in the framework of modern society is illustrated. Then, the meaning of the intermingled terms “Systems” and “Circuits” is discussed and clarified. Following that, the basic concepts of “digital”, “analog”, and “mixed” circuits (and systems) are briefly revised, and the great convergence of computers and telecommunications, characterizing the high-tech revolution of our time, is discussed. Short reviews of microelectronics and computer-aided design, enabling technologies at the root of CAS, are also included in order to make this introduction more complete and informative.

2. The Importance of CAS

The expansion of information on traditional media but, above all, on new ones (in particular, of course, the “Web”), perhaps represents the most evident aspect of the situation. But another spectacular evolution has come from the enormous expansion of telecommunications, in particular of the mobile ones, that has made it possible to get all information of interest (not only voice, but also, for instance, messages, music, and video) everywhere and whenever desired.

As discussed in some details later, this evolution is the result of the convergence of the digital world of computers and the analog one typical of telecommunications, that has led to a great expansion of the concept of “information”, ranging from data management (essential for any scientific, economic, administrative, social and industrial activity) to new areas, such as entertainment and games.

Actually, all aspects of modern society have been drastically modified by the technological revolution started in the 1950s, so that no financial or industrial activity can be imagined without the presence of ever more powerful electronic systems, taking care of the fantastic amount of data exchanged by banks, public administrations, hospitals, etc. or controlling the operation of production lines, industrial machines and plants, etc.

All this has been made possible by the extraordinary development of the so called Information and Communication Technology (ICT) and by its “pervasive” nature, namely the capacity to enter virtually in all products, processes, services, and objects of our world and life. Some of the consequences of this situation are obvious to everyone, when, for instance, booking a ticket for a plane through a system that explores a vast amount of data in search of the best available possibilities, overcoming national, language, and company barriers. Or when drawing money, safely and in no time, from an automatic teller machine far away from our home. Other examples are less exposed to the general public, but it is not difficult to understand, for instance, that the fabrication lines of all main industries (from automobiles to semiconductors) have become so complex that could not work (with the current specifications) without being controlled by sophisticated automatic systems. And the same holds for all complex structures of our society, from hospitals to social services, from universities to transportations and logistics.

In other terms, ICT systems have become more and more capable and have moved from the specific and focused applications (essentially defense and space) for which they were designed at the beginning of the electronic revolution about sixty years ago, to all commercial and civil markets. Thus, just to make a few examples, robotics originally developed for applications in space and production is now used in (micro-) surgery, while laser technology is used even in the simplest barcode readers present on the desks of all shops and markets.

An important factor in the pervasive growth of ICT has been the convergence of the digital and analog signal worlds, realizing the possibility of deploying significant computation and communication resources on the same objects, such as, for instance, the modern cellular phones that allow everybody to be always in touch with the rest of the world through voice communications and Web applications. To reach the current state of the art, the digital world has followed a path of continuous development, from the era characterized by big mainframes (very demanding in terms of power and space, but poorly reliable and with limited computation power), through the revolution of distributed informatics, bringing PCs on every office desks and homes, up to the new frontier of very small, reliable, and low-power computers entering an ever larger number of products to make them “intelligent”, namely able to understand the situation around them and react in the most appropriate way (smart pervasive systems and ambient intelligence).

In turn, telecommunications too have undergone a revolution, progressively becoming digital, thus reaching out for the world of computers, for important reasons. The most important one is that digital signals (namely strings of bits much easier to recognize than subtle analog quantities) are much less critical to transmit and receive correctly than their analog counterparts. On a technological side, instead, the change has exploited the formidable progress of digital microelectronics, continuously producing ever more powerful processors able to run sophisticated algorithms for signal processing (e.g., filtering and amplification), in the past reserved for analog electronics. Of course, an important role in this context has been played by fast and accurate analog-to-digital (A/D) converters, capable to transform analog signals in digital ones.

As a result, now a small fraction of modern telecommunications is still (and will remain) analog (in particular transmission and reception at higher frequencies), while the overwhelming part is digital, and this has opened the road to a large convergence of the two worlds with the creation of new services and products, shaping our life and society often even without being noticed.

What said so far, of course, indicates the importance of electronic systems, which involve different types of components and technologies, such as, for instance, mechanical and electromechanical engines and actuators, as well as various types of sensors. This volume, however, is dedicated only to their electronic part (their real "backbone"), with particular emphasis on hardware aspects (though, of course, software is the other central element of the Information Society), including a few software-related sub-topics, most closely associated with embedded systems design and implementation.

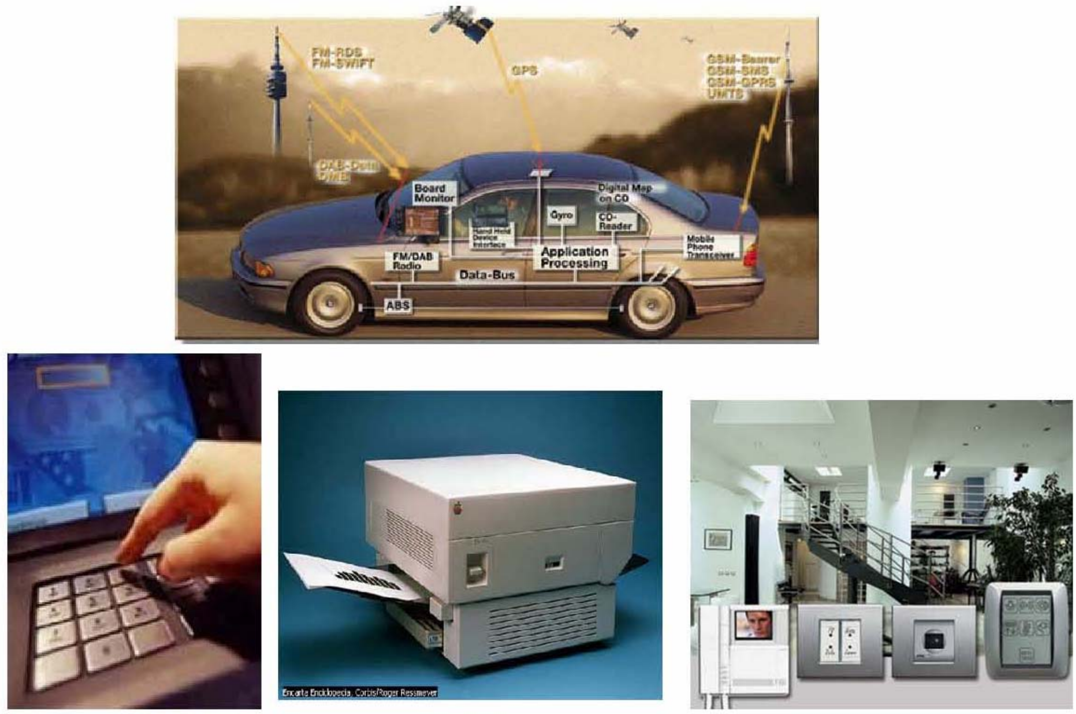

Figure 1. Some examples of today's CAS "pervasiveness", e.g., in the automotive industry, in ATMs and banking applications, and in different kinds of office/domestic appliances.

3. Circuits and Systems

In the context of interest here, the word "circuits" denotes an ensemble of (electronic) components, connected among them in order to perform a suite of "target functions". The components referred above can vary significantly from the point of view of their internal complexity, but are to be considered as "elementary" building blocks.

Instead, the term "system" normally indicates an ensemble, possibly very complex, of "sub-systems", interconnected and interacting with each other in order to achieve a target functionality (e.g., managing airplane booking or health data in a hospital; providing money at an automatic cashier; managing a semiconductor production line; controlling home power consumption for maximum efficiency; processing, storing, and reproducing data in different forms, as in the case of PCs; allowing voice communications, listening music, watch videos, as in cellular phones).

In general, "systems" are more complex than "circuits" in terms of both constitution and functionality. However, the two definitions are similar to each other, as they differ essentially for the type of constituents (sub-systems vs. elementary components). Ultimately, systems are big, often huge, circuits. Thus, the distinction between the two terms depends on the context and is largely conventional (a microprocessor, for instance, can be considered as a component or a system for designers of embedded systems or of integrated circuits, respectively). Therefore, a more detailed discussion on this point seems appropriate, at least to give additional technical elements and examples.

The system and component terms must be defined in their context of use, since their meaning can be very different from one case to another. The point is that the components of complex systems normally are themselves "systems", so as to be denoted as sub-systems. In practice, when dealing with complex systems, it is necessary to adopt an approach based on an iterative decomposition in smaller parts in order to create a hierarchy of different "levels of representation" (or, alternatively, of "abstraction"), spanning from the highest unitary vision (the whole system) down to the smallest elementary components (such as, for instance, transistors).

The essential question at this regard is that the overwhelming majority of the systems of interest are ultimately composed of billions and billions of single transistors, giving rise to a level of complexity impossible to dominate without a recursive "divide and conquer" approach. An example that might be useful to understand the situation is that of the human body, ultimately composed of an enormous amount of cells, themselves formed by multiple elementary components (such as proteins and DNA). As everyone knows, most medical doctors (except for those working in research labs) have a much higher view of their patients, made of their functions and physiology and, at most, of their set of important sub-systems (the main organs). The task of analyzing in details the problems at "cell level" (namely at a "lower level of abstraction") is necessarily left to other professionals, with different (though of course related) know-how, as it would be impossible to master the enormous complexity of the whole "systems" with a single and very fine-grained view.

Electronic systems too, and in particular the digital ones, can be viewed as formed by a series of sub-systems, with a decomposition procedure reaching down the elementary components. The resulting levels of abstraction form a hierarchical structure that can be gone through in the downward (top-down) direction, from the higher level (defining system functionalities and specifications, thus called "behavioral") to the lowest one (named "transistor", or "electrical" level) or vice versa (bottom-up direction). In particular, it must be possible to pass from one level to the next one, in both directions, by means of appropriate algorithms and tools allowing: when going down, a decomposition of the higher level components in terms of those of the lower one, with an operation called "synthesis"; when going up, instead, a "simulation" of the interconnected components of the lower level to verify that they behave as the single ones of the higher level they are forming. Of course, this implies that each level has its appropriate description language (defining the components and their interconnections) and tools (for synthesis and simulation). The top-down direction is followed in design, while the bottom-up one is used to verify the correctness of each synthesis step.

The number of representation levels increases with the complexity of the system to be represented. Those in any case necessary are the behavioral level, describing the system functionality and specification, and the lowest one, i.e., transistor or electrical level. Intermediate ones, commonly used in the description of digital systems, are the “Logic” or “Gate” level (using elementary logic gates, such as NOT, NOR, NAND, and digital signals) and the “Register Transfer Level (RTL)” (using hardware description languages, like Verilog and VHDL to describe the flow of signals between hardware registers as well as the logical operations performed on them).

An important issue at this regard, particularly but not exclusively valid for digital systems, relates to the complexity of components. As mentioned earlier, conceptually the essential elementary components of all electronic systems are transistors. In practice, however, single transistors are not available and system design/realization starts from much more complex components. This is because there are enormous advantages (in terms of all most important economic and technical parameters), in integrating systems and sub-systems on the same (silicon) chips in the form of monolithic components (Integrated Circuits, ICs): hence (but this is not the only motivation), the tendency to realize ever larger ICs to be used as “components” of large systems. For instance, microprocessors and microcontrollers, complex systems in their own rights, are considered as “components” for cellular phones, PCs, servers, robots, automatic controls, only to mention some examples.

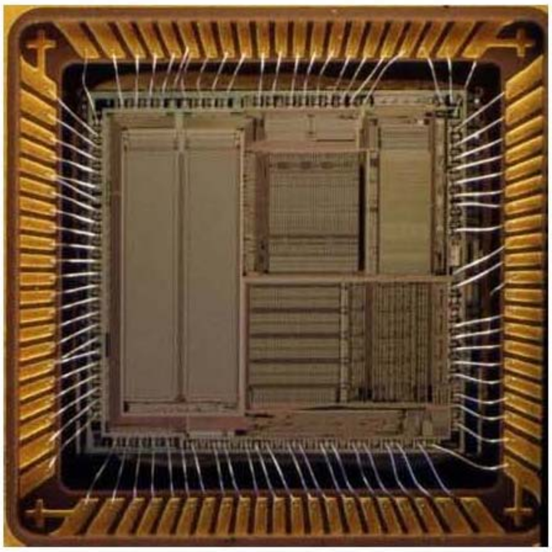

Figure 2. An example of IC realizing a microprocessor.

Naturally, the availability of ever more complex and powerful components allows the realization of ever larger and more sophisticated systems, in a process that is shaping our industry and society. In the context of interest here, an important consequence is that the boundaries between components and systems is continuously modified, with larger and larger parts of previous systems becoming single chip components, to be used for larger systems. This process offers new opportunities for system designers and companies, but represents also a challenge for them, forced to conceive new and more advanced products in order not to be overrun by the tremendous pace of semiconductor industries.

In essence, then, all electronic systems are (often huge) circuits, since they are made of interconnected components, but the same holds for these latter. This consideration holds qualitatively for both systems made of available components (cellular phones, PCs, robots, automatic controls, etc.) and for complex ICs or Integrated Systems (ISs), composed of a variety of functional blocks realized on the same chip. The modern microprocessors and micro-controllers are significant examples in this sense.

-
-
-

Bibliography

Since electronic "Circuits and Systems" (CAS) are the basic element of any information system nowadays, there are many valuable and useful bibliographic references that can cover the area, also by going into deeper and more technical details than we did in this overview for the sake of briefness. The topic-level writings in the following include references to many of these works in their annotated bibliography. Here, without any ambition of completeness, you can find a few references to general, introductory, and overview surveys in the CAS area, identified by selecting one reference work for each Section of this theme-level writing.

About the introduction to CAS and CAS relevance:

O. Bishop, "Electronics - Circuits and Systems", Newnes, 4th Edition, 2011.

About CAS in general:

S. Sedra, K.C. Smith, "Microelectronic Circuits", Saunders College Publishing, 3rd Edition, 1990.

About integrated electronics:

J.M. Rabaey, "Digital Integrated Circuits: a Design Perspective", Prentice Hall Electronics and VLSI Series, 1996.

About digital, analog, and mixed circuits:

G.G.E. Gielen, R.A. Rutenbar, "Computer-aided Design of Analog and Mixed-signal Integrated Circuits", Proceedings of the IEEE, Vol. 88, No. 12, 2000, pp. 1825-1854.

About the convergence of computers and telecommunications:

D.-E. Meddour, U. Javaid, N. Bihannic, T. Rasheed, R. Boutaba, "Completing the Convergence Puzzle: a Survey and a Roadmap", IEEE Wireless Communications, Vol. 16, No. 3, 2009, pp. 86-96.

About CAS technologies:

N. Weste, D. Harris, "CMOS VLSI Design: a Circuits and Systems Perspective", Addison Wesley, 4th Edition, 2010.

About CAS design:

R.K. Brayton, G.D. Hachtel, A.L. Sangiovanni-Vincentelli, "A Survey of Optimization Techniques for Integrated-Circuit Design", Proceedings of the IEEE, Vol. 69, No. 10, 1981, pp. 1334-1362.

About the envisioned future of CAS:

M. Haselman, S.; Hauck, "The Future of Integrated Circuits: a Survey of Nanoelectronics", Proceedings of the IEEE, Vol. 98 , No. 1, 2010, pp. 11-38.

Biographical Sketches

Bruno Riccò, full professor of Electronics at the University of Bologna, graduated in electrical engineering at the University of Bologna (Italy) in 1971; in 1975 received a Ph.D. from the University of Cambridge (U.K.) where he worked at the Cavendish Laboratory; in 1980 became Full Professor of Electronics at the University of Padua (Italy) and in 1983 at the University of Bologna (Italy); in the period 1981 – 1986 he was Visiting Professor at the University of Stanford, at the IBM Thomas J. Watson Research Center (Yorktown Heights) and at the University of Washington; from 1986 to 1996 was European Editor of the IEEE Transaction on Electron Devices; in 1995 received the G. Marconi Award for research by the Italian Association of Electrical and Electronics Engineers (AEI); 1998 became President of the Italian Group of Electronics Engineers; in 1999 was appointed European representative for the International Electron Device Meeting (IEDM); in 1999 founded the first university spin-off in Italy; in 2002 he has been elected Chairman of the IEEE North Italy Section; in 2003 was nominated Fellow of the IEEE. Prof. Riccò has worked in the field of microelectronics and is (co-) author of over 350 publications, more than half published on major international Journals, of 3 books, and several international patents.

Paolo Bellavista is an associate professor of computer engineering, within the Department of Electronics, Computer Science, and Systems (DEIS) of the University of Bologna, where he teaches several courses about distributed systems, advanced computer networks, and mobile systems/services. His research activities span from mobile computing to mobile middlewares, from location/context-aware services to adaptive multimedia streaming in wired/wireless heterogeneous networks, from vehicular sensor networks to social collaboration in spontaneous networks and scalable pervasive environments, also integrated with the cloud.
He has co-authored more than 120 papers, 35 of them in major international journals and magazines. He has organized several international conferences (as General/Technical Chair) and is serving in several Editorial Boards, e.g., for IEEE Transactions on Computers, IEEE Transactions on Network and Service Management, IEEE Transactions on Services Computing, IEEE Communications, Springer Journal of Network and Systems Management, and Elsevier Pervasive and Mobile Computing Journal. He is a senior member of IEEE and ACM.
You can find more information about him at his Web page: http://lia.deis.unibo.it/Staff/PaoloBellavista/