DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE -
PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 34TH CYCLE

Title of the research activity:	Compostable Electronics for Smart Systems **CE4SS**
State of the Art:	Recent United Nations estimates indicate that 50 millions of metric tons of electronic waste is produced each year world-wide [1]. This impressive number (almost nine times the mass of the Cheops pyramid) is expected to further increase with the development of the IoT, and the inherent use of billions of sensors distributed in the environment. Electronic waste is rich both in precious (gold, copper, etc.) and highly polluting materials. Printed Circuit Boards (PCB), typically made of glass fiber materials, are treated with phenolic resins, such as Brominated bisphenol-A BPA epoxy resins, and the release of these substances in the environment is risky for health due to their toxicity. For these reasons, the city of San Francisco, a world-leader in techniques for waste disposal, treats dismissed electronic equipments as hazardous waste. As a consequence, a new research trend has emerged in the last decade, which is focused on the introduction of cheap, flexible and compostable materials in electronics, and is producing a growing number of scientific studies worldwide [1]-[3]. In particular, cellulose based materials, such as paper, are attracting considerable interest. Cellulose, in fact, is a natural polymer very abundant on Earth, biodegradable, available at very low cost and for which there is already an established production chain. A considerable number of building blocks widely used in communication and sensing electronic hardware have already been demonstrated, such as antennas [4], oscillators [5], accelerometers [6], RIFD tags [7], energy harvesting systems [8] and devices like organic semiconductor MOS transistors [9]-[11]. The present Ph.D. research aims at exploring these novel possibilities: from the hardware conception of electronic systems and sensors to their on-field demonstration.
Short description and objectives of the research activity:	The adoption of new recyclable and biodegradable materials requires a deep re-thinking of traditional building blocks, which have to be adapted to the new materials and applications. The exploitation of the properties of the new adopted materials can also lead to the development of completely new devices and sensors. Essential RF building blocks have been designed, fabricated and experimentally

	validated to demonstrate their feasibility on exotic materials. Furthermore, validation has been performed for different operating frequencies ranging from VHF and UHF bands to microwave and millimeter-waves, according to the 5G approach. Along this line there are several open problems, requiring a deep study. First of all, the best materials and technologies must be investigated to allow integration of electronics into everyday objects. Second, these objects must be equipped with a wireless connectivity, which entails the presence of a number of RF/microwave circuits and building blocks. Third, energy harvesting solutions must be deployed whenever possible to make the object autonomous. Fourth, "zero-power" (i.e. passive) sensors must be introduced in the electronic nodes to make objects sensitive. Finally, as a fifth point, miniaturized radio frequency identification (RFID) and back-scattering radio technologies could be adopted to connect the objects to the Internet. Novel and original results are expected for each of the above issues. The activity will be synergic to the development of the approved EST4IoT (Electronic and Sensor Technology for IoT) laboratory in the sense that, on the one hand it will be carried out in the lab, on the other hand it will contribute to address the development of the EST4IoT lab to include the targeted technologies.
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