A Century of Radio Science in Italy: History, Developments and Perspectives

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1. Introduction

A century has passed since Italy joined the Union Radio Scientifique Internationale (URSI) in the International Research Council (IRC) during the First IRC General Assembly (GA) inaugurated in Brussels on July18th, 1919, by King Albert I of Belgium [1]. Three years later, in 1922, during the First URSI GA held again in Brussels, the Italian membership was ratified under the representative role of Consiglio Nazionaledelle Ricerche (CNR), a young National Research Council still under organization (officially established on Nov. 18th, 1923). For the development of radio science and relationships with URSI, the first CNR president Vito Volterra appointed an ad-hoc committee of experts, composed of university professors and researchers employed in military and civil institutions. Initially called Comitatoper gli Studi di Radiotecnica under the prestigious chairmanship of Guglielmo Marconi (Figure 1), eventually known as Comitatodi Studio per la Partecipazione del CNR all’URSI (briefly referred to as “URSI-CNR Committee” in the following), this group of experts continued to be important over the years.

After a century, not much has changed, and everything has changed as well. Still, the URSI-CNR committee is periodically appointed through an executive order signed by the CNR president, and continues to serve the national scientific community, providing proposals for the effective Italian participation in URSI activities and the necessary support to CNR in radio-science matters. Meanwhile, the set of research interests has greatly expanded from just four URSI Commissions in the twenties, whose terms of reference were common background for all the involved participants, to ten different, highly specialized research fields. Consequently, a richer, heterogeneous and multidimensional community, otherwise living apart in separate entities, has the effective opportunity to meet and exchange fruitful ideas.

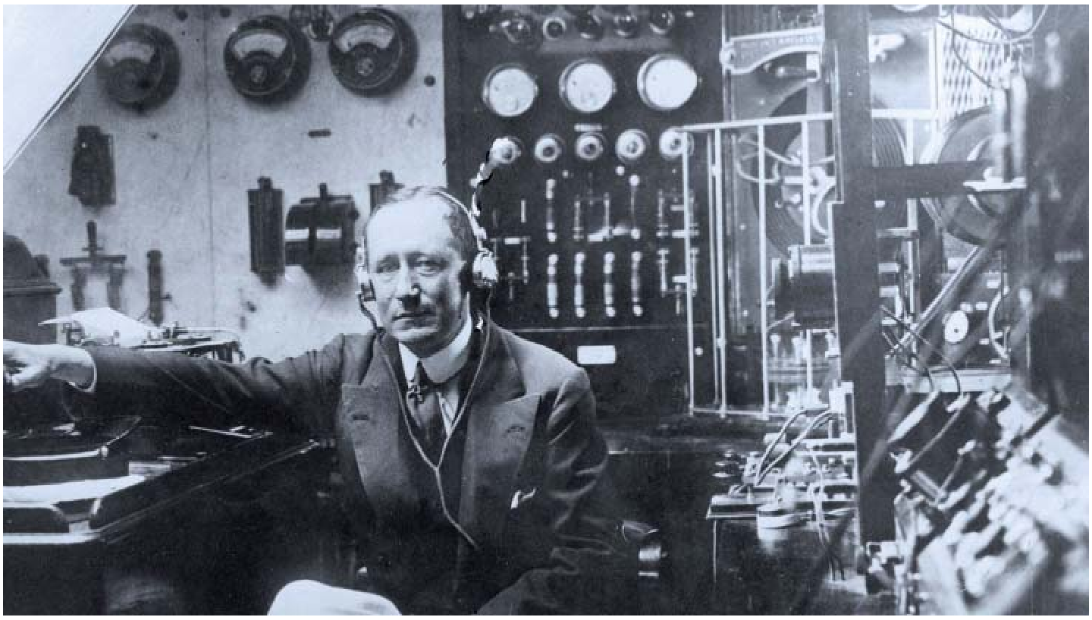

Figure 1. Guglielmo Marconi (1874-1937), Nobel Prize in physics and pioneer of radio telegraphy.

As current members of the URSI-CNR committee in the centennial, the authors are part of this community and owe previous generations of Italian radio scientists a debt of gratitude for the long path travelled across the years. This work is a humble and limited contribution to acknowledge them by recapping the history of radio science in Italy, starting with the achievements of early-time pioneers and traveling through their main successors. In this timeline, the VI (Venice/Rome, 1938) and the XXI (Florence, 1984) URSI GAs are recalled, in Section 2, as two symbolic milestones. Research of modern times, new developments and future perspectives are covered for each URSI Commission in Section 3. Finally, in Section 4 a short description of the future XXXIII URSI General Assembly and Scientific Symposium (GASS) to be held in Rome in 2020 concludes this paper as a consolidation of the strong link between Italian researchers and URSI.

2. Brief Historical Notes

2.1 The Pioneers

Inventions in radio technology anticipated and fostered advances in radio science. In this respect, the contribution of Italian pioneers between the late XIX century and the first World War was astonishing, starting with the figure of Guglielmo Marconi (1874-1937, Nobel prize, 1909). Son of an Italian landowner and an Irish mother, he did not attend any school as a child, being instructed at home by hired tutors, and later following some lectures on Hertzian waves delivered by Augusto Righi (1850-1920) at the University of Bologna. In his early twenties, he started experimenting with wireless transmission of telegraphic signals in his father's estate of Pontecchio. He excited grounded monopole antennas with spark gaps and used coherer tubes as receivers, reaching a transmission distance of 3 km. After he tried in vain to involve the Italian government in a large-scale exploitation of his invention, he finally got funding in 1897 from the British government, through which he was able to file patents and open the "Wireless Telegraph &Signal Company" in London. Soon, several achievements gained vast resonance in the world (e.g., the 51 km communication between the sides of the English Channel in 1898). Nevertheless, his dream was something judged to be impossible by his contemporaries, namely, a transatlantic wireless link between Europe and America. In the general, scepticism of academicians (maintaining that the Earth's curvature would prevent communications above 300 km), was challenged on the night between Dec. 11th and 12th, 1901. Marconi was able to hear the first message, the letter "S", in St. John of Terranova (Canada), transmitted from Poldhu (England) at a distance of about 3500 km along the ocean. Nobody knew about the ionosphere at the time, and still for many years the reason for Marconi's success was subject of lively debate for theoreticians. Reporting here on the rest of the life of such a giant and all his achievements is impossible. With his pragmatism, he literally invented radio technology and most of the questions and problems that radio scientists were called to answer and solve in the following years.

At the foundation of URSI in 1919, Giuseppe Vanni (1862-1934), director of Istituto Radiotelegrafico Militare in Rome, was appointed Vice-President (an office he held until his death), as well as chairman of Commission IV (liaison

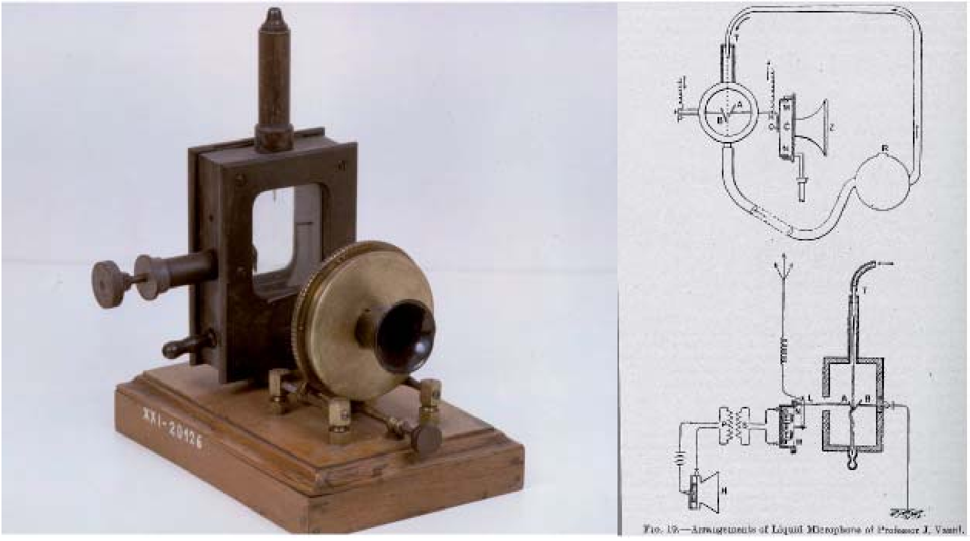

Figure 2. The 1911 "liquid microphone" of Giuseppe Vanni, URSI Vice-President from 1919 to 1934: original device (with broken parts) and principle drawing.

avec les opérateurs, les praticiens, les amateurs et le sciences connexes). Vanni is mainly remembered for pioneering achievements in radio telephony, when high-frequency sinusoids replaced the previous ineffective spark gaps, and it was understood that not only telegraphy, but also transmission of voice through amplitude-modulated signals was possible. Unfortunately, carbon microphones were unable to withstand the high power needed by radio transmitters. Similarly, the young vacuum-tube technology was still unable to provide high-power amplifiers. The solution proposed by Vanni was a "liquid microphone," (Figure 2) which exploited a metallic lamina vibrating in a flow of acid water kept circulating by a pump. Thanks to this device, he set the 1911 world-record radio telephone communication sending his voice across a distance of 1000 km between Rome and Tripoli (Libya).

After a few years, the golden age of thermionic valves began. Triodes and other devices were put into use even before working principles were fully understood. In 1917, one of the first seminal papers on triode modeling [2], though written in Italian, attracted the attention of the international community and encouraged many researches. It was written by a professor in the Naval Academy of Livorno, Giancarlo Vallauri (1882-1957). Later in 1923, with the collaboration of Marconi, Vallauri designed and opened the most powerful radiotelegraphic station in the world, in Coltano (Pisa), allowing inter-continental communication with the African colonies (Libya, Eritrea, Somalia), China, and the Americas. Hethen moved to Turin and became rector of the Polytechnic, founder and first president of Istituto Elettrotecnico Nazionale (IEN) "Galileo Ferraris," an advanced research institute. In URSI, G. Vallauri served as chairman of the above-mentioned Commission IV from 1938 to 1946.

Many other Italian radio scientists of the early period should be at least mentioned. Quirino Majorana (1871-1957), professor of physics in Bologna, contributed to radio telephony and made early discoveries about electronic tubes, later brought to perfection by W. Schottky. Gen. Giuseppe Pession (1881-1947) was firstly involved in radiogoniometry for the Navy, then director of Posts and Telegraphs, and URSI Vice-President from 1938 to 1946. Antonino Lo Surdo (1880-1949), eclectic physicist, founder of the National Geophysical Institute (ING), devoted a significant part of his research activity to radio science and its application to Earth science. Giorgio Abetti (1882-1982), astrophysics and director of the Arcetri Observatory in Florence gave fundamental contributions to the observation of solar phenomena and their effects on radio propagation. Gen. Luigi Sacco (1883-1970), serving for two World Wars as commander of military communications, and cryptography expert, was also an active researcher in radiophysics. Father Ernesto Gherzi (1886-1973), Jesuit, was a pioneer of scientific meteorology based on radiocommunications, working in England (with sir Appleton), Italy, China, USA, and Canada. Ivo Ranzi (1903-1985) carried out the first ionospheric measurements in Italy and the detection of cosmic rays in Eritrea.

2.2 The VIth URSI General Assembly: Venice/Rome, 1938

After decades of technological advancement, the Italian radio scientists of the thirties were eager to organize an URSI GA, initially foreseen in 1937 but later delayed until September 1938 just to make sure that all details were perfect for an ambitious and hectic programme. In the political climate of that time (Italy was ruled from 1922 by the autarchic regime

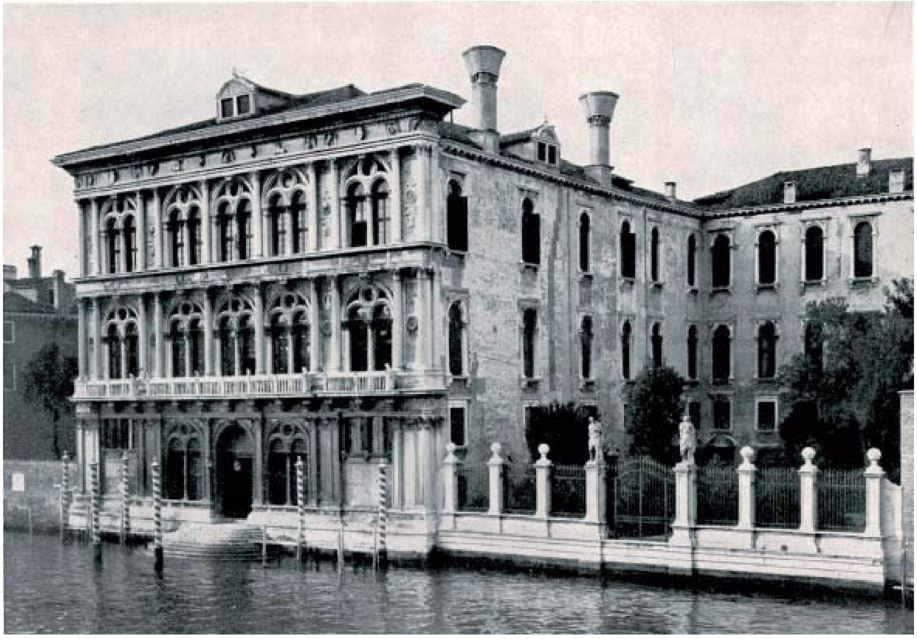

Figure 3. VI URSI GA, Venice, 1938: Vendramin-Calergi Palace, venue of the event.

led by the "Duce" Benito Mussolini), scientific conferences were seen by the government as occasions for propaganda, to demonstrate power and excellence to a selected international audience capable of orienting opinions in foreign countries. The organizational aspects were actually led by a notable official of the Fascist party, Count Giuseppe Volpi di Misurata (1877-1947), senator, president of Confindustria (General Industry Confederation). He provided support for the venue, by opening one of his superb mansions, palace Vendramin-Calergi on the Canal Grande in Venice (Figure 3) where, on purpose, he founded an institution called Centro Volpi di Elettrologia, to host scientific conferences on electrical subjects, starting with the VI URSI GA held from Sept. 4th to 8th , 1938. Count Volpi took much care of social events, including a concert in the Fenice Theatre, a tour of his Palladian villa in the countryside of Asolo, a gala evening in the Casinò, and an express-train transfer to Rome, where the closing session was solemnly held on Sept. 10th in the frescoed Marconi Hall of the CNR headquarter. Once in the eternal city, the delegates were offered a tour of the main monuments and, in the following days, of the national radio stations (Italo Radio in Torrenova for telecommunications, and EIAR in Santa Palomba for broadcasting), the Aeronautical Research Centre in Guidonia, as well as another train journey back to the

Figure 4. VI URSI GA, Venice, 1938: G. Volpi di Misurata welcomes the attendees to the opening session on Sunday, September 4.

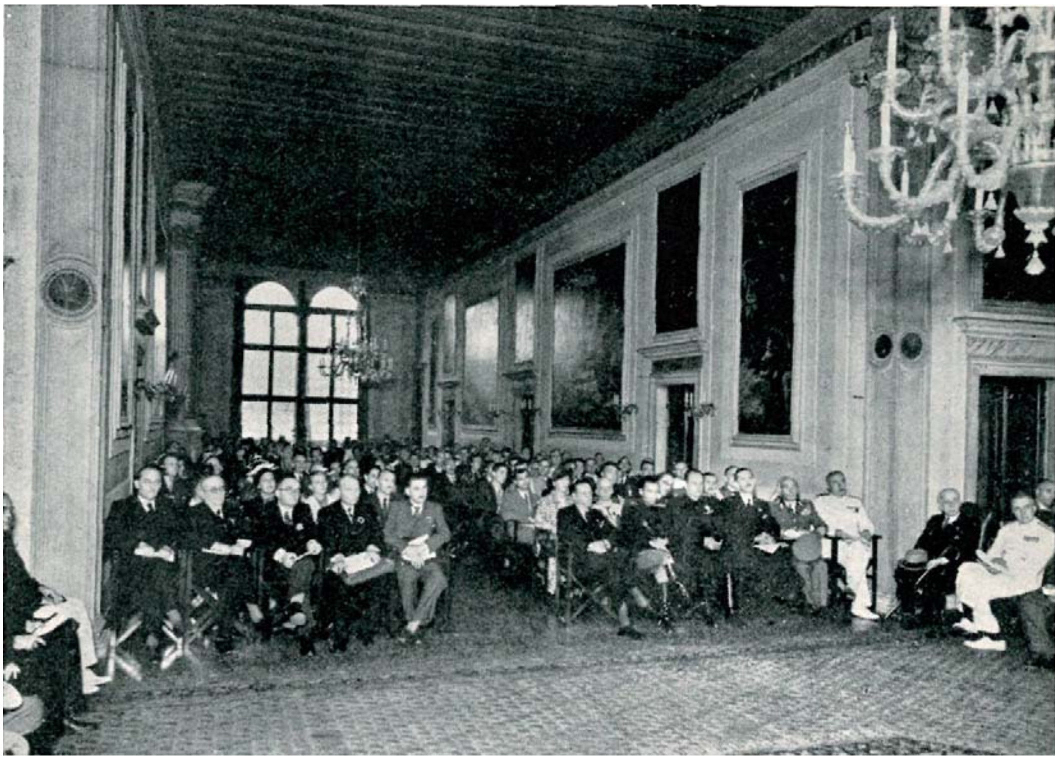

Figure 5. VI URSI GA, Venice, 1938: Attendees at the opening session.

north of the Country, stopping first at Livorno Naval Academy, and finally ending in Turin with a visit of the advanced IEN labs [3, 4]. Onlyon Sept. 15th ,1938, about a hundred pampered yet probably exhausted participants were able to return to their hometown, in Italy and foreign countries including Germany (invited to URSI for the first time, removing a ban dating back to IRC origins [1]), Belgium, France, Japan, the Netherlands, Switzerland, Sweden, UK, and USA.

The opening session on Sunday, Sept. 4th (Figure 4-5) was dominated by a wide-ranging address by URSI president Edward Victor Appleton (1892-1965). The British physicist (Nobel prize, 1947) started his speech with a commemoration of the recent demise of Marconi and R. Goldschmidt (former URSI Secretary), warmly welcomed the German newcomers, and continued by discussing the state of radio science after the V GA of London, 1934 [5]. Some URSI officials and delegates attending the GA are photographed in Figure 6.

In total, 115 papers were presented to five Commissions (though only a few of them were orally illustrated, according to past usages). Meetings were mainly collegial debates on the state of research, new challenges, international collaboration, and next resolutions [6]. From the minutes, no tensions and fears of a dramatic historical period can be detected. The delegates in Rome resolved to schedule the VII URSI GA for 1940 in Paris, France. They could not know how the devastation of a new World War would have severely divided and wounded the humankind by then. Eventually, the next GA was really held in Paris, but in 1946 and in a very different world.

2.3 The Post-War Period and the XXI URSI General Assembly, Florence, 1984

La Ricostruzione (the Reconstruction) is the significant term used in Italy to indicate the decade after World War II, characterized by enthusiastic willingness to take concerted actions, to work together despite the ruins, and to construct, on the basis of a democratic Constitution, a better Country that defines itself as "founded on labour". In a few years, the economic and social fabric was revitalized, universities and research centres were reorganized. Several radio scientists of those and subsequent times left an indelible mark of their work. A short description of the most authoritative radio scientists of this so-called second generation follows. Nello Carrara (1900-1983), professor in Livorno and Florence, was already well known for the word "microwave" that he had firstly coined in a paper dating back to 1932 [7]. In 1946, he founded the Institute for Research on Electromagnetic Waves (IROE) of the CNR in Florence. With their research activities on microwaves and radars, Carrara and his colleague Ugo Tiberio (1904-1980), professor in Livorno and Pisa

Figure 6. VI URSI GA, Venice, 1938: Front row, l-r: B. Van der Pol (Netherlands), J. Zenneck (Germany), E. V. Appleton (UK), G. Volpi (Italy), G. Pession (Italy), M. Philippson (Belgium). Second row, l-r: G. Vallauri (Italy), A. Dorsimont (Belgium), not identified, E. Herbays (Belgium), not identified.

and recognized as the "father" of Italian radar, contributed to the birth of important national maritime and aerospace industries. Mario Boella (1905-1989), professor in the Polytechnic of Turin, is remembered for contributing to modern telecommunications and electronics. Gaetano Latmiral (1909-1995), professor in the Naval University Institute of Naples, was among the founders of a modern school of electromagnetic fields in Italy. Giorgio Barzilai (1911-1987), professor in New York (Polytechnic of Brooklyn) and Rome, was known for his research on microwaves. Claudio Egidi (1914-2009), researcher at IEN and professor at the Polytechnic of Turin, gave noteworthy contributions to metrology (especially time measurement). Francesco Carassa (1922-2006), rector of the Polytechnic of Milan, was a protagonist of Italian initiatives in satellite communications. Ermanno Nano (1928-2006), professor in the Polytechnic of Turin, was the first Italian expert in electromagnetic noise and interference, with an active role in URSI Commission E and CISPR. Gianni Tofani (1939-2015), astronomer at the Arcetri Observatory, was one of the main contributors to radio astronomy in Italy.

In the Eighties, the Italian community was ready to host the URSI GA again. The XXI edition was held in Florence, at the conference centre Palazzo deiCongressi and nearby Centro Affari from Monday Aug. 27th to Wednesday Sept. 5th, 1984 (excluding a two-day break in the weekend). The URSI-CNR committee appointed an ad-hoc GA organizing committee composed of V. Cappellini (chairman), A. M. Scheggi (executive secretary), G. Barzilai, G. Biorci, F. Carassa, G. Dal Monte, G. d'Auria, C. Egidi, E. Nano, N. Rubino. The scientific programme was coordinated by an international group formed by the URSI officers W.E. Gordon (President, USA), J. Van Bladel (General Secretary, Belgium), W. J. Granville Beynon (former President, UK), and A. L. Cullen (Vice-President, UK) [8].

About 1000 participants from 49 countries attended the regular sessions organized by nine URSI commissions, where 372 papers were presented strictly under invitation [9]. Additionally, three general lectures on highly topical content were given to the whole body of participants in distinct days, namely, "Very Long-Baseline Interferometry" by R. T. Schilizzi (Netherlands), "Twenty Years of Satellite Communication" by J. V. Evans (USA), and "Solitons in Biology" by A. Scott (USA) [10]. In parallel to regular sessions, four "open symposia" (i.e., non-invited papers submitted to a call) were organized on specific topics: 1) "Interaction of Electromagnetic Fields with Biological Systems" chaired by M. Grandolfo (Italy) and E. Postow (USA); 2) "Data, Signal and Image Processing" chaired by J. L. Lacoume (France), D. Jones (UK), and K. Tsuruda (Japan); 3) "Active Experiments in Space Plasmas" chaired by R. L. Dowden (New Zealand), P. Stubbe (Germany) and J. Fejer (USA); 4) "Radio Techniques in Planetary Exploration" chaired by K. Runcorn (UK) and G. Beynon (UK). These open symposia added 129 papers to the overall scientific conference [9].

An interesting aspect was the presence of 43 Young Scientists (19 from developing countries), not so large for todays' standard, but significant of an on-going generational evolution [9]. One of them, Asta Pellinen (Sweden), was also one of

Period	Members of the URSI-CNR National Italian Commitee
23/09/1985 16/09/1994	G. Barzilai[32], E. Bava[10], P. U. Calzolari[21], F. Carassa[19], G. Dalu[6], G. D'Auria[32], F. De Marco[8], P. Dominici[15], **C. Egidi**[10], F. Fedi[9], G. Fiocco[32], G. Franceschetti[27], G. Gerosa[32], M. Grandolfo[17], S. Leschiutta[10], L. Millanta[3], ***E. Nano***[20], A. Paraboni[19], A. M. Scheggi[3], G. Tartara[19], G. Tofani[18], G. Tomasetti[2], Rod. Zich[20]
27/12/1995 30/05/2002	A: S. Leschiutta[20], ***E. Bava***[19], F. Giannini[33]; B: G. Gerosa[32], Rod. Zich[20], G. Franceschetti[5]; C: G. Tartara[19], F. Carassa[29], G. Immovilli[26]; D: R. Sorrentino[30], **A. M. Scheggi**[3], C. Naldi[20]; E: E. Nano[20], A. Longoni[19]; F: F. Fedi[9], A. Paraboni[19]; G: P. Dominici[32], P. Spalla[3]; H: A. Gilardini[1], G. Perona[20], G. Falciasecca[21]; J: G. Tofani[18], G. Grueff[21]; K: P. Bernardi[32], F. Bardati[33], A. Chiabrera[24]
31/05/2002 05/05/2008	A: S. Leschiutta[20], ***E. Bava***[19]; B: G. Gerosa[32], R. Tiberio[35]; C: G. Tartara[19], M. Luise[31]; D: R. Sorrentino[30], C. G. Someda[28]; E: E. Nano[20], Ric. Zich[19]; F: F. Fedi[9], P. Pampaloni[3]; G: P. Spalla[3], B. Zolesi[15]; H: G. Perona[20], G. Falciasecca[21]; J: **G. Tofani**[18], S. Montebugnoli[2]; K: P. Bernardi[32], F. Bardati[33]
06/05/2008 13/07/2011	B. Carli[7]; M. Brenci[7]; A: P. Tavella[16], ***E. Bava***[20]; B: G. Manara[31], F. Bardati[33]; C: M. Luise[31], M. Lops[22]; D: **R. Sorrentino**[30]; E: F. Canavero[20], S. Pignari[19]; F: P. Pampaloni[7]; C. Capsoni[19]; G: P. Spalla[7], B. Zolesi[15]; H: G. Perona[20], G. Falciasecca[21]; J: R. Ambrosini[11], S. Montebugnoli[11]; K: P. Bernardi[32], G. D'Inzeo[32]
14/07/2011 31/12/2014	**R. Sorrentino**[30]; S. Paloscia[7]; A: ***P. Tavella***[16], L. Callegaro[16]; B: G. Manara[31], M. Pastorino[24]; C: M. Luise[31], S. Buzzi[22]; D: S. Selleri[29], G. Marrocco[33]; E: F. Canavero[20], S. Pignari[19]; F: P. Pampaloni[7]; C. Capsoni[19]; G: B. Zolesi[15], M. Materassi[7]; H: D. Farina[4], A. Tuccillo[8]; J: R. Ambrosini[11], P. Bolli[12]; K: G. D'Inzeo[32], F. Apollonio[32].
06/05/2015 31/12/2018	**R. Sorrentino**[30]; ***P. Tavella***[16]; A: L. Callegaro[16], P. Carbone[30]; B: M. Pastorino[24], G. Manara[31]; C: S. Buzzi[22], M. Luise[31],; D: S. Selleri[29], G. Marrocco[33]; E: S. Pignari[19], ***C. Carobbi***[23]; F: C. Capsoni[19], S. Paloscia[7], G: M. Materassi[7], C. Scotto[15]; H: G. Granucci[4], M. Cavenago[14]; J: R. Ambrosini[11], P. Bolli[18]; K: G. D'Inzeo[32], F. Apollonio[32].
16/04/2019 31/12/2022	**R. Sorrentino**[30]; I. Rendina[5]; A: F. Lamonaca[34], S. Pisa[32]; B: M. Pastorino[24], G. Manara[31]; C: F. Santucci[25], M. Luise[31]; D: G. Marrocco[33], S. Selleri[29], E: ***C. Carobbi***[23], G. Spadacini[19]; F: S. Paloscia[7], C. Capsoni[19]; G: M. Materassi[7], C. Scotto[15]; H: M. Cavenago[14], L. Figini[4]; J: P. Bolli[18], M. Messerotti[13]; K: F. Apollonio[32], L. Crocco[5]

Legenda: **President and Italian delegate in the URSI council: bold**; ***Secretary: bold italic***; Commissions: A-K; Commission Chair: underlined;
Affiliations: 1: Alenia (Roma), 2: CNR (Bologna), 3: CNR (Firenze), 4: CNR (Milano), 5: CNR (Napoli), 6: CNR (Roma), 7: CNR (Sesto Fiorentino, Firenze), 8: ENEA (Frascati, Roma), 9: Fondazione "Ugo Bordoni" (Roma), 10: Ist. Elettrotecnico Naz. "Galileo Ferraris" (Torino), 11: Ist. Naz. Astrofisica (Bologna), 12: Ist. Naz. Astrofisica (Cagliari), 13: Ist. Naz. Astrofisica (Trieste), 14: Ist. Naz. Fisica Nucleare (Legnaro, Padova), 15: Ist. Naz. Geofisica e Vulcanologia (Roma), 16: Ist. Naz. Ricerca Metrologica (Torino), 17: Istituto Superiore di Sanità (Roma), 18: Osservatorio di Arcetri (Firenze), 19: Politecnico di Milano, 20: Politecnico di Torino, 21: Univ. Bologna, 22: Univ. Cassino, 23: Univ. Firenze, 24: Univ. Genova, 25: Univ. L'Aquila, 26: Univ. Modena, 27: Univ. Napoli, 28: Univ. Padova, 29: Univ. Parma, 30: Univ. Perugia, 31: Univ. Pisa, 32: Univ. "La Sapienza" Roma, 33: Univ. "Tor Vergata" Roma, 34: Univ. Sannio di Benevento, 35: Univ. Siena

Figure 7. Members of the URSI-CNR National Committee from 1985 to the present.

the few female attendees. She recently went back to those days in a pleasant column of the Radio Science Bulletin, speaking about the role of women in radio science [11]. She recalls "At the get-together event, I felt totally lost. The other participants looked like my father's generation, serious Humphrey Bogart-type gentlemen from the black-and-white movie era". While URSI and its GA were surely reflecting the state of society, yet changes were in the air, and young women were finally finding a well-deserved role in science and technology. In this connection, the Secretary of the GA organizing committee, Anna Maria Verga-Scheggi (1929-2015), must be remembered for her contributions to lasers and as director of IROE.

3. Activities of URSI Commissions

In recent years, most of the organizers of the Florence GA, followed by their alumni, and new generations of radio scientists have been actively involved in the URSI-CNR committee (Figure 7). Their work is here summarized for each URSI Commission, together with new developments and perspectives on national research in radio science.

3.1 Commission A: Electromagnetic Metrology

Since the early times, the field of electromagnetic precision measurements was a strongly developing area driven by progress in science and technology and the evolving needs of industry. In the following is a non-exhaustive report on the state of the art and the new challenges in a broad variety of electromagnetic metrology disciplines in which Italian researchers have made their contribution [12, 13]. These include microwave metrology (extending its frequency range up to THz), vector network analysers calibration, complex permittivity of materials, human safety and health, Internet of Things (IoT) and time synchronization.

The efforts in microwave metrology to fulfil the "terahertz (THz) gap" are opening new measurement scenarios especially concerning THz high-precision molecular spectroscopy. Hz-linewidth transitions represent key molecular signatures and the THz range can be considered a novel molecular fingerprint region. Some applicative examples are: the study of star formation and decay through the discrete lines emitted by light molecular species (98% of the photons emitted since the Big Bang fall in the THz gap); the study of ozone depletion, pollution monitoring, and global warming through the THz thermal emission from gases in the stratosphere and upper troposphere [14].

An important contribution to the field of electromagnetic metrology concerns the calibration and uncertainty evaluation for vector network analysers. In particular, the basic research development of simplified calibration techniques for two ports and multiport [15] find current applications in most commercial instruments. More recently, a complete, robust, analytical solution suitable for real-time calculations of S-parameter measurement uncertainty was developed [16].

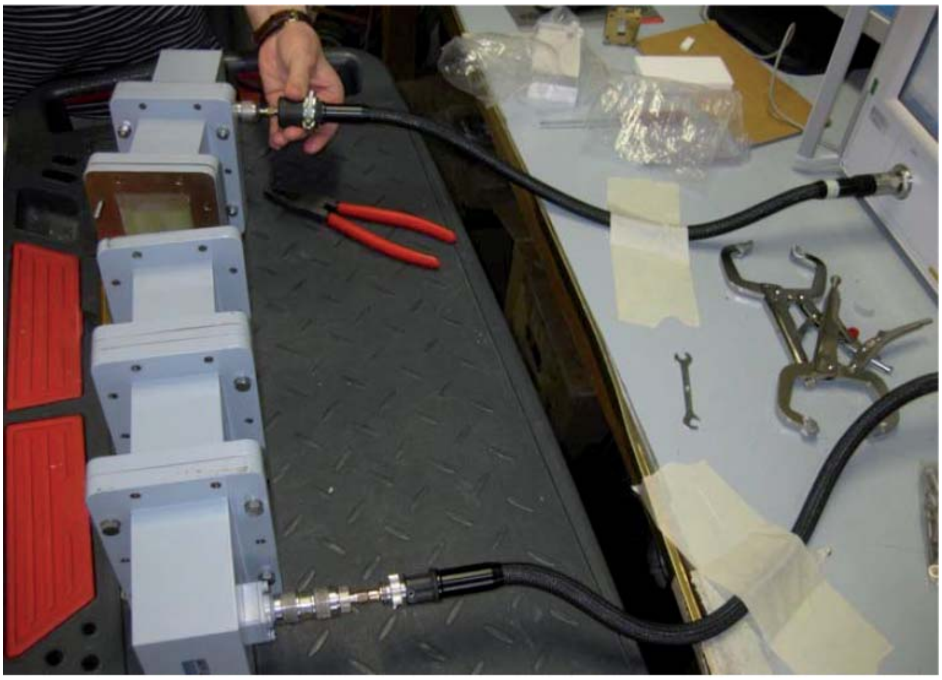

Figure 8. The WR430 measurement system proposed in [17] for evaluating dielectric permittivity of granular materials in the 1.7 to 2.6 GHz band.

One of the most widespread and studied electromagnetic measurements is the one related to complex permittivity of materials. Besides the direct evaluation of permittivity, this kind of measurement is interesting because it permits the indirect assessment of different properties of the material under test (Figure 8) [17]. One of the most studied and established applications is the assessment of the moisture content of materials and the different measurement solutions that were proposed suitable for non-homogeneous materials [18].

Concerning human safety and health monitoring, several papers deal with the design of measurement methods for the evaluation of the human exposure to electromagnetic fields [19] and to assess the traceability of measurements of vital signs and health parameters.

Current researches concentrate on measuring quantifiable properties of microwave electronics [20], the robustness of integrated circuit materials, and advanced integrated-circuit testing to radiated electromagnetic fields [21]. This research, together with those devoted to shared spectrum management, will facilitate a world where diverse wireless devices and systems can coexist [22].

At global level, the realization and dissemination of time and frequency standards is typically achieved by exploiting satellite systems [23]. Locally, synchronization is typically obtained by sharing signals [24]. In IoT systems the synchronization is typically achieved by the exchange of messages among smart objects, and the main challenges are the heterogeneity of the devices, the energy consumption constraints [25], and that some objects are mobile. Consensus seems a promising synchronization paradigm because it is robust to network topology changes [26] and admits the reduction of the average system energy consumption.

3.2 Commission B: Fields and Waves

The research activity of the Italian Commission B (Fields and waves) has a long history with relevant contributions in almost all areas related "to field and waves, encompassing theory, analysis, computation, experiments, validation and applications." At the Italian national level, all scientific activities belonging to Commission B are associated with the SocietàItaliana di Elettromagnetismo (SIEm) (Italian Electromagnetics Society). SIEm was founded in 2002 and all Italian universities working on engineering electromagnetics have a SIEm Unit with a representative in the SIEm Council. Every two years, SIEm organizes a national meeting on engineering electromagnetics: the Riunione Nazionale di Elettromagnetismo (RiNEm) (Italian National Meeting on Electromagnetics), which were held several times in combination with the URSI-CNR Committee. The first President of SIEm was Prof. Roberto Sorrentino, followed by Prof. Paolo Lampariello, Prof. Paolo Bassi, and Prof. Giuseppe Mazzarella.

Figure 9. A picnic in the wood: the social dinner at the EMTS 2016 meeting of the School for Young Scientists (Espoo, Helsinki, Finland). The school was held on Sunday August 14, before the main conference, and took place in the Finnish Nature Centre Haltia in the Nuuksio National Park. The topic of this short course was "Electromagnetic Fields and Waves: Mathematical Models and Numerical Methods."

The major event, i.e., the URSI Commission B International Electromagnetic Theory Symposium (EMTS) has always had strong participation by the Italian scientific community, with a considerable number of technical contributions. Moreover, the EMTS was held twice in Italy. The first time took place in Stresa in 1968, where a reduced number of Italian scientists (working in universities and research centres) provided important contributions, in which rigorous approaches, strongly founded on Maxwell equations, was the characterizing element, largely affecting successive studies in the field of applied electromagnetics in Italy [27].

During the years, the Italian community working on themes related to URSI Commission B has grown significantly. In 2004, the EMTS was held in Pisa [28]. The scope of the symposium covered all areas of electromagnetic theory and its applications. In particular, a total of 421 papers were selected to be presented at the symposium. A rich set of sessions were organized, that is, 62 oral sessions, 4 plenary sessions and 1 poster session. They included both progress in traditional Commission B topics, such as electromagnetic theory, guided waves, scattering and diffraction, and emerging topics such as metamaterials, ultra-wide band applications, practical aspects of ground penetrating radars, and others. One of the key features of the Pisa EMTS was a series of plenary sessions, held every morning, entitled: "Perspectives into the History and Development of Electromagnetics - Past, Present, and Future."

Since 1996, the activities connected to Commission B have been coordinated at a national level by the URSI-CNR Committee under the guidance of prestigious scientists, whose names are reported in Figure 7. As far as the Italian contribution at international level is concerned, it is worth mentioning that Prof. Giuliano Manara served as the Chair of URSI Commission B for the triennium 2011-2014. Under Prof. Manara's guidance, the URSI Commission B School for Young Scientists was established. In particular, the first session of the School was organized at the Hiroshima EMTS in 2013. The instructors of the school were Prof. Prabhakar H. Pathak and Prof. Donald R. Wilton, and the title of the school was: "Fundamentals of Numerical and Asymptotic Methods." Since 2013, URSI Commission B School for Young Scientists have been regularly organized on an annual basis coinciding with the main URSI conferences (GASS, AT-RASC, EMTS), reaching its sixth edition at the 2019 EMTS, held in San Diego (California, USA, May 27-31, 2019). The school, whose instructors are selected from among leading scientists of Commission B, provides an important occasion for Young Scientists to learn the fundamentals and future directions in the area of electromagnetic theory and applications from the corresponding lectures. The school is also a way to let the youngest researchers in the URSI Commission B context get together, socialize, and start a friendship that will hopefully continue for all their scientific professional lives (Figure 9). URSI tradition places a strong emphasis on young scientists, which is why in 2014, URSI introduced the election of an URSI Early Career Representative (ECR) among the officers of each Commission. Indeed, Dr. Andrea Michel (University of Pisa) was elected Commission B ECR at the 2017 URSI GASS in Montreal, for the triennia 2017-2020 and 2020-2023.

In recent years, the Italian scientist participation in URSI Commission B related activities has increased further. Presently, the URSI Commission B Technical Advisory Board (B-TAB) includes 7 members from Italy (Matteo Albani, Francesco Andriulli, Giuliano Manara, Andrea Michel, Paolo Nepa, Matteo Pastorino, Giuseppe Schettini). In the 2019 EMTS more than 10 scientific sessions were organized or chaired by Italian scientists and about 30 scientific contributions included the participation of members of Italian research teams. The main subjects of these contributions were: scattering and diffraction, antennas and reflectarrays, metasurfaces, wireless applications, RFID, reverberation chambers, inverse problems and imaging, and numerical techniques [29]. This list of topics highlights the main directions in which the Italian research related to the URSI Commission B has recently moved.

3.3 Commission C: Radiocommunication Systems and Signal Processing

In celebrating the first century of the URSI, we cannot miss acknowledging the fundamental role that radio science has played in the development of communication and radar systems to a large extent through many outstanding contributions of both research and related industrial development [30]. As we cannot compress in a single page the more than 100 year-long history, we can just take the opportunity to focus on a few relevant activities that currently involve the whole national community and then emphasize how the long-lasting tradition has implicitly fed the latest developments.

Again, moving on from early impressions, the radio medium has exhibited unique features in supporting communications with mobile entities at larger and larger distances: starting with the first communications with aircraft and then moving to the challenging space exploration missions required by deep space communications, the role, and the many contributions of the Italian community, are apparent. Early efforts were made in technology in the experimental divisions of the Italian Air Force to support the pioneering missions over the North Pole between the First and the Second World War. Leading researchers like Ugo Tiberio and Algeri Marino [31, 32] promoted fundamental advances in theory and practice for radars and communications, and then supported the development of the Italian academic community after the Second World War as they joined the faculties in the University of Pisa and Rome, respectively.

Still along the way of exploiting the unique features of the radio medium to enable long distance communications, Italian scientists and industries have actively contributed to the development of high capacity radio relay systems and satellite communications. Just mentioning two leading academics: Francesco Carassa and Francesco Valdoni played pioneering roles in conceiving and developing modern satellite systems for digital communications in the nineties [33, 34]. They are considered the fathers of ITALSAT, the first satellite with fully regenerative transponder and on-board switching matrix that was designed and built by Italian industry in the eighties. On the industrial side, Guido Vannucchi and Telettra deserve particular mention as leading innovators of digital radio relay technology.

While the interest for very-long-range communications is still alive, and Italian industry has developed advanced solutions for space exploration (i.e., the transceiver for the Rosetta rocket that delivered beautiful pictures of comets a couple of years ago), it is clear that modern scientific and industrial interests were strongly motivated by the “pervasive communication” feature of the wireless medium, which can, in turn, be exploited over shorter and shorter distances. For instance, again, the modern scientist can recognize the insight of A. Marino, who was still a talented high school student when, motivated by Marconi’s experiences, he clearly predicted the advent of modern personal communications and Internet of Things in a paper [32] published in 1912! Following this theme, we can acknowledge the relevant contributions by the Italian academic community (just to mention a few, Sergio Benedetto, Ezio Biglieri, Gianni Immovilli, Marco Luise, Umberto Mengali, Aldo Paraboni, Silvano Pupolin, Guido Tartara) in the development of fundamental techniques underlying digital cellular communications and the inputs provided by the industrial community (e.g. CSELT research centre of Turin) in the definition of the first pan-European GSM standard for cellular digital telephony during the eighties.

Moving closer to the today’s radio arena, it can of course be stated that the latest developments towards 5G wireless technologies are eventually implementing the true pervasiveness of the radio medium that was in the minds of researchers a century ago. While on one side, 5G is formally defined as a next generation in the evolution process of cellular mobile radio systems, it is more often interpreted as a revolution that enables connections of people and things in an integrated and global eco-system that explicitly includes novel application domains for telecoms. For example: the 5G Automotive Association (5GAA) and the 5G Alliance for Connected Industries and Automation (5G-ACIA) were recently constituted in order to let telecom manufacturers and operators work elbow-to-elbow with big industrial assets of some relevant “verticals” like automotive (Figure 10) and industrial automation. The declared objective is to design and develop the 5G network infrastructure to satisfy unprecedented challenging requirements, especially from safety critical applications. While providing the traditional industrial domains the clear perception of the breakthrough that pervasive connectivity can

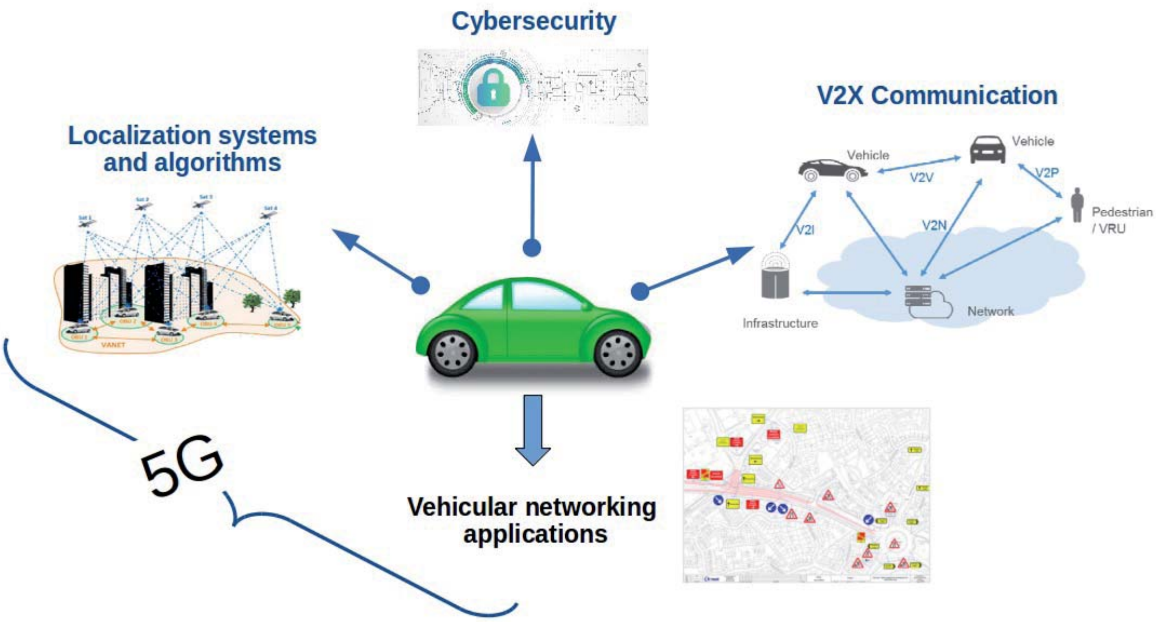

Figure 10. Pervasive communications and localization technologies for connected vehicles [36].

provide, it also enables both product and process innovation and finally brings remarkable social benefits. As a matter of fact, three main classes of 5G network functionalities are envisaged to meet requirements of rather different application scenarios: enhanced mobile broadband (eMB); massive machine type communications (mMTC); and ultra-reliable low latency communications (URLLC). The synergy between broadband wireless and broadband photonic technologies, along with softwarization of network architectures and cloud-edge computing, devise novel and interesting perspectives for adaptive resource allocation through network slicing.

The 5G Action Plan for Europe, undertaken by the European Commission (EU), is likely the largest research and development program in the world, with the 5G Infrastructure Public Private Partnership (5GPPP) coordinating the efforts of research institutions and industries. In this frame the EU recommended starting with at least a 5G trial per country by the end of 2018 in order to stimulate development of services and novel business models. Italy was proactive, with, in 2017, the Ministry of Economic Development launching a tender to design, develop and experiment with 5G pre-commercial trials in 5 cities (Milano, Prato, L'Aquila, Bari, Matera). The network infrastructure roll-out was almost completed by the network operators in all cities in the spring 2019 and in many cases are currently experimenting in the 3.7-3.8 GHz band. Furthermore, other trials were started in other cities (e.g. Roma, Torino) after frequency bands for commercial deployments were assigned at the end of 2018.

Being driven by network operators, and involving telecom manufacturers and other industries related to vertical domains, the 5G trials have also involved the whole Italian academic telecommunications community. In particular, more than 1000 faculties and researchers are working together under the coordinating action of the Italian Inter-University Consortium for Telecommunications (CNIT) on several 5G related projects. In this frame CNIT promoted and coordinated the large dissemination initiative (https://www.5gitaly.eu) that was held in Rome from 4 to 6 December 2018 and produced an eBook [35], which is available and continuously updated as the standard evolves, the research activities progress, and the trials advance. After the success of the first edition, considering the coordinated efforts by the whole Italian telecommunications community, the next edition is planned for December 2019.

3.4 Commission D: Electronics and Photonics

As the wireless technology becomes increasingly more pervasive to our lives, International Symposium on Signals, Systems and Electronics (ISSSE) becomes one of the most important meetings for URSI that is emphasizing the telecommunication. ISSSE series was jointly organized by Commissions C (Signals and Systems) and D (Electronics and Photonics). The first meeting was held in Erlangen, Germany in 1989, followed by Paris in 1992 and San Francisco in 1995, the fourth event was organized in Pisa, Italy. The Symposium was intended to develop three main areas of DSP-

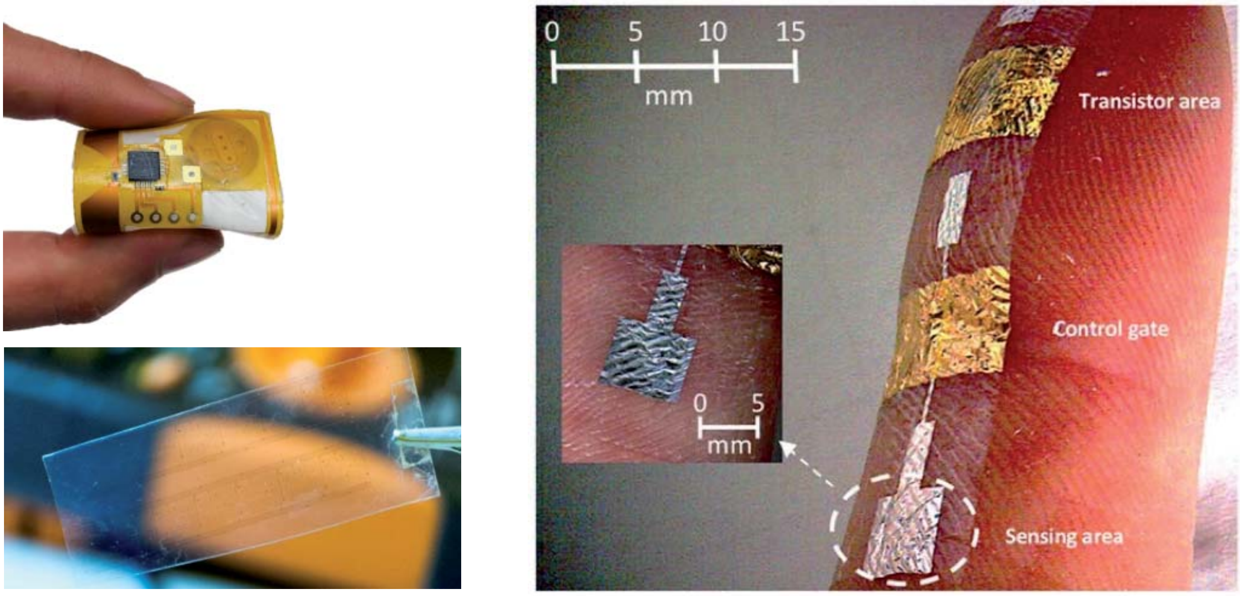

Figure 11. (a) SECOND SKIN, Università di Roma Tor Vergata; (b) Printed and Molecular Electronics, IIT; (c) Tattoo Electronics, University of Cagliari.

based Communication Equipment and Systems, VLSI design and Components, and Microwave Theory and Techniques. The Conference Chairman, Professor Luise, was successful in raising a considerable amount of sponsor funds from Italian telecommunication companies and from the University of Pisa. The conference was well organized and carried out in a relaxed and congenial atmosphere. There were ample occasions of technical exchange at coffee breaks and on-site luncheons for all participants. An excellent banquet was organized at a local restaurant with excellent Italian cuisine. The last two ISSSE were incorporated within AT-RASC [36].

From a scientific point of view, we notice that the pioneering research of Materials and Chemical engineers, mostly driven by the last 5-10 years' work of Prof. J. Rogers in USA, has led to a new kind of Electronics [37], made by ultra-thin and stretchable elastomeric membranes patterned with electrodes and sensors, memories, batteries, solar cells, and even displays by means of inkjet printing, screen printing and laser induced forward transfer. Devices become therefore suitable to a conformable application onto fabrics and even on the human skin, like plasters or tattoos. The resulting Epidermal or Skin Electronics is going to potentially revolutionize the way sensors are embedded with objects in the era of Internet of Things and in the forthcoming 5G communications. This new paradigm is quickly spreading outside the original Materials community toward Communication and Electromagnetics [38-43] Electronics and Photonics [44-46], thus leading to a new fascinating research topic within the Commission D.

Open technological challenges concern the robustness of the circuit vs. bending and stretching, the adhesion of components over thin films, the communication performance in presence of the human body, the repeatability of the sensing results and the large area manufacturing. Thanks to its intimate nature, the Skin Electronics will benefit from a tight cross-fertilization among several backgrounds of URSI commissions but also stimulates novel interactions with Materials and Chemistry scientists.

There are currently several active teams in Italy with different and complementary backgrounds spanning from solid state technology for flexible substrates to skin antennas and sensors and soft robotics. Next, without any presumption of completeness, a summary of some hot topics and the corresponding research teams (see Figure 11):

- SECOND SKIN: Epidermal Antennas for Radiofrequency Identification and Sensing, Università di Roma Tor Vergata (ref. Prof. Gaetano Marrocco), www.pervasive.ing.uniroma2.it: Optimal skin flexible antennas in the UHF band coupled with sensors and electronics to monitor body temperature, sweat, pH, breath and to recover/augment human senses. Manufacturing over ultra-thin stretchable substrates. Communication models involving the human body. Clinical trials, application to wellness and to the monitoring of personnel in harsh environments.

- Printed and Molecular Electronics, Italian Institute of Technology IIT at Politecnico di Milano (ref. Dr. Mario Caironi), https://www.iit.it/people/mario-caironi: Investigations of the opto-electronic properties of solution-processable semiconductors, in particular conjugated organic materials, with focus on their printability. Organic thermoelectrics and Edible Electronics.

- Tattoo Electronics, University of Cagliari (ref. Prof. Annalisa Bonfiglio), http://sites.unica.it/dealab/: Organic Electronics: knowledge and applications based on large area technologies applied on unconventional substrates. Organic Bioelectronics aiming at the development of multimodal sensing systems for biomonitoring applications.

3.5 Commission E: Electromagnetic Environment and Interference

Several reports (from 1990) and proceedings (from 2002) of the URSI flagship conferences represent a fundamental information source for the contribution of Italian radio scientists to Commission E, which became significant in 2002, after the appointment of Prof. Flavio Canavero (Politecnico di Torino) as Vice-Chair, during the XXVII URSI GASS in Maastricht, while the Chair of Commission E was Pierre Degauque (Université de Lille, France) [47]. Three years later, during the New Delhi XXVIII URSI GASS Prof. Canavero was appointed Chair of Commission E and Prof. Christos Christopoulos (University of Nottingham, United Kingdom) succeeded as Vice-Chair [48].

Under the Chairmanship of Prof. Canavero, the terms of reference of Commission E were changed with the official introduction of "electromagnetic compatibility" (EMC) [48], and they were finally consolidated in the present form in 2008 during the Chicago XXIX URSI GASS [49]. Indeed, before 2005, EMC appeared in the terms of reference only through a note stating that "many of the subjects mentioned are treated under the common title of Electromagnetic Compatibility". Several EMC symposia were sponsored by URSI in those years: EMC Zurich, EMC Wroclaw, EMC Roma (later EMC Europe), as well as IEEE and non-IEEE sponsored EMC symposia in the western and eastern world. The Chairs and Vice-Chairs of Commission E were organizers of numerous oral sessions at those conferences. Hence, by introducing EMC in the terms of reference, a direct connection was established between the scientific activity of URSI Commission E and the international EMC community. This was an important step forward in broadening the scientific interests of Commission E, which were, until then, limited to radio noise of natural origin eventually extended to man-made noise, mitigation of interference to equipment (not necessarily radio equipment) and the limitation of non-intentional electromagnetic emission. Actually, many papers presented in the above-mentioned conferences were notable examples of this extension of scope to the peculiar technical aspects of EMC, like the modeling of conducted and radiated emission/susceptibility phenomena. Among them, it is worth mentioning [50] as a specific contribution from the Italian URSI community, dealing with the experimental characterization and modeling of the bulk current injection (BCI) probe and the related test setup for conducted immunity.

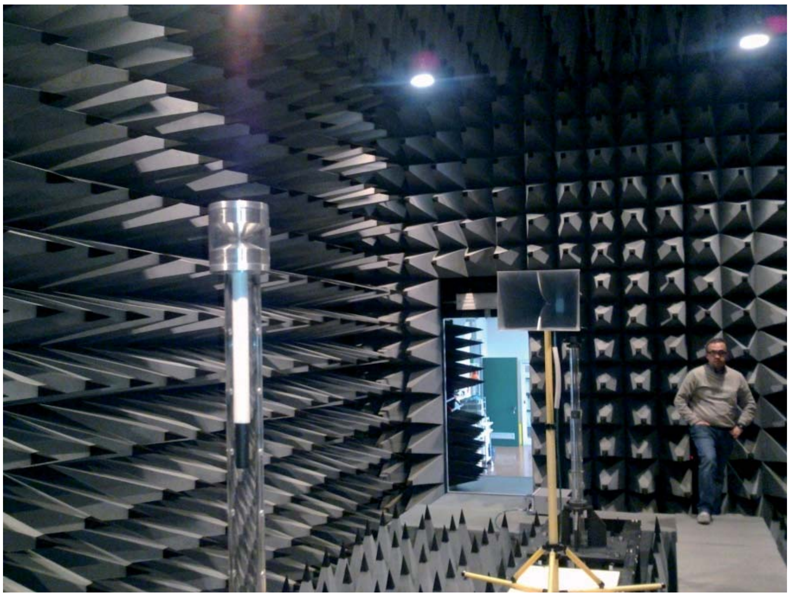

Figure 12. Calibration of a reference source of electromagnetic fields for inter-laboratory comparisons of EMC measurements in the anechoic chamber of the Italian National Metrological Institute (INRIM).

A co-author of that work, Prof. Sergio Pignari (Politecnico di Milano, Italy), was later invited by Commission E to write a "Review of Radio Science" paper on the role of statistics in EMC [51], an emerging topic within the community that showed many potential applications in the following years, up until the present day. For instance, the minutes of Commission E meetings of the 2011 Istanbul URSI GASS [52] mention Topic 3 "Complex Systems" and Topic 7 "Numerical Modeling of Complex and Large Systems," both implying the use of statistical techniques. During the same GASS, Prof. Pignari and Prof. Luk Arnaut (Queen Mary University of London, United Kingdom) organized the session "Stochastic Techniques in EMC," a subject that attracted (and it is still attracting) the interest of many researchers. Papers presented in this session by Italian attendees covered computationally efficient modeling techniques for interconnects and complex systems [53], and some were extended for publication in Radio Science [54]. Prof. Canavero also co-chaired with Dr. Christopher Holloway (NIST, United States of America), the session "EMC Interactions in Complex Systems," during which Prof. Christopoulos presented a paper about complexity in EMC modeling [55]. In the same vein of research, we can identify the contribution of Prof. Gabriele Gradoni (University of Nottingham, United Kingdom, presently Early Career Representative of commission E) and Prof. Ramiro Serra (Technical University of Eindhoven, The Netherlands, co-chair with Arnaut and Pignari of the commission E working group "Stochastic Techniques in EMC"), in the field of wave chaos modeling and mode stirred reverberation chambers, respectively.

Prof. C. Carobbi, currently chair of Commission E in the Italian URSI-CNR Committee (see Figure 7), contributed to the 2017 Montreal URSI GASS, AT-RASC 2018 in Gran Canaria and AP-RASC 2019 in New Delhi, by chairing sessions of Commission E during the last two conferences. He also contributed to papers dealing with EMC measurements and evaluation of EMC measurement uncertainty, emphasizing, inter alia, the importance of rigorous assessment of measurement reproducibility through inter-laboratory comparisons (Figure 12). During the 2017 URSI GASS a scientific collaboration was started among Prof. Carobbi, Prof. Sébastien Lalléchère (Université Clermont Auvergne, France) and Prof. Arnaut on the topic of uncertainty quantification of measurement and computational modeling in EMC, which produced a series of two review papers [56-57].

3.6 Commission F: Wave Propagation and Remote Sensing

The Italian contribution, over the years, to electromagnetic wave propagation in the troposphere at microwave frequencies is of undeniable importance for the research in this field. In the sixties, Francesco Carassa, director of the Telecommunication laboratory at Politecnico di Milano, designed a SHF satellite experiment to materialize his vision of the future of telecommunication. This has provided the research community with a tool for field-testing theoretical results on propagation impairments during adverse weather conditions. At the end of 1974, after a long and rocky period, the Carassa project got a new kick and the geostationary satellite SIRIO (Satellite Italiano di RicercaIndustriale e Operativa), developed under the First Italian space private public partnership between CNR and Compagnia Industriale Aerospaziale, was launched in August 1977. Although it was designed for a lifetime of 2 years, thanks to a precise manoeuvre to reach the final geostationary orbit, SIRIO operated for more than 10 years and allowed the most important research teams in the world (from USA to China) to investigate electromagnetic propagation at 12 and 18 GHz.

In 1991, the recently established Italian Space Agency (ASI) launched another advanced Italian gigahertz satellite, the ITALSAT F1, which allowed experimentations at different frequencies from 18 to 40 and 50 GHz. The data collected during this experimental campaign in many sites, spread all over Europe, are unique and still used for the development of channel models and the design of propagation impairment mitigation techniques. The ASI mission to anticipate the use of millimeter waves, although it is not yet considered for commercial applications, is still continuing. Indeed, within the ASI Q/V band program, a telecommunication and propagation experimental payload was developed in Italy in collaboration with the European Space Agency (ESA) and it placed on the Alphasat satellite. The Alphasat-Aldo Paraboni Payload was designed to study and test the potential of Q/V band frequencies. The experimentation is still ongoing and almost all the European research groups active in the propagation field are participating as a network.

The scientific contributions proposed by many Italian and foreign universities, as well as public/private research bodies involved in the space research, made possible thanks to those experiments, are numerous. Moreover, many of the papers are presented at URSI GAs and various URSI Commission F Open Symposia, where people involved in propagation and remote sensing meet, exchange their ideas and organize joint activities. The active participation in URSI by the Italian propagation community is exemplified in [58-62].

Remote Sensing is a relatively new discipline. Research in this field was stimulated by URSI after the Microwave Signatures Symposium, held in Berne, in 1974, and hence, before Commission F was renamed "Wave Propagation and Remote Sensing" (1978). At that time the Microwave Remote Sensing community in Italy was almost non-existent at the international level, and only two individuals from Italy attended that meeting as observers, as well as the following

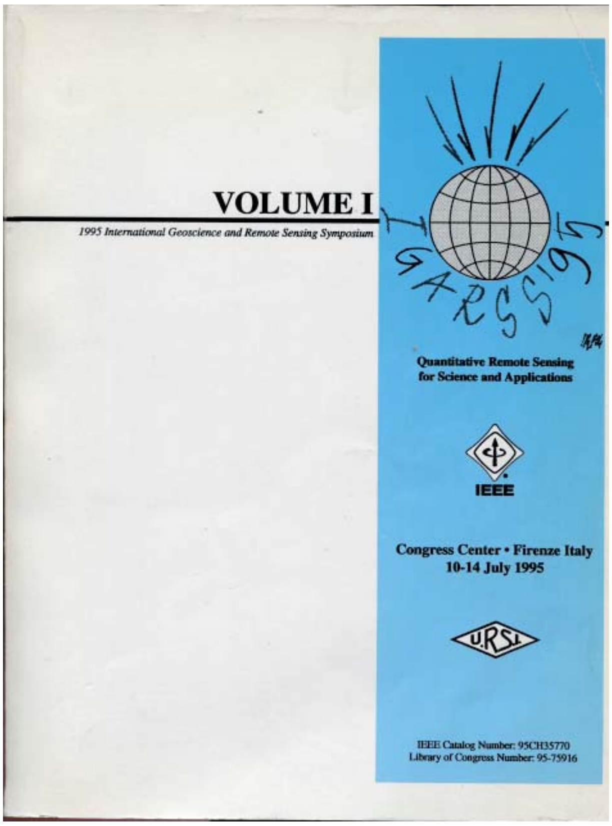

Figure 13. Cover page of the first volume of the 1995 International Geoscience and Remote Sensing Symposium Proceedings.

one in Kansas (1981). We had to wait a few more years before a significant interest in this discipline developed among Italian researchers, initially in the optical field, but then also in microwaves. An important motivation came from the Earth Observation programs promoted by national and international space agencies, firstly ASI, ESA and NASA. The European SAR 580 airborne campaign, organized by the Joint Research Center (JRC) in 1981 was the first opportunity for European scientists to evaluate the potential of data collected with a Synthetic Aperture Radar (SAR) on a few test sites, some of them in Italy. At that time digital processing was still in its infancy, and the optically processed SAR images were distributed on long strips of film. The programs of Earth Observation by ESA, with the satellites ERS followed by ENVISAT and SENTINEL, and the SIRC/XSAR mission of NASA/DLR/ASI (1994) to fly an L, C and X band SAR on a shuttle, have made possible a significant consolidation of knowledge for the monitoring, at high spatial resolution, of the Earth's surface. These sensors also contributed to the realization of one of the most important ASI projects: The Cosmo Skymed, a constellation of 4 small satellites (launched between June 2007 and November 2010) equipped with X-band SAR, orbiting in order to allow the use of repeat-pass interferometry.

In parallel with the high-resolution SAR missions, mostly oriented to the monitoring of ocean and land surfaces at regional and local scale, the potential of medium and low-resolution sensors for the retrieval of surface and atmosphere parameters at global scale was exploited in several experiments with ground-based, airborne, and satellite sensors. The most popular satellite sensors for these purposes were the multi-frequency SSM/I and AMSR-E/2 microwave radiometers and the two L-band SMOS and SMAP focused on the retrieval of soil moisture. Important results are expected from the ASI PRISMA, a medium-resolution hyperspectral imaging system launched by ASI in March 2019 and focused on the delivery of pre-operational hyper-spectral products.

Stimulated by these missions, the Italian Remote sensing community is now among the strongest and most productive in the world. Its contributions to URSI Commission F are highlighted by the participation in all the URSI conferences, also with Tutorials and Invited Papers, as well as by the organization of two important events such as IGARSS'95 (Figure 13) and Microwave Signatures 2010, both in Florence [e.g. 63-67]. The Italian scientists who alternate as Official members of the Commission F are noted in Figure 7.

3.7 Commission G: Ionospheric Radio and Propagation

Within the Italian scientific community, the study of ionospheric variability, i.e., how the physical parameters describing the ionosphere vary with time, depending on the present conditions of the Sun-Earth interaction and of our planet herself [68], has, in the past, taken great advantage from radio science, in particular from active and passive radio sounding [69, 70]. As the electromagnetic waves crossing the ionosphere are altered, depending on the local state of the medium, information about the latter can be inferred by collecting electromagnetic signals sounding the ionosphere. The use of the trans-ionospheric signals of satellites for positioning and navigation (the GNSS) provide the opportunity for both wide-area mappings of the ionization density (one of the crucial ionospheric proxies) [71], and small-scale structure studies [72, 73]; while the use of radio-occultations from low-orbiting satellites (LEOs) make it possible to monitor the local vertical ionization density profiles [74].

The great challenge of ionospheric variability, and the great opportunity for radio science in this branch, is the study of the actual predictability of the Earth's ionospheric state: this challenge is not just a technical issue because of the intrinsic complexity of the system [75]; it also raises the issue about how deterministic the Earth's ionosphere is as a physical system. Indeed, the ionosphere is a space-extended system with a huge number of degrees of freedom, that interact in non-linear ways; moreover, the ionosphere is open, as far as both matter and energy are concerned. This really puts the ionosphere on the border between chaos and probabilistic systems: it is theoretically challenging, and definitely uncertain, establishing to what extent the ionosphere is predictable, and to try to make predictions. Still, it is necessary for applications, and urgent from a fundamental science point of view.

Ionospheric modeling is a wide field of research that has received important contributions from the Italian scientific community [76]. The biggest problem was always modeling ionospheric plasma irregularities that cause severe and apparently stochastic disturbances to trans-ionospheric radio signals, namely radio scintillation [77]. New data analysis and mathematical tools from the science of complexity will be of great help in the quest for ionospheric predictability [78] (Figure 14). Recently, the constellations of GNSS satellites have increased their space-time coverage, creating a huge amount of data for unprecedentedly rich monitoring. Moreover, the near future is going to be the era of big data manipulation, hyper-fast computers and networks, and this will be a great chance, for the URSI community, to work on the most challenging points of Earth's ionospheric dynamics.

3.8 Commission H: Waves in Plasmas

Since a plasma is a collection of electrically charged particles (usually in disordered motion), and therefore unavoidably coupled to the electromagnetic (EM) field, the theme of EM waves in plasmas encompasses a large variety of aspects, ranging from astrophysical phenomena to laboratory devices and technological applications [79].

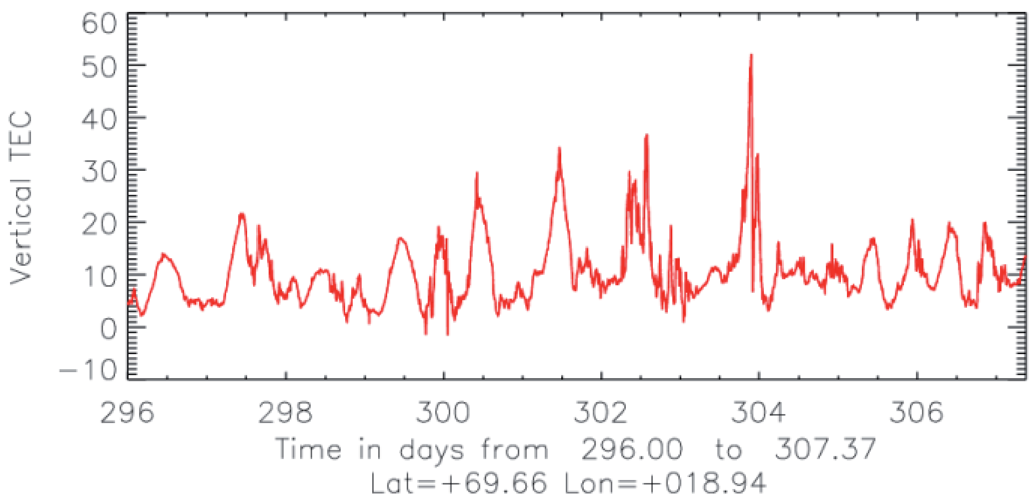

Figure 14. Plot representing the vertical total electron content (TEC) above the GPS station at Tromsø, between days 296 and 308, 2003, i.e., during a geomagnetically active period (from [78]). The irregular time series plot highlights how the complexity of ionospheric physical phenomena turns into apparent unpredictable behaviour of ionospheric proxies.

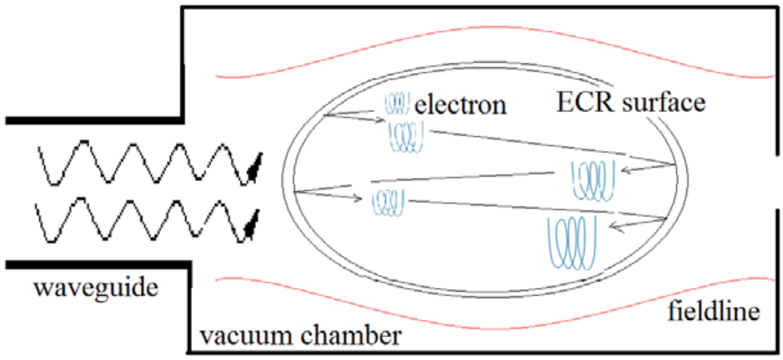

Figure 15. The electron cyclotron resonance (ECR) ion source is an example of EM waves and a plasma device in the laboratory. Using a nonuniform magnetic field (due to a magnet, not shown) the electrons, confined by the field and waves, can gain energy from waves at a resonant frequency; and they can then ionize heavy elements multiple times.

Even if a plasma is commonly associated with an arc, that is an electric discharge between metallic objects (electrodes), sometimes sharpened, electromagnetic waves are often a more convenient method to energize a plasma: the contactless transmission of power avoids the consumption of electrodes and leads to more stable plasma conditions (see applications later). Conversely plasmas and particle beams (collections of charges with ordered motions) can be a source of EM waves, which may be a natural effect (when a beam impinges on a plasma, giving the so called two-stream instability), or a desired effect (as in electron tubes), or a problem (fusion plasmas are cooled also by instabilities [79]).

As a first instance of interest to the Italian URSI Commission H, the complicate phenomena of the solar wind [80] (one stream) impinging on a planetary magnetic field and upper atmosphere (plasmas known as ionosphere and Van Allen belts) involve several wave generation processes, with the name "space weather" to encompass most of the EM disturbances in the space [81], that is the space EM environment. Observation devices include both Earth-based radio-telescopes [82] and satellites, either in geostationary orbit or in Low Earth Orbit (LEO). Conversely, since nowadays geostationary and LEO satellites have out-paced natural ionosphere EM wave reflection as relays of long-distance communications, the description of space weather is also of technological importance. Satellite propulsion by ion and plasma thrusters [83] is *also* actively developed in Italy.

As regards to laboratory devices, first of all, most high power microwave generators are based on electron-beam instabilities; to cite a few: the klystron [84] where a beam is bunched in the longitudinal direction; the similar Travelling Wave Tube [85]; the gyrotron where the azimuthal velocity of electrons (spiralling around a magnetic field, with the so-called cyclotron frequency) is the bunched variable; and others. Optimization of beam/wave interaction and of tube efficiency is actively pursued by the accelerator physics community [86] and by the fusion community [87]. The Italian plasma physics community is deeply involved with fusion research, where EM waves in plasma plays an important role, both for observation and for plasma heating. Microwave emission of plasma gives important information on plasma temperature; microwave propagation into plasma measures the plasma density; and 170 GHz microwaves can contribute to fusion plasma heating [87].

Another class of devices encompasses radiofrequency and collective accelerators [88, 89] and the related particle traps. Ion sources (for accelerators) greatly benefit from the contactless heating with EM waves. In Italy, we have several examples of 2 to 30 GHz microwave used in plasma ion sources (Figure15), mainly using the Electron Cyclotron Resonance (Catania, Legnaro, Milano, Pavia) [90]; and of heating plasma with 1 to 13 MHz radiofrequency, mainly with inductive coupling (Padova) [91]. These sources find applications in nuclear physics, medical adrotherapy, the semiconductor industry, and research for injecting particle beams into fusion reactors [91].

3.9 Commission J: Radio Astronomy

While radio astronomy began in 1933 with the serendipitous discovery, by Karl Jansky, of natural radio signals coming from space [92] it was only in the late fifties that Italian astronomers started to look at the Universe at radio wavelengths. The first attempts were conducted with dishes up to 10 m diameter built in Medicina (close to Bologna) and at the Arcetri Astrophysical Observatory for solar radio astronomy. In 1960, the Physics Institute of the Bologna University, directed by

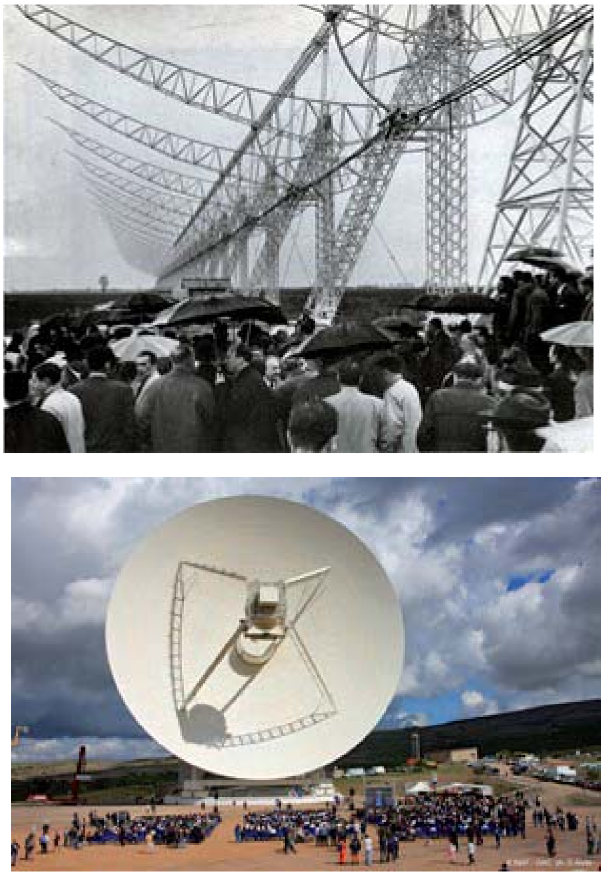

Figure 16. Inaugural ceremonies of: (a) The Northern Cross radio telescope, in October 1964, and (b) The Sardinia Radio Telescope, in September 2013.

Prof. G. Puppi, began the construction, in Medicina, of the Northern Cross, a huge interferometer consisting of parabolic cylinders distributed along two perpendicular arms. After an initial phase, the instrument was rearranged in its present configuration, with the two arms being 640 m and 576 m long and an overall collecting area of about 30 000 m^2. An interesting activity report was given at the 1966 URSI GA, where Prof. G. Righini reviewed the status of the Northern Cross, with the East-West arm operating regularly since the inauguration in 1964 (Figure16(a)), while the North-South foreseen to be commissioned in 1966 [93]. This instrument was mainly designed to perform radio surveys and it allowed the production of popular catalogues called B1, B2 and B3.

In later years, with antenna engineers developing large reflector antennas for telecommunication systems, the times were right to use such reflectors for scientific purposes, as well. Under the umbrella of the Institute of Radio Astronomy, two 32 m radio telescopes were inaugurated in Medicina and Noto (Siracusa) respectively in 1983 and 1988. They were subsequently used for observations up to 23 GHz (43 GHz for Noto) both in single dish mode and as participants in interferometric experiments within European and worldwide networks. Apart from constant upgrades at the two antennas, no other major infrastructure was built for 25 years, although smaller antennas were installed by the Trieste Astronomical Observatory for solar observations as an ante litteram Space Weather monitor.

It was in 2013, after the establishment of the National Institute for Astrophysics (INAF) in the early years of 2000, that the original idea to have a network of three Italian large radio telescopes was successfully completed, thanks to the advent of the Sardinia Radio Telescope (SRT) (Figure16(b)). This fully-steerable, wheel-and-track dish, 64 m in diameter, was designed to operate in the frequency range from 300 MHz to 100 GHz and beyond [94]. A significant contribution to the SRT project was made by Prof. G. Tofani [95] and Dr. R. Ambrosini who have chaired the Italian URSI Committee Commission J since its establishment until 2014 (see Figure 7).

The Italian reflector antennas are flexible instruments able to contribute to different branches of astrophysical research: compact objects, spectral lines of molecules associated with star formation, radio galaxies, interstellar masers, pulsars and much more. Furthermore, INAF envisages using SRT, Medicina, and Noto single-dish radio telescopes for solar radio imaging in the K band and above for Solar Radio Weather monitoring [96]. Recently, the 20-million-euro PON project entitled "Enhancement of the SRT for the study of the Universe at high radio frequencies" was funded and it will fully exploit the technical characteristics of SRT up to 100 GHz.

Besides national projects, INAF is currently involved in the development of the next generation of radio-astronomy infrastructures such as the Atacama Large Millimeter Array (ALMA), now hosting one of its Regional Centres in Bologna, and the Square Kilometer Array (SKA) project, with the Italian team presently taking part in the design of different elements that will constitute the final radio telescope. In particular, it is worthwhile mentioning how much the experience gathered in developing and operating the Northern Cross has contributed to forming a technical team who is now playing a primary role in the Low Frequency Aperture Array (LFAA) system of SKA [97].

In recent years, the Medicina observatory has participated in a wider range of projects, such as LOFAR (LOw Frequency ARray) with one station planned to be installed there. In line with this renovation phase, the Northern Cross, now 55 years old, is beginning a second life as ESA has funded a partial re-engineering of the instrument to join the European Space Surveillance and Tracking (EUSST) network for monitoring space debris.

3.10 Commission K: Electromagnetics in Biology and Medicine

Commission K is the youngest among URSI Commissions, as it was created during the Prague XXIII GA, in 1990 [98], due to the increasing interest and activities in the field of bioelectromagnetics. Since the beginning, the interdisciplinary character and the cooperation with other international organizations were particular attributes of this Commission.

The Italian national Commission K inherits similar features, promoting research on the biological effects of electromagnetic (EM) fields and waves, and their uses in diagnostic and therapeutic medicine. In particular, it has always cooperated with international organizations, such as EU COST Actions, the European Bio-Electromagnetics Association (EBEA), the Bioelectromagnetics Society (BEMS), the European Association of Antennas and Propagation (EurAAP), and was strongly involved in the European Framework Programs since the late 90's. At a national level, the close interaction with the national Inter-university Research Center for Interactions between Electro-magnetic Fields and Biosystem (ICEmB) is worth mentioning since researchers of this community have played important roles as member of the International Commission on Non-Ionizing Radiation Protection (ICNIRP), as part of the Electromagnetic Field project of the World Health Organization (WHO) and as external experts of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Moreover, the national Commission contributed to URSI with two Chairs of the International Commission K, Paolo Bernardi (1993-1996), who was one of the promoters of the Commission itself, and Guglielmo D'Inzeo (2008-2011).

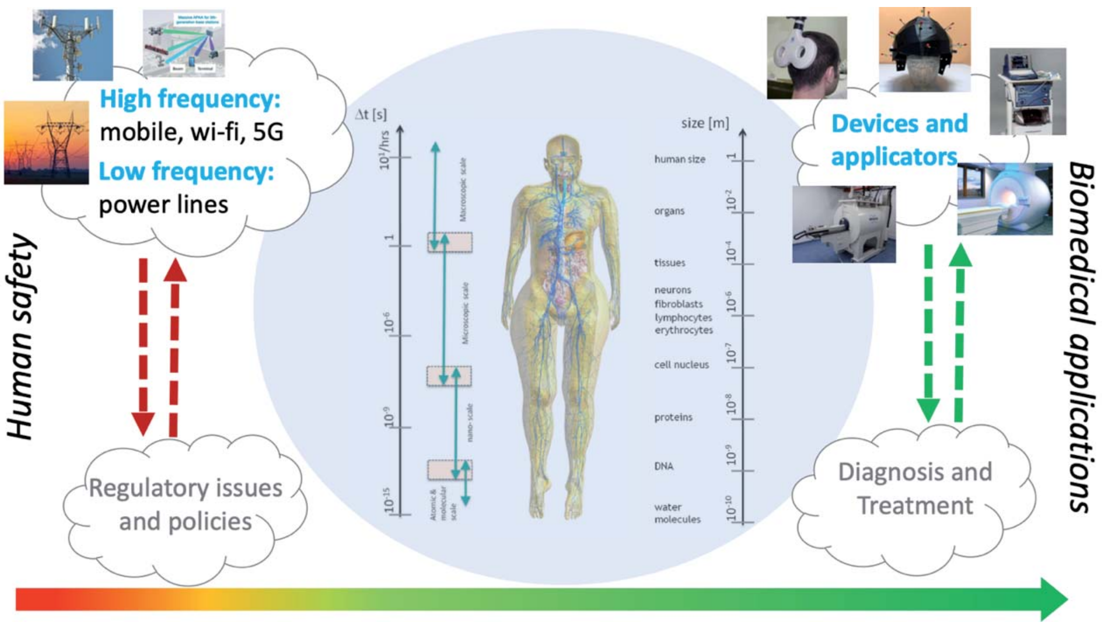

Figure 17. Schematics of a multiscale approach to the study of the interaction of electromagnetic fields and human systems either for safety assessment or for biomedical applications.

Figure 18. Logo of the URSI GASS 2020 showing the skyline of some of the main monuments in Rome.

During the first years, the national Commission K had a central role on the risk assessment for wireless communication, reinforcing a unique body of knowledge on the mechanisms of interaction [99], exploring the plethora of induced biological effects [100-102], developing advanced computational methodologies and dosimetric modeling [103], defining guidelines and regulatory limits [104], and exploiting more and more accurate measurement techniques [105, 106]. Notably, the outcomes of these research activities nowadays provide important milestones to face the challenges posed by the upcoming introduction of the 5G technology.

In subsequent years, the activities were focused on methodological approaches towards the multiscale-problem underlying the interaction of EM fields and human living systems. Whatever the source of the field (either coming from communications systems or from devices for biomedical applications) the interaction problem involves processes with length scales ranging from molecules to the whole organism, and with time scales going from tens of nanoseconds for ionic transport to many years of the human life (Figure 17). Therefore, a single mathematical model cannot describe such a variety of processes covering a factor of 10^9 in the spatial scale and 10^{17} in the timescale [107]. A suitable solution is the development of a hierarchy of models valid in a limited range of spatial and temporal scales and linked together through suitable parameters.

More recently, a huge effort was addressed to develop innovative medical devices, which exploit known mechanisms of EM field interaction the with the human body to achieve a therapeutic goal, guide a treatment, or diagnose a disease. Interestingly, as these aspects involve the same EM technologies, their study can lead to a novel generation of theragnostic devices. In this respect, researchers of national Commission K have developed ad-hoc approaches for the design of imaging systems [108], EM sensors [109], and smart nano-systems [110], as well as for the accurate characterization of the electromagnetic properties of human tissue [111, 112]. As far as therapeutic applications are concerned, the activities of the national Commission K are related to electroporation and electrochemotherapy [113], electrical and magnetic stimulation of the nervous system [114, 115], applications of pulsed EM fields (PEMFs) for acute ischemia stroke [116] and for anti-inflammatory diseases [117], microwave hyperthermia [118] and thermal ablation therapies [119]. Whereas, the diagnostic applications include microwave imaging for diagnosis of brain strokes [120], breast cancer [121], contrast enhanced microwave imaging for early stage tumour diagnosis [122], microwave imaging for treatment monitoring [123], and electrical property tomography via magnetic resonance imaging for both treatment planning and diagnosis [124].

4. Conclusion

The previous sections provide, without any presumption of completeness, a mix of historical facts, past, present and future research activities, and prominent personalities to highlight the remarkable contribution, over the years, of Italian radio scientists towards the URSI mission. The Italian URSI Committee was recently awarded the honour of hosting the coming URSI General Assembly and Scientific Symposium (GASS). This will be the third URSI GASS organized on the Italian territory and furthermore will coincide with the centenary anniversary of the establishment of URSI. Indeed, the

XXXIII GASS will take place in the prestigious Sapienza University Campus in Rome from August 29 to September 5, 2020 (see Figure 18). It is expected that URSI GASS 2020, in the Eternal City, will enjoy great success with outstanding participation by top-level researchers from all over the world. The guiding theme of the GASS2020, in Rome, will be centred on 100 years of Radio Science, with exhibitors, stand, movies, and panels dedicated to radio-frequency electromagnetic propagation and related applications. The Italian URSI Committee is looking forward to welcoming you in the Eternal City for this unmissable appointment. Please refer to the GASS 2020 website for further details: https://www.ursi2020.org/. [Note: Since this was written, GASS2020 was postponed until 2021, to be held in the same location at approximately the same dates in 2021.]

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6. References

1. A. G. Cock, "Chauvinism and Internationalism in Science: The International Research Council, 1919-1926," *Notes and Records of the Royal Society of London*, **37**, 2, March 1983.

2. G. Vallauri, "Sul Funzionamento dei Tubi a Vuoto a tre Elettrodi (Audion) Usati nella Radiotelegrafia," *L'Elettrotecnica*, **4**, 3, 1917, pp. 43-53.

3. "La VI Assemblea Internazionale dell'Unione Radioscientifica," *Corriere della Sera*, Sept. 5, 1938, pp. 1.

4. G. Viola di Campalto, "Sextièmeassembléegénérale de l'union radio scientifiqueinternationale," *Bulletindu Centro Volpi di Elettrologia*, Sept. 30, 1938, pp. 3-12.

5. *RecueildesTravaux de l'AssembléeGénerale tenue à Venise et a Rome en Septembre 1938*, *Comptes-RendusdesSéances*, **V**, 2, Bruxelles, Belgium, URSI, 1938.

6. T. Gorio, "La VI Assemblea Generale dell'Unione RadioscientificaInternazionale," *Rassegna delle Poste, dei Telegrafi e dei Telefoni*, **X**, 10, Oct. 1938, pp. 769-771.

7. N. Carrara, "The Detection of Microwaves," *Proceedings of the IRE*, **20**, 10, 1932, pp. 1615-1625.

8. *URSI XXIst General Assembly Programme*, Florence, Italy, CNR, 1984.

9. "Notizie e Informazioni",*L'Elettrotecnica*, **72**, 1, 1985, p. 76.

10. W. J. Granville Beynon, "Preface, URSI General Lectures", *Radio Science*, **21**, 4, 1986, pp. 646.

11. A. Pellinen-Wannberg, "Women in Radio Science," *Radio Science Bulletin*, 354, Sept. 2015, pp. 44-45.

12. L. Briatore, S. Leschiutta, "Verifying the Gravitational Shift Due to the Earth's Rotation", *Il Nuovo Cimento B*, **37**, 1976, pp. 219-223.

13. C. Svelto, M. Norgia, E. Bava and G. Galzerano, "FM Spectroscopy of Monodeuterated Methane as a Frequency Standard at 1.54 /spl mu/m," *IEEE Transactions on Instrumentation and Measurement*, **54**, 4, Aug. 2005, pp. 1630-1633.

14. L. Consolino, S. Bartalini, and P. De Natale, "Terahertz Frequency Metrology for Spectroscopic Applications: A Review," *Journal of Infrared, Millimeter, and Terahertz Waves*, **38**, 11, 2017, pp. 1289-1315.

15. A. Ferrero, U. Pisani, and K. J. Kerwin, "A New Implementation of a Multiport Automatic Network Analyzer," *IEEE Transactions on Microwave Theory and Techniques*, **40**, 11, 1992, pp. 2078-2085.

16. M. Garelli and A. Ferrero, "A Unified Theory for S-parameter Uncertainty Evaluation," *IEEE Transactions on Microwave Theory and Techniques*, **60**, 12, 2012, pp. 3844 – 3855.

17. E. Piuzzi, G. Cannazza, A. Cataldo, S. Chicarella, E. De Benedetto, F. Frezza, S. Pisa, S. Prontera, and F. Timpani, "Measurement System for Evaluating Dielectric Permittivity of Granular Materials in the 1.7 - 2.6 GHz Band," *IEEE Transactions on Instrumentation and Measurement*, **65**, 5, 2016, pp. 1051-1059.

18. E. Piuzzi, E. Pittella, S. Pisa, A. Cataldo, E. De Benedetto, G. Cannazza "Microwave Reflectometric Methodologies for Water Content Estimation in Stone-Made Cultural Heritage Materials," *Measurement*, **118**, 2018, pp. 275-281.

19. N. Pasquino, "Measurement and Analysis of Human Exposure to Electromagnetic Fields in GSM Band," *Measurement*, **109**, 2017, pp. 373–383.

20. A. Caddemi and E. Cardillo, "On the Microwave Noise Figure Measurement: A Virtual Approach for Mismatched Devices," *Measurement*, **137**, 2019, pp. 116-121.

21. A. Baccigalupi, A. Liccardo, and N. Pasquino, "A Methodology for Testing Immunity of Field Programmable Analog Arrays to Radiated Electromagnetic Field," *Measurement*, **44**, 2011, pp. 2165-2174.

22. L. Angrisani, D. Capriglione, G. Cerro, L. Ferrigno, and G. Miele, "Optimization and Experimental Characterization of Novel Measurement Methods for Wide-Band Spectrum Sensing in Cognitive Radio Applications," *Measurement*, **94**, 2016, pp. 585-601.

23. E. F. Arias, D. Matsakis, T. J. Quinn and P. Tavella, "The 50th Anniversary of the Atomic Second," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, **65**, 6, June 2018, pp. 898-903.

24. F. Lamonaca and D. Grimaldi, "Trigger Realignment by Networking Synchronized Embedded Hardware," *IEEE Transactions on Instrumentation and Measurement,* **62**, 1, 2013, pp. 38-49.

25. M. Rizzi, A. Depari, P. Ferrari, A. Flammini, S. Rinaldi, and E. Sisinni, "Synchronization Uncertainty Versus Power Efficiency in LoRaWAN Networks," *IEEE Transactions on Instrumentation and Measurement*, **68**, 4, 2019, pp. 1101-1111.

26. F. Lamonaca, D. L. Carnì, M. Riccio, D. Grimaldi and G. Andria, "Preserving Synchronization Accuracy from the Plug-in of Mon Synchronized Nodes in a Wireless Sensor Network," *IEEE Transactions on Instrumentation and Measurement*, **66**, 5, 2017, pp. 1058-1066.

27. "Selected papers from the URSI Symposium on Electromagnetic Waves, Stresa, Italy, June 24-29, 1968," *Alta Frequenza*, special issue, **38**, May 1969.

28. *Proceedings of the 2004 URSI Commission B International Symposium on Electromagnetic Theory* (EMTS 2004), Pisa, Italy, May 23-27, 2004.

29. *Proceedings of the 2019 URSI Commission B International Symposium on Electromagnetic Theory* (EMTS 2019), San Diego, California, USA, May 27-31, 2019.

30. G. Balbi, "The Origins of the Telephone in Italy, 1877–1915: Politics, Economics, Technology and Society," *International Journal of Communication*, **5**, 2011, pp. 1058-1081.

31. U. Tiberio, "Ricordo del Primo Radar Navale Italiano," *Rivista Marittima*, **425**, 12, Dec. 1976, pp. 17-30.

32. A. Marino, "La Radiotelegrafia e i suoi Progressi," *Cronache di Scienza*, Feb. 1912.

33. F. Carassa, "New Satellite Systems and Higher Frequency Utilization," *Alta Frequenza*, **56**, 1987, pp. 5-13.

34. F. Gargione, T. Iida, F. Valdoni, and F. Vatalaro, "Services, Technologies, and Systems at Ka Band and Beyond - A Survey," *IEEE Journal on Selected Areas in Communications*, March 1999, pp. 133-144.

35. M. Ajmone Marsan, N. Blefari Melazzi, and S. Buzzi, eds, *5G Italy White eBook: from Research to Market*, CNIT, 2018, https://www.5gitaly.eu/white-ebook/.

36. S. Chiocchio, A. Persia, F. Valentini, E. Cinque, M. Pratesi, and F. Santucci, "Integrated Simulation Environments for Vehicular Communications in Cooperative Road Transportation Systems," 2018 2nd URSI Atlantic Radio Science Meeting (AT-RASC), Meloneras, 2018, pp. 1-4.

37. S. Park, S. Lee, and J. A. Rogers, "Circuits, Sensors and Radios for the Skin," 2016 IEEE International Symposium on Antennas and Propagation (AP-S/URSI), Fajardo, 2016.

38. S. Amendola, S. Milici, G. Marrocco and C. Occhiuzzi, "On-Skin Tunable RFID Loop Tag for Epidermal Applications," 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, 2015, pp. 202-203.

39. S. Amendola and G. Marrocco, "Epidermal UHF Antennas for Skin Sensing: Fundamental Limitations and Optimal Performance," 2016 AP-S/URSI Puerto Rico, 2016.

40. S. Amendola, G. Bovesecchi, P. Coppa and G. Marrocco, "Thermal Characterization of Epidermal RFID Sensor for Skin Temperature Measurements,"2016 IEEE International Symposium on Antennas and Propagation (AP-S/URSI), Fajardo, 2016, pp. 461-462.

41. S. Nappi and G. Marrocco, "Inkjet-Printed RFID-Skins for the Detection of Surface Defects," 2018 2nd URSI Atlantic Radio Science Meeting (AT-RASC), Meloneras, 2018, pp. 1-4.

42. J. C. Batchelor, O. O. Rakibet, C. V. Rumens and S. J. Holder, "Accurate RFID Strain Gauges for Skin Mounting," 2014 IEEE Antennas and Propagation Society International Symposium (AP-S/URSI), Memphis, TN, 2014, pp. 836-837.

43. J. C. Batchelor, O. O. Rakibet, M. A. Ziai, C. V. Rumens and S. J. Holder, "Conformal RFID Sensing for Assisted Living," XXXIth URSI General Assembly and Scientific Symposium, Beijing, 2014, pp. 1-4.

44. D. Pani, A. Achilli, P. P. Bassareo, L. Cugusi, G. Mercuro, B. Fraboni, and A. Bonfiglio, "Fully-Textile Polymer-Based ECG Electrodes: Overcoming the Limits of Metal-Based Textiles," Computing in Cardiology Conference (CinC), 2016.

45. P. Cosseddu, G. Casula, S. Lai, S. Conti, and A. Bonfiglio, "Towards All Inkjet Printed Electronics," Proc. SPIE 10366, Hybrid Memory Devices and Printed Circuits, 2017, 1036607.

46. G. E. Bonacchini, C. Bossio, F. Greco, V. Mattoli, Y. H. Kim, G. Lanzani, and M. Caironi, "Tattoo-Paper Transfer as a Versatile Platform for All-Printed Organic Edible Electronics," *Advanced Materials*, **30**, 14.

47. Records of URSI General Assemblies: Chicago General Assembly, URSI, August 2008.

48. Records of URSI General Assemblies: New Delhi General Assembly, URSI, October 2005.

49. Records of URSI General Assemblies: Maastricht General Assembly, URSI, August 2002.

50. S. A. Pignari, F. Grassi, F. Marliani, F. G. Canavero, "Experimental Characterization of Injection Probes for Bulk Current Injection," URSI GASS 2005, New Delhi, India, Oct. 23-29, 2005.

51. S. A. Pignari, "Statistics and EMC," (invited paper), *URSI Radio Science Bulletin*, **316**, Mar. 2006, pp. 13-26.

52. Records of URSI General Assemblies: Istanbul General Assembly, URSI, August 2011.

53. S. A. Pignari and G. Spadacini, "Influence of Twist-Pitch Random Non-Uniformity on the Radiated Immunity of Twisted-Wire Pairs," URSI GASS 2011, Istanbul, Turkey, Oct. 13-20, 2011.

54. P. Manfredi, M. Fontana, I. S. Stievano, and F. G. Canavero, "Comparison of Stochastic Methods for the Variability Assessment of Technology Parameters," *Radio Science*, **47**, 6, 2012, pp. 1-8.

55. C. Christopoulos, "Dealing with Complexity in EMC Modelling," URSI GASS 2011, Istanbul, Turkey, Oct. 13-20, 2011.

56. C. F. M. Carobbi, S. Lalléchère, and L. R. Arnaut, "Review of Uncertainty Quantification of Measurement and Computational Modeling in EMC Part I: Measurement Uncertainty," *IEEE Transactions on Electromagnetic Compatibility*, early access article, 2019, DOI 10.1109/TEMC.2019.2904973.

57. S. Lalléchère, C. F. M. Carobbi, and L. R. Arnaut, "Review of Uncertainty Quantification of Measurement and Computational Modeling in EMC Part II: Computational Uncertainty," *IEEE Transactions on Electromagnetic Compatibility*, early access article, 2019, DOI 10.1109/TEMC.2019.2904999.

58. F. Fedi, “Rain Attenuation on Earth to Satellite Links: A Prediction Method Based on Point Rainfall Intensity,” URSI Open symposium on Radio Wave Propagation and Remote Sensing, Lennoxville, Canada, May 26 -30,1980.

59. F. Barbaliscia, A. Paraboni, and G. Ravaioli “Analysis and Modelling of Rain Correlation Over Wide Areas,” 5th URSI Open Symposium on Radio Wave Propagation and Remote Sensing, La Londe-les-Maures, France, Sept. 11-15, 1989.

60. C. Capsoni, D. Ferraro, L. Luini, M. S. Pontes, and L. A. R. Silva Mello: “One-Parameter Model for the Prediction of Cumulative Rain Statistics: Preliminary Results,” 11th URSI Commission F Triennial Open Symposium on Radio Wave Propagation and Remote Sensing, Rio de Janeiro, Brazil, Oct. 30 – Nov. 2, 2007.

61. R. Nebuloni, C. Capsoni, and M. Luccini, “Advanced Time Series Synthesizer for Simulation of Joint Rain Attenuation Conditions,” *Radio Science*, **49**, 9, Sept. 2014, pp. 699-708.

62. E. Regonesi, C. Capsoni, L. Luini, C. Riva, and R. Nebuloni “Investigation of Rain Induced Depolarization by Means of a Physically Based Simulator,” 2nd URSI AT-RASC, Gran Canaria, Spagna, May 28 – June 1, 2018.

63. P. Pampaloni and S. Paloscia, “Passive Microwave Remote Sensing of Vegetated Surfaces,” URSI General Assembly, Kyoto, Japan, Aug. 25 - Sept. 3, 1993.

64. P. Ferrazzoli, L. Guerriero, “Modelling Microwave Emission from Forests,” Proc. IEEE-URSI International Geoscience and Remote Sensing Symposium, Florence, 1995, pp.611-613.

65. S. Paloscia, P. Pampaloni, E. Santi, S. Pettinato, X. Chuanand M. Brogioni, “Multi-layer Model Simulations of Backscattering and Emission from Snow Covered Soils,” 31th URSI General Assembly and Scientific Symposium, 2014.

66. P. Pampaloni, “Looking at the Earth as a Planet: Passive Microwave Remote Sensing of Land Surfaces,” *The Radio Science Bulletin*, **351**, Dec. 2014, pp. 5-28.

67. D. Comite, N. Pierdicca, F. Ticconi, and L. Guerriero, “On the Modeling of the Bistatic Coherent Scattering from a Rough Surface,” Proc. IEEE Antennas and Propagation Society International Symposium and USNC/URSI National Radio Science Meeting, APS-URSI 2018, Boston, MA, July 8-13, 2018.

68. W Dieminger et al., *The upper atmosphere: Data Analysis and Interpretation*, Springer-Verlag, Berlin Heidelberg 1996.

69. E. Zuccheretti, G. Tutone, U. Sciacca, C. Bianchi, and J. A. Baskaradas, “The New AIS-INGV Digital Ionosonde,” *Annals of Geophysics*, **46**, 4, pp. 647-659.

70. L. Ciraolo and P. Spalla, “Preliminary Study of the Latitudinal Dependence of TEC, *Advances in Space Research*, **22**, 6, pp. 807-810.

71. M. Materassi and C. N. Mitchell, “Imaging of the Equatorial Ionosphere,” (2005) Annals of Geophysics, **48**, 3, pp. 477-482.

72. M. Materassi and C. N. Mitchell, “Wavelet Analysis of GPS Amplitude Scintillation: A Case Study, *Radio Science*, **42**, 1, 2007.

73. G. De Franceschi, L. Spogli, L. Alfonsi, V. Romano, C. Cesaroni, and I. Hunstad, “The Ionospheric Irregularities Climatology over Svalbard from Solar Cycle 23,” accepted for publication in *Scientific Reports*, https://doi.org/10.1038/s41598-019-44829-5.

74. F. Vespe, G. Perona, V. De Cosmo, M. Petitta, M. Materassi, N. Tartaglione, A. Zin, R. Notarpietro, C. Benedetto, S. Casotto, A. Speranza, A. Sutera, “ROSA - The Italian Radio Occultation Mission Onboard the Indian OCEANSAT-2 Satellite,” in A. Steiner, B. Pirscher, U. Foelsche (eds.), *New Horizons in Occultation Research: Studies in Atmosphere and Climate*, Springer, Berlin, Germany, 2009, pp. 263-274.

75. M. Materassi, A. Coster, B. Forte, and S. Skone (eds.), *The Dynamical Ionosphere*, to be published by Elsevier.

76. G. Hochegger, B. Nava, S. Radicella, and R. Leitinger, “A Family of Ionospheric Models for Different Uses,” *Physics and Chemistry of the Earth, Part C: Solar, Terrestrial & Planetary Science*, **25**, 4, 2000, Pages 307-310.

77. A. W. Wernik, L. Alfonsi, and M. Materassi, “Scintillation Modelling Using in situ Data,” *Radio Science*, **42**, 2007.

78. Materassi, M., L. Ciraolo, G. Consolini, and N. Smith, “Predictive Space Weather: An Information Theory Approach,” *Advances in Space Research*, **47**, 2011, pp. 877-885.

79. F. F. Chen, *Introduction to Plasma Physics and Controlled Fusion*, 2nd ed., New York, NY, Plenum Press, 1984.

80. G. Einaudi, and M. Velli, “The Distribution of Flares, Statistics of Magnetohydrodynamic Turbulence and Coronal Heating,” *Phys. Plasma*, **6**, 1999.

81. M. Messerotti et al., “Solar Weather Event Modelling and Prediction,” *Space Science Reviews*, **147**, 3-4, 2009, pp. 121-185.

82. A. Zanichelli et al., “An RFI Mitigation Project at the Italian Radio Telescopes,” XXXIInd URSI GASS, Montreal, QC, 2017, pp. 1-4.

83. F. Taccogna and P. Minelli, “Three-Dimensional Particle-in-Cell Model of Hall Thruster: The Discharge Channel,” Physics of Plasmas, **25**, 061208, 2018.

84. R. H. Varian and S. F. Varian. “A High Frequency Oscillator and Amplifier,” Journal of Applied Physics,**10**, 321, 1939.

85. J. R. Pierce and L. M. Field, “Traveling-Wave Tubes,” Proceedings of the IRE, **35**, 1947, pp 108- 111.

86. A. Y. Baikov, C. Marrelli and I. Syratchev, *IEEE Transactions Electron Devices,* **62**, 2015, pp. 3406-3412.

87. S. Garavaglia et al., “EU DEMO EC system preliminary conceptual design,” *Fus. Eng. Design*, **136B**, 2018, pp. 1173-1177.

88. F. Califano et al. “Nonlinear filamentation instability driven by an inhomogeneous current in a collisionless plasma,” *Physical Review E*, 58, 7837, 1998.

89. F. Filippi et al., “3D-Printed Capillary for Hydrogen Filled Discharge for Plasma Based Experiments in RF-Based Electron Linac Accelerator,” *Rev. Sci. Instrum.*, **89**, 083502, 2018.

90. G. Ciavola et al., “Multipurpose Superconducting Electron Cyclotron Resonance Ion Source, the European Roadmap to Third-Generation Electron Cyclotron Resonance Ion Sources,” *Rev. Sci. Instrum*., **77**, 03A303, 2006.

91. P. Agostinetti et al., “Detailed Design Optimization of the MITICA Negative Ion Accelerator in View of the ITER NBI”. *Nucl. Fusion*, **56**, 016015, 2016.

92. R. Nesti, “1933: Radio Signals from Sagittarius,” *IEEE Antennas and Propagation Magazine*, **61**, 4, Aug. 2019, pp. 109-115.

93. G. Righini, Report of the Italian Committee, XV URSI General Assembly, Munich, Germany, Sept. 5-15, 1966. pp. 51-55.

94. R. Ambrosini, et al., “Commissioning of the Sardinia Radio Telescope in Italy: Results and perspectives,” 2014 XXXI URSI General Assembly and Scientific Symposium, Beijing, China, Aug.16-23, 2014.

95. P. Bolli, N. D’Amico, and R. Nesti, Preface to the Special Section on “Radio Astronomy: A Continuous Demand for Breakthrough Technology,” *URSI Radio Science Bulletin*, **362**, 2017.

96. P. Bolli, et al., “From MAD to SAD: The Italian Experience for the Low-Frequency Aperture Array of SKA1-LOW,” *Radio Science*, **51**, 3, 2016.

97. A. Pellizzoni et al., “High-Resolution Imaging of the Solar Chromosphere in the Centimetre-Millimetre Band Through Single-Dish Observations,” 2nd URSI Atlantic Radio Science Meeting, Gran Canaria, Spain, May 28-June 1, 2018.

98. J. C. Lin et al., “The Formation and Early Years of URSI Commission K on Electromagnetics in Biology and Medicine,” *The Radio Science Bulletin*,**330**, 2009, PP51-58.

99. A. Chiabrera, et al., "Zeeman–Stark Modeling of the RF EMF Interaction with Ligand Binding." *Bioelectromagnetics*, **21**, 4, 2000, pp. 312-324.

100. L. Stronati et al., "935 MHz Cellular Phone Radiation. an in Vitro Study of Genotoxicity in Human Lymphocytes," *International Journal of Radiation Biology*, **82**, 5, 2006, pp. 339-346.

101. M. R. Scarfi et al., "Exposure to Radiofrequency Radiation (900 MHz, GSM signal) Does Not Affect Micronucleus Frequency and Cell Proliferation in Human Peripheral Blood Lymphocytes: An Interlaboratory Study," *Radiation Research*, **165**, 6, 2006, pp. 655-663.

102. D. Platanoet al., "Acute Exposure to Low-Level CW and GSM-Modulated 900 MHz Radiofrequency Does Not Affect Ba2+ Currents Through Voltage-Gated Calcium Channels in Rat Cortical Neurons," *Bioelectromagnetics*, **28**, 8, 2007, pp. 599-607.

103. P. Bernardi et al., "SAR Distribution and Temperature Increase in an Anatomical Model of the Human Eye Exposed to the Field Radiated by the User Antenna in a Wireless LAN," *IEEE Transactions on Microwave Theory and Techniques*, **46**, 1998, pp. 2074-2082.

104. G. Ziegelberger, P. Vecchia, et al., "Guidelines on Limits of Exposure to Static Magnetic Fields," *Health Physics*, **96**, 4, 2009, pp. 504-514.

105. S. Pisa et al., "Numerical Experimental Validation of a GM-FDTD Code for the Study of Cellular Phones," *Microwave and Optical Technology Letters*, **47**, 4, 2005, pp. 396-400.

106. G. A. Lovisolo et al., "Specifications of in vitro Exposure Setups in the Radio-Frequency Range," *The Radio Science Bulletin*, **331**, 2009.

107. F. Apollonio, et al., "Feasibility for Microwaves Energy to Affect Biological Systems Via Nonthermal Mechanisms: A Systematic Approach," *IEEE Transactions on Microwave Theory and Techniques*, **61**, 5, 2013, pp. 2031-2045.

108. O. M. Bucci, et al., "On the Design of Phased Arrays for Medical Applications," *Proceedings of the IEEE*, **104**, 3, 2016, pp. 633-648.

109. M. Pieralisi, et al., "Design and Realization of an Electromagnetic Guiding System for Blind Running Athletes," *Sensors (Switzerland)*, **15**, 7, 2015, pp. 16466-16483.

110. M. Nardoni et al., "Can Pulsed Electromagnetic Fields Trigger On-Demand Drug Release from High-Tm Magnetoliposomes?" *Nanomaterials*, **8**, 4, 2018, art. no. 196.

111. A. Martellosio, et al., "Dielectric Properties Characterization from 0.5 to 50 GHz of Breast Cancer Tissues," *IEEE Transactions on Microwave Theory and Techniques*, **65**, 3, 2017, pp. 998-1011.

112. S. Gavazzi, et al., "Comparison of Microwave Dielectric Properties of Human Normal, Benign and Malignant Thyroid Tissues Obtained from Surgeries: A Preliminary Study," *Biomedical Physics and Engineering Express*,**4**, 4, 2018, art. no. 047003.

113. R. Cadossi, et al., "Locally Enhanced Chemotherapy by Electroporation: Clinical Experiences and Perspective of Use of Electrochemotherapy," *Future Oncology*, **10**, 5, 2014, pp. 877-890.

114. Priori et al., "Transcranial Cerebellar Direct Current Stimulation and Transcutaneous Spinal Cord Direct Current Stimulation as Innovative Tools for Neuroscientists," *Journal of Physiology*, **592**, 16, 2014, pp. 3345-3369.

115. V. Di Lazzaro et al., "A Consensus Panel Review of Central Nervous System Effects of the Exposure to Low-Intensity Extremely Low-Frequency Magnetic Fields," *Brain Stimulation*, **6**, 4, 2013, pp. 469-476.

116. F. Capone, et al., "An Open-Label, One-Arm, Dose-Escalation Study to Evaluate Safety and Tolerability of Extremely Low Frequency Magnetic Fields in Acute Ischemic Stroke," *Scientific Reports*, **7**, 1, 2017, art. no. 12145.

117. K. Varani, et al., “Role of Adenosine Receptors in Clinical Biophysics Based on Pulsed Electromagnetic Fields,” Pier Andrea Borea, et al, (eds) *The Adenosine Receptors*, Springer International Publishing; Humana Press, Receptors Series, **34**, 2018, pp. 557-580.

118. D. A. M. Iero, et al., 1st URSI Atlantic Radio Science Conference, URSI AT-RASC, 2015, art. no. 7303223.

119. M. Cavagnaro, et al., “A Minimally Invasive Antenna for Microwave Ablation Therapies: Design, Performances, and Experimental Assessment,” *IEEE Transactions on Biomedical Engineering*, **58**, 4, 2011, pp. 949-959.

120. R. Scapaticci, et al., “Design and Numerical Characterization of a Low-Complexity Microwave Device for Brain Stroke Monitoring,” *IEEE Transactions on Antennas and Propagation*, **66**, 12, 2018, pp. 7328-7338.

121. M. R. Casu et al., “A COTS-Based Microwave Imaging System for Breast-Cancer Detection,” *IEEE Transactions on Biomedical Circuits and Systems*, **11**, 4, 2017, pp. 804-814.

122. O. M. Bucci, et al., “Assessing Detection Limits in Magnetic Nanoparticle Enhanced Microwave Imaging,” *IEEE Access*, **6**, 2018, pp. 43192-43202.

123. R. Scapaticci et al., “Monitoring Thermal Ablation via Microwave Tomography: An Ex Vivo Experimental Assessment,” *Diagnostics*, **4**, 2018, pp. 81.

124. A. Arduino et al., “CSI-EPT in Presence of RF-Shield for MR-Coils,” *IEEE Transactions on Medical Imaging*, **36**, 7, 2017, pp. 1396-1404.