Eur. Phys. J. H (2026)51:9
https://doi.org/10.1140/epjh/s13129-026-00121-5

THE EUROPEAN
PHYSICAL JOURNAL H

Regular Article

An epistemology of the province: Alessandro Serpieri and experimental physics in Italy across unification (1851–1878)

Roberto Mantovani[a]

Department of Pure and Applied Sciences (DiSPeA), Physics Laboratory: Urbino Museum of Science and Technology, University of Urbino Carlo Bo, Collegio Raffaello, Piazza della Repubblica 13, 61029 Urbino, PU, Italy

Received 29 July 2025 / Accepted 17 April 2026
© The Author(s) 2026

Abstract In Italy, in the decades surrounding Italian Unification—especially in the early years of the Kingdom of Italy—figures such as Pietro Blaserna and Carlo Matteucci commented critically on the state of the physical sciences, addressing institutional and pedagogical arrangements as much as research practices. At the same time, an alternative mode of knowledge production was emerging: an "*epistemology of the province*"—an analytical and historiographical category for forms of scientific research and experimental practice that were locally rooted yet sustained by supra-local circuits of communication and validation. This article examines such a provincial epistemic configuration through the work of Alessandro Serpieri (1823–1885), a scientist whose career at the University of Urbino spanned thirty-seven years. The analysis centres on three paradigmatic case studies: the first Italian replication of Foucault's pendulum (30 March 1851); pioneering research into duplex telegraphy (1854–1855); and investigations of the first Bell telephones in Italy (1877–1878). These episodes collectively demonstrate how Serpieri's locally grounded practice remained consistently engaged with the most advanced international technological debates. Across these episodes, Serpieri's trajectory moves from mechanical and astronomical phenomena to electrotechnical questions and culminates in his study of the telephone, which foregrounds the listener as an active component in the device's operation. He argued that much of the apparatus's effectiveness in transmitting sound should instead be attributed to the listener's interpretative capacity. This claim invites a retrospective comparison with later themes in cybernetics and the cognitive sciences, while remaining grounded in Serpieri's nineteenth-century vocabulary of perception, judgement, and interpretation. Serpieri's work thus encourages us to read provincial science not as a peripheral appendage, but as a productive epistemic environment, capable of transforming marginal constraints into methodological opportunities and of challenging centre–periphery hierarchies in the production of original knowledge.

Keywords Alessandro Serpieri · Nineteenth-century Italian physics · Italian Unification · Provincial science · Centre–periphery · Knowledge circulation · Physics cabinets · Foucault's pendulum · Duplex telegraphy · Telephone

1 Introduction

This article analyses three paradigmatic case studies of experimental research conducted by the Piarist Alessandro Serpieri, an Italian scientist active in a provincial setting, between 1851 and 1878. These years span the political rupture of Italian Unification: the end of the Papal States, the proclamation of the Kingdom of Italy, and the annexations of Veneto (1866) and Rome (1870). The choice of this chronological interval is deliberate: it was in the pre-Unification decades that the technical skills, operational routines, and material resources that made "*provincial science*" possible were formed and consolidated. Investigating these pre-existing conditions is therefore essential for understanding how Serpieri's experimental practices could not only emerge but also maintain continuity across such a profound institutional rupture. From this perspective, I use the term "*epistemology of the province*" as an analytical and historiographical category through which to characterise forms of scientific research and experimental practice that, while locally rooted, were sustained by supra-local circuits of communication and validation. This approach reframes the role of "*the province*" in nineteenth-century Italy: no longer as a site of deficiency or

[a] e-mail: roberto.mantovani@uniurb.it (corresponding author)

passive marginality, but as a productive epistemic ecosystem capable of generating original knowledge within—and sometimes through—the constraints of the periphery.

1.1 Scientific fragmentation in pre-Unification Italy and the epistemology of the province

The pre-Unification decades of the nineteenth century were marked by profound contradictions for the Italian scientific community. On the one hand, the political fragmentation of the peninsula and the inadequacies in the organisation of university systems hindered the rapid and widespread circulation of ideas. As early as January 1842, the Milanese physicist Giovanni Alessandro Majocchi (1795–1854) observed that the circulation of scientific work in Italy faced "*very great obstacles*" and suffered from "*very slow communication*"; consequently, topics treated as "*new*" in one state might already be widely discussed in another (quoted in Lacaita 2001, 11).[1]

On the other hand, this relative marginality *vis-à-vis* Europe's major institutional centres also fostered alternative and resilient forms of scientific knowledge production.

Lacking the strongly centralised institutions exemplified by the *Académie des Sciences* in Paris or the *Royal Society* in London, the Italian scientific landscape consisted of a distributed network of smaller centres. In these localities, scientists often operated outside the most visible metropolitan institutions, developing forms of inquiry that were locally grounded yet oriented towards wider European scientific debates; for heuristic purposes, I refer to this configuration as a "*glocal*" mode of inquiry, while using "*epistemology of the province*" as the paper's primary historiographical category.

This perspective builds on Barbara J. Reeves's analysis of Italian academic physics. Reeves framed the predicament of Italian physics not only in institutional terms but also through "*research traditions*"—coherent models of inquiry defined by key problems, methods, and instruments, and sustained by intellectual and institutional support (Reeves 1989, 54). Although Reeves developed this framework for the post-Unification system, it serves here as a historiographical lens to conceptualise how locally anchored practices could achieve continuity under conditions of fragmentation. In this sense, the provincial epistemology functioned as a research tradition whose survival relied on access to instruments and channels of validation beyond the local setting. Such channels were not only domestic; transnational endorsement could be decisive, as when Faraday publicised Melloni's research on radiant heat at the *Royal Institution*, thereby helping Melloni secure the Rumford Medal of the *Royal Society* (James 2002, 157).[2]

A crucial structural feature of this configuration was the fluidity of institutional roles. In nineteenth-century Italy, the boundary between education and research was often porous: advanced teaching, the use and construction of scientific instruments, and experimental investigation typically coexisted within the same institutions—universities, secondary schools (*licei*), and technical schools—and, in particular, within their physics cabinets. As Giuliani emphasises, this porosity was materially enabled by the availability of apparatus suitable for experimental research in secondary-school laboratories and was reinforced by the scarcity of academic posts, which channelled many young graduates into school teaching (Giuliani 1996, 22).

To mitigate their isolation, provincial scientists developed compensatory channels of scientific communication through extensive epistolary correspondence and an emerging specialised periodical press. Such channels were increasingly conceived as practical correctives to fragmentation, intended to reduce informational delays and to coordinate dispersed efforts across state borders. Epistolary exchange became a key instrument for sharing data, discussing hypotheses, and obtaining informal validation of results before their official publication.

Moreover, political fragmentation did not prevent the establishment of numerous scientific journals, which were typically the direct expression of academies or university institutions based in urban centres such as Milan, Turin, Padua, Florence, Rome, and Naples. These periodicals played a crucial role, serving as platforms for the supra-regional circulation of theories and experimental reports and fuelling a scientific debate that transcended state boundaries.

As Reeves notes, the programme of the Pisa-based circle around *Il Cimento* (and later *Il Nuovo Cimento*)[3] explicitly aimed to provide Italy with a national research forum comparable to major European journals (Reeves 1980, 82–83). In practice, the journal also served as a conduit: studies first published in local venues were republished or summarised, while foreign periodicals often carried near-literal translations of the *Nuovo Cimento* version (Giuliani 1996, 1).

[1] Unless otherwise indicated, translations from Italian sources are my own.

[2] James shows that this validation combined public communication (Faraday's Royal Institution lecture of 23 Jan. 1835, reported in *The Literary Gazette*, 31 Jan. 1835, 73) with institutional gatekeeping (Royal Society Council Minutes, 6 Nov. 1834, vol. 1, 55) (James 2002, 157, nn. 60–61).

[3] In Giuliani's reconstruction, the last two volumes of *Il Cimento* (1844–47) were compiled by Carlo Matteucci, Ottaviano Fabrizio Mossotti, Luigi Pacinotti, Leopoldo Pilla, Raffaele Piria, and Paolo and Pietro Savi; publication was interrupted in 1848 and resumed in 1855 under the new title *Il Nuovo Cimento*. From its early years, the journal *Il Nuovo Cimento* organised translations and extended summaries in dedicated sections ("Estratti" / "Estratti e traduzioni"); from the fourteenth volume of the second series (1875) short notices appeared under "Rivista" (Giuliani 1996, 77–79).

Despite this polycentric landscape, Italy could still produce scientists of European stature, although such achievements often did not translate into durable research schools. For instance, Alessandro Volta (Fig. 1) emerged along a trajectory from Como to Pavia, showing that geographical distance from Europe's major metropolitan centres did not necessarily preclude scientific achievement. In the decades that followed, and especially from the 1820s onwards, a small elite of scientists achieved results of European significance. Figures such as Leopoldo Nobili (1784–1835) and Macedonio Melloni (1798–1854) (Fig. 2), who were forced into political exile in France before returning to Italy, and Carlo Matteucci (1811–1868), with his links to French electrophysiology, illustrated that access to transnational circuits of publication, patronage, and institutional judgement was often necessary—but not sufficient—for securing lasting international recognition.

Conversely, the case of Giovanni Battista Amici (1786–1863) (Fig. 3), a self-taught optician active in Modena until 1831 and later in Florence (1831–1863), testifies to the potential inherent in a productive periphery capable of sustaining autonomous scientific networks; Amici's subsequent move to Florence reflected the strength of his scientific achievements. His career as a brilliant microscope maker, whose instruments were in demand across Europe, helped transform the province from a space of marginality into a laboratory of innovation.

A further mechanism that mitigated both provincial isolation and political fragmentation was the emergence of supra-regional venues and congress networks for scientific exchange. From 1839, the *Congresses of Italian Scientists* acquired particular relevance as innovative venues for exchange and technical-scientific comparison.[4] These meetings continued uninterrupted from 1839 to 1847 and, after 1861, resumed from 1862 to 1875 in the changed climate of national unity. They provided key opportunities to overcome the scientific isolation of provincial research communities, enabling the circulation of ideas across diverse local contexts (Reeves 1980, 88–91; Pancaldi 1983).

1.2 Structural critiques of the physical sciences in post-Unification Italy: research and training

In the decades after 1861, the political unification process (initiated in 1861, with Veneto annexed in 1866 and Rome in 1870), together with an intensified exposure to European ideas and debates, generated high expectations of scientific renewal. Greater territorial cohesion and the affirmation of Positivism as the most influential philosophy—with its exaltation of science as an engine of civil and social progress—seemed to promise the modernisation of the institutions in which the physical sciences were pursued. In Italy, however, as already noted, research and training remained closely intertwined. Advanced teaching, the organisation of physics cabinets, and experimental investigation largely unfolded within the same universities and technical schools.

This renewed emphasis on circulation also took an institutional form in the technical and scientific periodical press. A revealing example comes from Milan. The mathematician and engineer Francesco Brioschi (1824–1897)—a central figure in higher technical education and scientific publishing—regarded the technical-scientific periodical press as a tool of renewal and an infrastructure enabling Italian research to circulate and gain recognition beyond local settings. He first sought to relaunch Carlo Cattaneo's wide-ranging journal *Il Politecnico*[5]; he also worked with a network of collaborators to reorganise the *Annali di matematica pura ed applicata* by building on an existing Roman title, the *Annali di scienze matematiche e fisiche* (1850), which also carried physics. His explicit aim was to make the Italian scientific movement known abroad and to keep Italian readers abreast of scientific developments in other "*civilised*" nations (Lacaita 2016, 16).

Precisely because expectations were so high, contemporaries increasingly framed the "*condition of the physical sciences*" as a national problem requiring diagnosis and reform. These ambitions were echoed in 1868 by Enrico Dal Pozzo di Mombello (1822–1892), a Barnabite priest and professor of physics at the Free University of Perugia, who framed "*scientific teaching*" as extending both "*in school and outside it*" and explicitly linked physics teaching practices to collective scrutiny—for instance by proposing that professors publish annual course summaries for colleagues' critical examination (Dal Pozzo di Mombello 1868, 5). In this context, the rising prestige of applied sciences and technology—bolstered by the foundation of polytechnic schools[6] and a partial reorganisation of higher technical institutes—seemed to promise a convergence with Central European models. However, as Pietro Blaserna (1836–1918) lucidly remarked, much of this anticipated renewal remained unfulfilled.

---

[4] On the long-standing historiographical tendency to privilege the political/Risorgimento meanings of the Italian Scientists' Congresses while neglecting their technical-scientific functions, see (Lacaita 2001, 12).

[5] *Il Politecnico* here refers to the Milanese periodical founded by Carlo Cattaneo (1839) and later relaunched under Brioschi; it should not be confused with the Milan higher-technical institution founded in 1863 (the *Regio Istituto Tecnico Superiore*, later the *Politecnico* di Milano).

[6] Here and throughout, "*polytechnic schools*" refers to higher technical institutions created or reorganised in the decades around Unification—*istituti tecnici superiori* and *scuole di applicazione per gli ingegneri*—rather than to secondary-level technical schools. Examples include the *Istituto Tecnico Superiore di Milano* (directed by Francesco Brioschi) and the *Scuola di applicazione per gli ingegneri di Torino* (from 1862 complemented by the *Regio Museo Industriale*), often discussed as Italian counterparts to the French *École polytechnique* and related Central-European models.

Fig. 1 Alessandro Volta. Engraved portrait by Luigi Rados after Roberto Focosi. Source: Author's private collection (photo by the author)

Fig. 2 Leopoldo Nobili (left) and Macedonio Melloni (right). Sources: Left panel, U.S. National Library of Medicine, public domain; via Wikimedia Commons; Right panel, image reproduced from (Nobile 1855), Author's private collection (scan by the author)

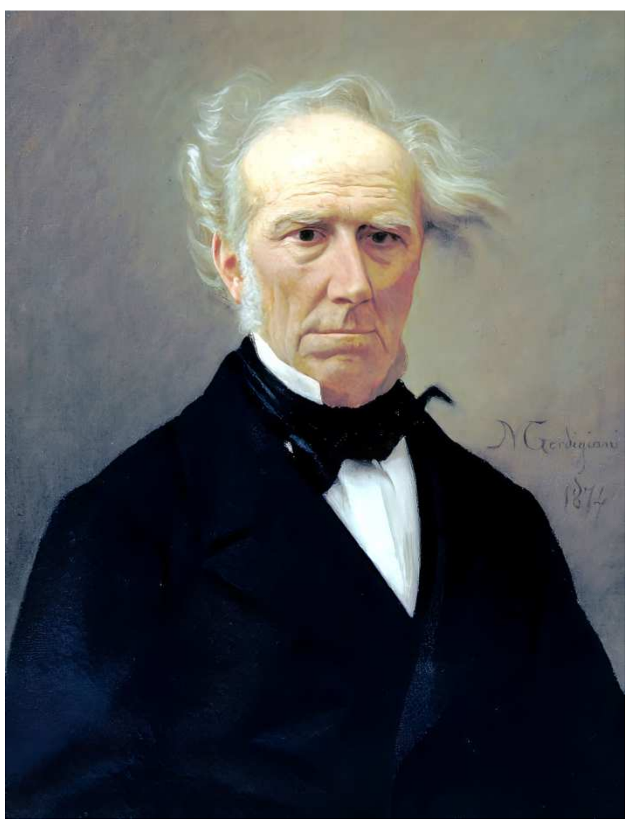


Fig. 3 Giovanni Battista Amici, portrait by Michele Gordigiani, 1874. Source: Courtesy of Museo Galileo (Florence)

Writing in 1868, he offered an intervention that is treated here not as a causal turning point but as a clarifying and consolidating statement, coherently synthesising post-Unification diagnoses of the state of physical research and training. Trained in Vienna and Paris under Andreas von Ettingshausen (1796–1878) and Henri-Victor Regnault (1810–1878), and later Professor of Experimental Physics at Palermo, Blaserna visited the 1867 Paris *Exposition Universelle*. Drawing on that first-hand observation, he formulated in 1868 a critique of the state of "*physical studies in Italy*" (Blaserna 1868), focusing in particular on the link between educational organisation and instrumental culture. His analysis highlighted a structural paradox: while Italy continued to produce scientists of distinction, they operated as "*generals and captains without soldiers*" (Blaserna 1868, 70), lacking the network of pupils and collaborators that characterised German laboratories. The phenomenon was not new: Blaserna noted how the great masters of Italian physics—from Volta to Nobili, from Melloni to Amici—had not left structured scientific schools. Upon Melloni's death, his pioneering research on "*radiant heat*" was no longer pursued in Italy; similarly, Amici's microscopic tradition was interrupted with his passing. Italian microscope-making virtually ceased, with the accumulated tradition of workshop know-how and instrument-making practice not transmitted to successors (Blaserna 1868, 71). In his analysis, successors were forced to "*start again from scratch, as if nothing had existed*" (Blaserna 1868, 71).

Blaserna traced the central problem to a distorted understanding—shared by instructors and students—of what teaching and learning should entail: excessive importance was attached to lectures and to their rhetorical form, as if the quality of teaching lay in professors "*dictating*" and students "*listening*" to a good lecture. The decisive issue, he insisted, was instead the place and the mode of training: "*true teaching begins where the lecture ends*" and must take place in the laboratory, where students acquire "*the handling of instruments and a rigorous understanding of methods*"; in other words, "*we teach in the amphitheatre, they in the laboratory*" (Blaserna 1868, 71). In this connection, not even the French paradigm, with its special schools of a quasi-industrial character, represented a valid alternative. He argued that its strong organisation could produce engineers and teachers, yet still failed to cultivate a sustained research culture, leaving "*true scientific laboratories*" deserted (Blaserna 1868, 72). This critique struck at the heart of the Italian system for the physical sciences, where training and research were tightly intertwined, and where, in his words, "*one speaks well but works little, and works badly"* (Blaserna 1868, 71).

This structural diagnosis was confirmed and further elaborated in Carlo Matteucci's review, published in *Nuova Antologia* in 1868. Discussing Blaserna's short essay on the state of the physical sciences in Italy, Matteucci—an Italian physicist and physiologist and a Senator of the Kingdom of Italy—offered a complementary yet divergent explanation, shifting the locus of causality from university method alone to the broader pre-university and social setting (Matteucci 1868). In his view, the "*first root*" of the problem lay in secondary schooling: German students, shaped by rigorous *Gymnasium* studies and the *Maturität* examination, entered the university at twenty or twenty-two with solid scientific and literary preparation, whereas in Italy they arrived at seventeen or eighteen, intent only on "*snatching an academic degree*" (Matteucci 1868, 423). Hence, he argued, universities ought to function as "*academies for scientific progress*" rather than as mere "*degree factories*" (Matteucci 1868, 423). At the same time, Matteucci acknowledged significant improvements in material infrastructure—above all in physics cabinets—pointing to Pisa and Palermo as emblematic cases (Matteucci 1868, 423).[7] Yet such material endowment had not produced the practical schools of physics envisioned by reformers. He recalled that Article 31 of the university regulations prescribed practical exercises in the experimental and observational schools (as the regulation itself termed them), but that this provision progressed slowly and was often thwarted; nonetheless, he noted that in a few universities laboratories and cabinets were already attended by "*twenty-five or thirty*" students, who spent many hours there studying and experimenting (Matteucci 1868, 424).[8] Crucially, Matteucci attributed the principal responsibility not to professors but to the country itself—"*errors and prejudices spread among the public*"—since university study was too often pursued not for knowledge but for the academic degree (Matteucci 1868, 423).

Read together, Blaserna and Matteucci thus highlight two complementary bottlenecks in the failed renewal of the physical sciences: methodological–instrumental deficits in laboratory culture (Blaserna) and a broader pre-university and social incentive structure that discouraged sustained scientific training (Matteucci).

1.3 The provincial scientific ecosystem: a resilient network

Despite the structural weaknesses highlighted by Blaserna and Matteucci, the second half of the nineteenth century saw the consolidation in Italy of a distinctive, polycentric scientific ecosystem centred on provincial universities and a broader network of local educational institutions. As Reeves's institutional survey shows, after the Restoration

[7] Matteucci considered the Physics Cabinet in Pisa "*perhaps the richest and best supplied—even with instruments of measurement and precision—in Europe*", while the one in Palermo, under Blaserna's direction, "*cost the State more than thirty or forty thousand lire*" (Matteucci 1868, 423).

[8] The General University Regulations were issued by Royal Decree on 14 September 1862 (no. 842), under the Minister of Public Instruction Carlo Matteucci. Article 31 required that "*schools of experiment and observation*" be equipped for students' practical exercises and that professors and assistants support them (Regno d'Italia 1862, Art. 31, 2234).

(1815) Italy retained a remarkably dense university landscape: almost every state contained at least one university, and most institutions suppressed or downgraded under French rule were revived by the restored governments (Reeves 1980, 47; Table 1.1, 48–49). In the decades after Unification, municipalism and regionalism repeatedly thwarted attempts to reduce this dense university network and thereby concentrate financial and intellectual resources in a few national centres. Matteucci and other reformers explicitly pursued this aim as part of a broader programme of standardisation and centralisation (Reeves 1980, 118–119; see also 106–107). While this network did not match the institutional scale of leading European centres, it nonetheless enabled the wide diffusion of scientific culture and partially compensated for the absence of a strongly centralised national system. These institutions maintained close territorial links through colleges, observatories, and secondary schools; given that many students attended their nearest university, these centres should not be interpreted simply as marginal outposts—even if, as Reeves reports (echoing Matteucci's polemical diagnosis), students were often depicted as choosing universities on the basis of reputedly easier examinations or lower fees (Reeves 1980, 117). As noted earlier, nineteenth-century Italy rarely drew a clear boundary between training and research. Ministerial regulations in 1860 and 1862 formally required practical exercises for degree students, while physics cabinets typically combined teaching functions with spaces and equipment for the investigations of assistants and advanced students, as well as for the professor-director's own research (Reeves 1980, 278–281). Beyond universities, licei and technical or professional schools—and, as will be illustrated below, certain institutions managed by religious orders—could likewise sustain such material resources and personnel.[9]

This post-Unification configuration did not emerge ex nihilo, but built on earlier, pre-Unification investments in material infrastructure. In the 1830s–1840s, for instance, the Barnabite *Liceo S. Alessandro* in Milan maintained a physics cabinet alongside a natural history museum, a meteorological observatory, a botanical garden, and a chemistry laboratory; the physics cabinet directed by Giovanni Alessandro Majocchi, "*entirely renewed*" in 1837, was well-equipped and organised into ten sections (Lacaita 1996, 200). Such settings helped sustain a materially grounded scientific culture in which instruction, demonstrations, and long-term locally anchored observational routines—especially in meteorology—could be pursued within the same institutional setting. This longer genealogy also helps clarify why "*the province*" could remain epistemically active even under post-Unification administrative centralisation.

As Vittorio Ancarani observes, the Italian university system was marked by a structural paradox: strong juridical–administrative centralisation coexisted with limited effective oversight, a configuration that could leave centre–periphery boundaries less clear-cut in practice (Ancarani 1989, 11–12). The Barnabite physicist Enrico Dal Pozzo di Mombello, already cited above, offered a concrete provincial example of such pragmatic adaptation: despite the limited experimental means often associated with the so-called *free provincial universities*, he reported that in Perugia he separated theoretical lectures from dedicated experimental sessions in the physics cabinet, thereby providing the practical exercises to which students were formally entitled but which in several universities were often "*expected in vain*" (Dal Pozzo di Mombello 1868, 17). Scientific activity was thus not confined to the major university seats but relied on a socio-educational network distributed across the country.

A paradigmatic example of this dynamic is offered by Urbino, a historic ducal city and university town in the Marche region, where Alessandro Serpieri was active for thirty-seven years. Even as a minor seat,[10] its institutional continuity and local support helped preserve the material and pedagogical routines within which experimental work could be pursued. As a multifaceted figure of provincial science, Serpieri embodied a distinctive synthesis between teaching and both experimental and theoretical research, between territorial rootedness and transnational openness—an orientation that will be examined in detail in the following section through his education and career, the physics cabinet, and his scientific production.

[9] In nineteenth-century physics cabinets—and in astronomical, meteorological, and seismic observatories—a specialised technical figure, often termed a "*macchinista*" (mechanician), supported teaching and, at times, research. Dal Pozzo di Mombello notes that it was typically the *macchinista*'s task to "*prepare and carry out the experiments*", whose number varied "*according to the richness of the local scientific apparatus*" (Dal Pozzo di Mombello 1868, 15). Beyond preparing demonstrations, the "*macchinista*" was responsible for routine instrument maintenance and, at the cabinet director's request, for repairing, adapting, or constructing new apparatus required for teaching or experimental investigations.

[10] Urbino belonged to the pontifical higher-education system reorganised by Leo XII's *Quod divina Sapientia* (1824). Since the University of Urbino was not included among the universities listed in the 1824 reorganisation, it was "*suppressed*"; it was then "*fully reinstated*" by a decree of the Congregation of Studies dated 12 February 1826 and approved by the Pope (Moroni 1857, 223). Moroni further notes that the revived university was supported by an annual provincial subsidy and equipped with a library, scientific cabinets, and a notably rich botanical garden, and that it was later relocated to a palace purchased specifically to provide more suitable accommodation (Moroni 1857, 223). After Unification, in 1862 Urbino was declared a "*free provincial university*" and brought under the general regulations of the Kingdom of Italy for the conferral of academic degrees (Renzetti 1929, 8).

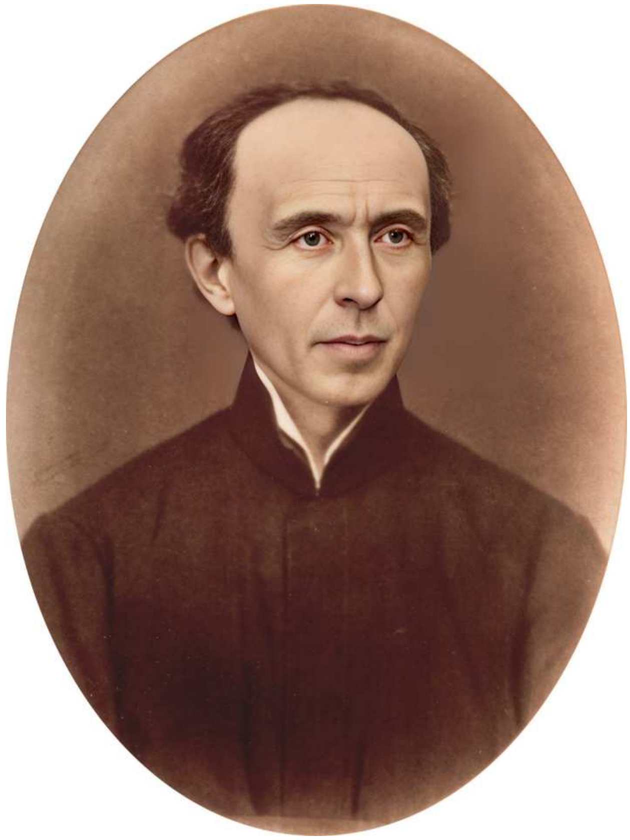


Fig. 4 Father Alessandro Serpieri. Photographic portrait. Source: *Physics Laboratory: Urbino Museum of Science and Technology (PLUMST) Collection*, University of Urbino Carlo Bo

2 Alessandro Serpieri and the physical sciences

2.1 The provincial scientist: education and career

In the second half of the nineteenth century, Alessandro Serpieri (1823–1885) (Fig. 4), a priest, educator, physicist, astronomer, meteorologist, naturalist, and seismologist, emerged as the most prominent and influential man of science not only in Urbino but across the *Marche* region. His work was distinguished by an innovative integration of research and teaching. He arrived in Urbino in 1846, following the death of the Piarist Father Cesare Magherini.

Although he had not yet entered the Order at that time, Serpieri was entrusted with the same teaching positions that Magherini had previously held: physics and philosophy at the *Collegio dei Nobili*, and the Chair of Physics at the University (Giovannozzi 1887, 21). He began teaching at the Collegio in late 1846 and was subsequently appointed to the university chair as well. He held both posts until 1884, devoting himself throughout to the education of young students[11] (Giovannozzi 1887, 21). His appointment to the university chair, formalised by ministerial decree in January 1847, also made him Director of the *Physics Cabinet*, which, under his guidance, underwent a period of extraordinary development.

He took his vows in the Piarist Order in 1848 and, in 1850, established a meteorological observatory in Urbino (Serpieri 1850). Over the following decades, Serpieri enriched both the Cabinet and the Observatory, equipping them with new scientific instruments and cultivating an extensive correspondence with Italian and foreign scientists. In 1884, amid a shifting political climate, Serpieri was compelled to leave Urbino and retire to the abbey of Fiesole, near Florence, where he died the following year.[12]

[11] Among his most illustrious pupils were the physicist Angelo Battelli (1862–1916) and the celebrated Italian poet Giovanni Pascoli (1855–1912).

[12] For a more detailed biographical discussion of Serpieri, see: Mantovani, R. *Alessandro Serpieri and his seismographs: innovations in late nineteenth-century Italian seismology*. *Eur. Phys. J. H* 50, 20 (2025). https://doi.org/10.1140/epjh/s13129-025-00106-w

Fig. 5 Urbino Science Museum: exhibition views (left, right) and physics cabinet displaying heat-related instruments, books, and prints (centre). Source: *PLUMST Collection*, University of Urbino Carlo Bo

His scientific activity is documented by numerous publications in physics, astronomy, seismology, meteorology, and the natural sciences. These were complemented by a substantial literary output and by an extensive correspondence amounting to 1,113 extant incoming letters[13] (Mantovani and Vetrano 1991). His principal biographer, the Piarist Giovanni Giovannozzi, listed 103 publications, of which approximately seventy were of a scientific nature[14] (Giovannozzi 1887, 129–134).

2.2 The instrumental legacy: the physics cabinet collection

A significant collection of historical scientific instruments, largely transmitted by Father Serpieri, is preserved and catalogued today (Mantovani 1996) at the *Physics Laboratory and Museum of Science and Technology* of the University of Urbino Carlo Bo.[15] This collection constitutes a historically and scientifically significant testament to the teaching and research in physics pursued at the University of Urbino from the late eighteenth century onwards. With the exception of a limited number of eighteenth-century instruments and those from the early decades of the nineteenth century, the collection—currently estimated at over 700 items—was expanded year by year by Serpieri through numerous acquisitions from Italian and foreign makers. Among the latter, instruments from the Paris workshop of the brothers Marc and Auguste Secretan—among the most renowned scientific instrument makers of the second half of the nineteenth century—are particularly well represented. The heritage also includes numerous specimens of fine local craftsmanship, produced by the Urbino maker Achille Scateni. The Museum's restored late-nineteenth-century display cabinets (Fig. 5), each topped with a wooden pediment labelled with the instrument category, offer a systematic classification of the apparatus preserved: Mechanics; Liquids and Gases; Acoustics; Heat (labelled "*Caloric*"); Miscellaneous (including Meteorology, Seismology, Telegraphy, and Telephony); Static Electricity; Dynamic Electricity; Astronomy and Geography; and Atomic and Molecular Physics.

As this classification suggests, physics instruments constitute the most substantial and diversified nucleus of the entire collection.

Some were intended for research purposes, while others served a didactic or demonstrative function, illustrating theories through controlled experiments and thereby supporting the validation of physical principles and laws.

[13] The extant correspondence comprises only letters received by Serpieri and forms part of a larger archival holding of manuscripts and printed papers preserved at the Provincial Archive of the Tuscan Piarist Schools in Florence. This corpus was collated by the Piarist Giovanni Giovannozzi (1860–1928) following Serpieri's death. The collection comprises three bound volumes, each chronologically organising the scientific correspondence (totalling 1,113 letters received) addressed to Serpieri during the following periods: 1843–1867 (Regesto Religioso N. 470 [Religious Register no. 470]), 1868–1875 (Regesto Religioso N. 471 [Religious Register no. 471]) and 1876–1885 (Regesto Religioso N. 472 [Religious Register no. 472]). To these are added 33 autograph letters from Serpieri to the Piarist Filippo Cecchi. Furthermore, the University of Urbino has recently acquired 55 letters from the Pontifical Gregorian University written by Serpieri and addressed to the Jesuit scientist Angelo Secchi.

[14] In actuality, Giovannozzi's count is an underestimate. A more accurate quantification of the scientific publications reveals the following disciplinary distribution: seventeen contributions to physics, twenty-five to meteorology, thirty-eight to astronomy and celestial physics, twenty-three to seismology, and three to botany.

[15] Its official name is the *Physics Laboratory: Urbino Museum of Science and Technology* (see https://physlab.uniurb.it/Museum.html). Hereafter cited as PLUMST.

The section devoted to apparatus reflecting Serpieri's specific research interests merits particular attention. Among the fields that were the subject of his systematic investigations, preserved instruments include devices for telegraphy, telephony, electrostatics, and the production and study of electrical discharges in rarefied gases. The telegraphic section comprises two pairs of letter telegraphs, one of which is the Guattari Atmospheric Telegraph, and a complete telegraph-station set consisting of: Grenet cells, a Morse receiver with telegraph key, a line discharger, a Swiss commutator, telegraph compasses, Weiler's pachytrope, and a telegraph relay. The telephonic section preserves three pairs of Bell telephones (see Fig. 29), a pair of Siemens & Halske telephones with whistle call, and a receiver and transmitter of the type developed by Augusto Righi. Finally, worthy of note are several high-vacuum glass tubes, known as Crookes tubes, with which Serpieri investigated so-called *radiant matter*: a flow of negatively charged "*molecules*" (modern cathode rays) which, according to the theories of the English physicist William Crookes (1832–1919), were thought to reveal a hypothetical "*fourth state of matter*" (Mantovani 1998, 75).

2.3 Scientific production: publications and research

Serpieri's contributions to the physical sciences are documented by a publication corpus comprising seven items before 1868 and a further fourteen produced between 1868 and 1884. Of these latter fourteen, ten are examined here; the two papers concerning the first Bell telephones in Italy (1877–78) are reserved for Case Study III, while the remaining two fall outside the scope of the present analysis. I focus on the 1868–1884 group because it represents Serpieri's most sustained phase of publication in the physical sciences and intersects a broader national debate on the "*condition of the physical sciences*" that crystallised in 1868. The year 1868 serves here as a discursive marker rather than as a causal divide: the case studies show methodological continuity in Serpieri's experimental practice well before—and well after—that moment. Across these papers, Serpieri adopts an eclectic approach ranging from theoretical analysis to experimental work, often at the boundary between research and training. Even when framed in didactic or popularising terms, his texts presuppose—and display—experimental skills, instruments, and locally situated laboratory routines. Among his most significant theoretical contributions is *La forza considerata nelle sue principali trasformazioni* (Serpieri 1868a), republished with additions the following year (Fig. 6) owing to its favourable reception (Serpieri 1869). The work, arising from the inaugural address for the Academic Year 1867–1868 of the University of Urbino, presented a historical reading of nineteenth-century attempts to unify physical phenomena under a single concept of force, structured around the four major domains of nineteenth-century physics: heat, light, electricity, and magnetism.

Serpieri argued that nineteenth-century physics had been profoundly renewed by two inventions: the voltaic pile, which inaugurated electrodynamics, and the steam engine, which drove thermodynamics and applied mechanics.

Its inductive method, original exposition, and Newtonian-mechanistic outlook place the book alongside comparable European works—such as W. R. Grove's *On the Correlation of Physical Forces* (Grove 1846) and Angelo Secchi's *L'unità delle forze fisiche* (1864)—while distinguishing it through its explicit pedagogical intent. In the preface, Serpieri dedicated the theories of modern physics to his students with the aim of promoting, through "*synthetic tableaux*", the teaching of the "*new restoration of Natural Philosophy*". In the same year, 1868, Serpieri published *Sulle leggi teoriche dell'efflusso dei gas* (Serpieri 1868b), where, applying emerging thermodynamic principles and adopting simplifying hypotheses on the constitution of gases, he derived through elementary procedures some of the principal laws of gas diffusion in a vacuum.

Electricity was the subject of his didactic work *Il potenziale elettrico nell'insegnamento elementare della elettrostatica* (Serpieri 1882), a methodologically innovative publication, and arguably the first Italian textbook of its kind to treat the notion of electric potential without recourse to infinitesimal calculus, making it virtually unique in the post-Unification context. The volume, subtitled *La moderna teoria dei fenomeni elettrici trattata in modo elementare per i Licei e gli Istituti Tecnici Italiani*, arose from the declared objective of "*composing an elementary Course of Electrostatics worthy of the current Italian school*", a purpose matured after over thirty-five years of didactic experience at the *Collegio* and the University. In the preface, Serpieri diagnoses a structural gap in the Italian educational system: the lack of "*an elementary book that treats electrical phenomena according to the theories of modern science*", a deficiency particularly damaging for *licei* and technical institutes. In his view, this absence widened the methodological distance between university and secondary teaching, since access to the tools of "*advanced calculus*" increasingly shaped the language in which physical "*facts and laws*" could be formulated.

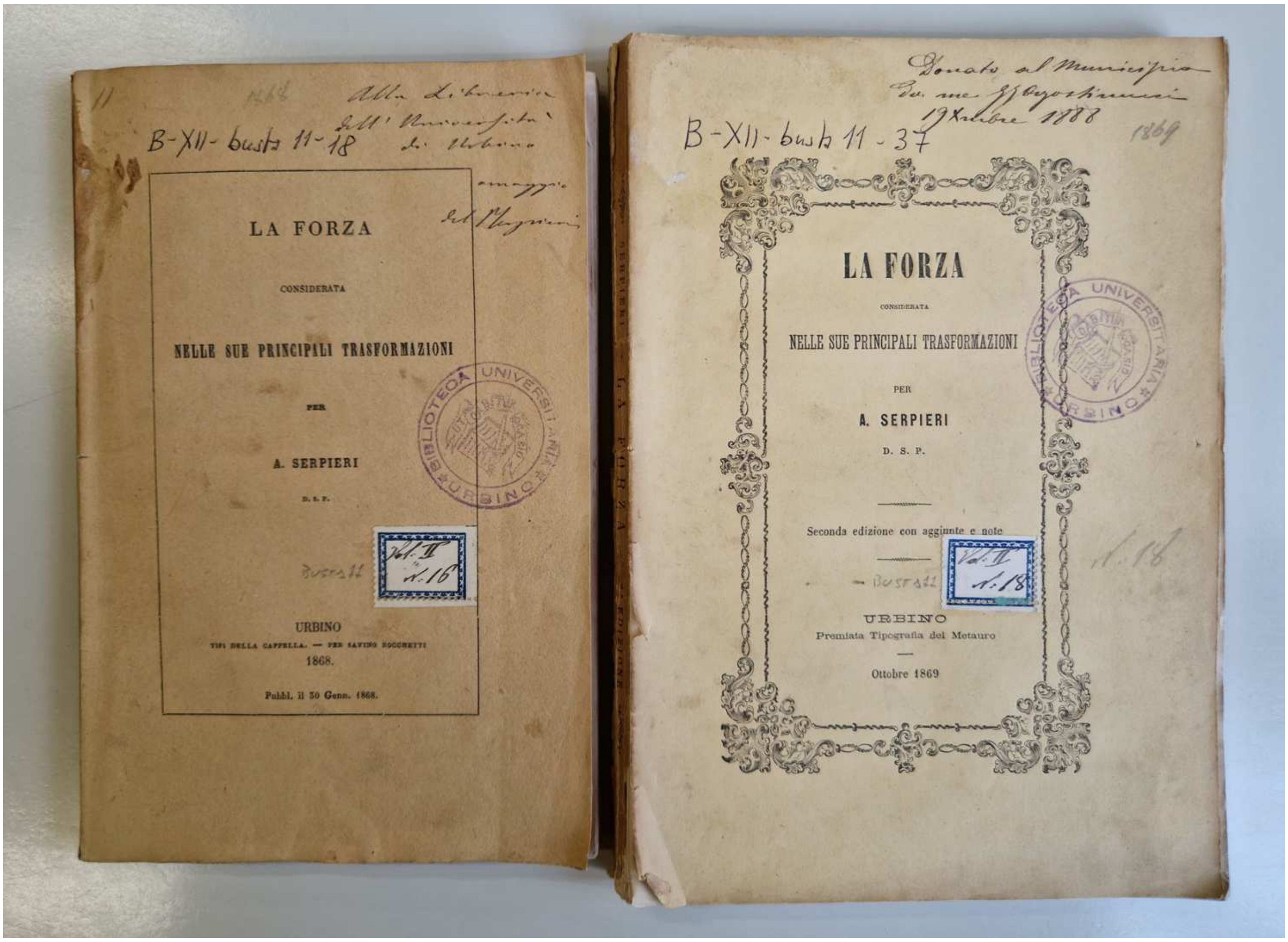


Fig. 6 Title pages of the 1868 and 1869 editions of Alessandro Serpieri's booklet *La Forza Considerata nelle sue Principali Trasformazioni* [*The Force Considered in its Principal Transformations*]. Source: *University Library* of Urbino (photo by the author)

To support his thesis, Serpieri cited numerous foreign courses[16] as well as a recent course by Antonio Ròiti,[17] arguing that none provided the didactic mediation required for secondary-level teaching.

His methodological innovation thus consisted in rendering the concept of electric potential accessible through a geometrical, qualitative, yet rigorous treatment, avoiding the use of infinitesimal calculus and plane trigonometry—an approach that he regarded as unprecedented in Europe. Before publication, the text was extensively tested at the Urbino Liceo, where Serpieri reported excellent learning outcomes that, in his view, confirmed its didactic efficacy.

Upon its release, the work also received favourable attention abroad: it was translated into German by R. von Reichenbach[18] (Serpieri 1884) and, in June 1884, Paul Marcillac, general delegate of the *Société internationale des Électriciens* of Marseille, requested its translation into French. It was precisely in anticipation of this latter edition that Serpieri decided to substantially expand the brief appendix originally present in the 1882 volume—entitled *Piccolo trattato dei sistemi di misure assolute, meccaniche, elettrostatiche, elettromagnetiche*—thereby transforming

[16] In the preface to the work, Serpieri asserts: "*The treatments provided by Messrs. Fleeming Jenkin, Brisse and André (1873), D'Almeida (1874), Abria (1876) and Blavier (1881), do not correspond to the syllabus of a school course...*" (Serpieri 1882, IX).

[17] Ròiti had held the Chair of Physics at the University of Palermo (1878–1879) before moving to the *Istituto di Studi Superiori di Firenze* in February 1880; the first volumes of *Elementi di Fisica* appeared in 1880, during this transitional period. It was the first Italian physics textbook intended for use in Italian Licei. The third volume was published in 1881, and the final volume, which treated the subject of electricity, appeared in 1883.

[18] Reichenbach, who resided in Graz, published the work in Vienna in 1884. Serpieri's correspondence preserves four letters from Reichenbach dating from the two-year period of 1884–1885.

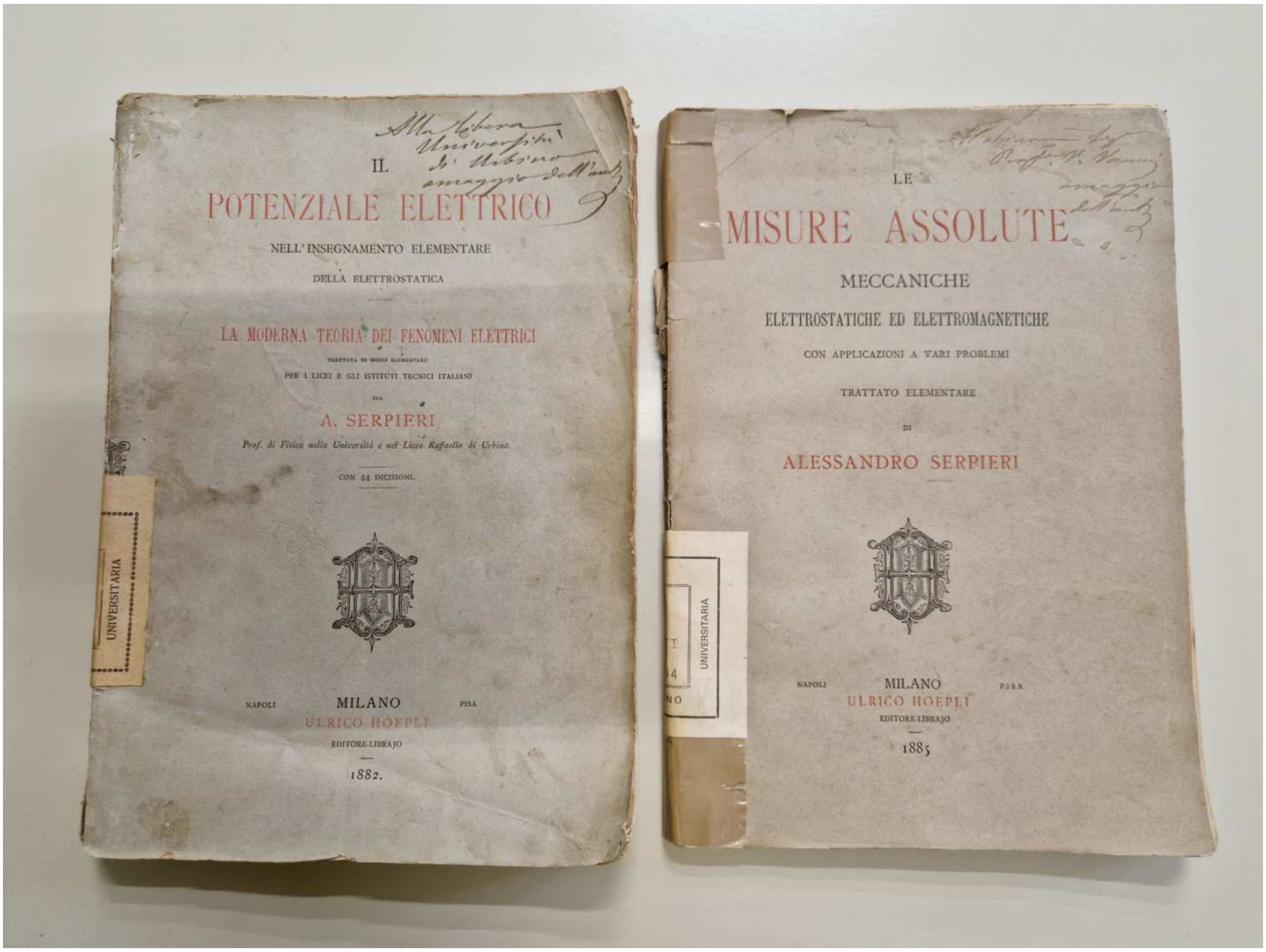


Fig. 7 Title pages of Alessandro Serpieri's Il Potenziale Elettrico (1882) [*The Electric Potential*] and Le Misure Assolute (1885) [*The Absolute Measurements*]. Source: University Library of Urbino (photo by the author)

it into an autonomous work, consistent with the new normative framework emerging following the Paris conference of 1881. This decision initiated the drafting of his final work, *Le misure assolute meccaniche elettrostatiche ed elettromagnetiche* (Serpieri 1885a), published shortly before his death (Fig. 7). This book probably marked the opening of a broader project aimed at producing a treatise on electrodynamics. The volume systematised the new units of measurement, supplementing the theoretical treatment with numerous applied exercises. The subject was still relatively new and internationally debated.[19] The work was translated into German by R. von Reichenbach in 1885 (Serpieri 1885b) and into French by Paul Marcillac[20] in 1886 (Serpieri 1886). Serpieri did not live to see these foreign editions, owing to his sudden death.

On the experimental front, despite the limited means available to the *Physics Cabinet*, Serpieri conducted significant research. Of particular note were his 1880 experiments with Crookes' apparatuses for the study of "*radiant matter*". William Crookes had hypothesised the existence of a fourth state of matter, called "*ultra-gaseous*" or "*radiant*", consisting of a flow of negatively charged molecules (modern cathode rays). These particles, projected from the cathode, produced fluorescent, thermal, and mechanical effects. On this line of work, Serpieri published three notes between May and July 1880 (Serpieri 1880a; Serpieri 1880b) that appeared in the *Rivista Scientifico-Industriale* in the form of letters addressed to its director, Guido Vimercati.[21] The impetus for this

[19] In 1881, the first International Congress of Electricians, held in Paris, sanctioned the adoption of the system of absolute units proposed by the *British Association for the Advancement of Science* in 1873, known as the CGS (centimetre-gram-second) system. The following year, also in Paris, an international conference ratified the adoption of the Ohm as the fundamental unit of electrical resistance.

[20] Serpieri's correspondence preserves twelve letters from Marcillac dating from the two-year period of 1884–1885.

[21] Count and civil engineer Guido Vimercati (Venice 1847–?) founded in 1869 the *Rivista Scientifico-Industriale delle principali scoperte fatte nella Scienza e nell'industria*, a journal that achieved notable success and addressed the principal

Fig. 8 Serpieri's booklets on Crookes' experiments (1880) and contemporary Crookes tubes from the *PLUMST Collection*, University of Urbino. Sources: Urbino University Library; *PLUMST Collection*, University of Urbino Carlo Bo

research, as Serpieri himself states, arose from his reading of an article by the Engineer Emilio Piazzoli (1880, 141–155) that appeared in April 1880 in the *Rivista Scientifico-Industriale,* summarising Crookes's celebrated experiments and raising a crucial doubt: why did gaseous molecules appear to be projected only from the negative pole?

Serpieri replicated Crookes's experiments using several high-vacuum Crookes tubes (Fig. 8), an induction coil, and a set of simple yet consequential experimental variations. His most significant finding was that the characteristic green fluorescence also appeared when only the positive pole was connected to the tube, with the negative pole left isolated, a result in apparent contradiction with Crookes's theory.

He also observed that a similar effect could be induced simply by touching the outer surface of the glass globe with a finger. To perform these experiments, he used two vacuum tubes, still present in the Urbino Museum: one highly rarefied, with a concave cathode electrode, and the other containing a metallic Maltese cross that projected its shadow onto the fluorescent glass wall. Serpieri questioned the nature of these phenomena, hypothesising that the green fluorescence might derive from a "*reverse current*" in the coil. This interpretation was also discussed by the Bologna-based physicist Augusto Righi (1850–1920), whom Serpieri already cites in his third letter as a contemporary interpreter of the phenomena. It should be emphasised that these experiments, according to the judgements of the engineers Rinaldo Ferrini (1831–1908) and Pietro Pogliaghi, were, together with those of Augusto Righi, among the first performed in Italy (Ferrini and Pogliaghi 1882, 268). Indeed, after examining this body of research—from the Italian contributions of Serpieri and Righi to the international work of Crookes, Hittorf, Wiedemann, and Goldstein—Ferrini and Pogliaghi concluded that "*the hypothesis of a new physical state of matter*" was not justified (Ferrini and Pogliaghi 1882, 305–309). Taken together, these lines of work situate

scientific and technological topics of the era in a manner that was both rigorous and accessible. In 1870, he also founded the *Società tecnica di Ingegneria ed Industria*, a purveyor that distributed natural science collections, mineralogy specimens, and didactic apparatus for chemistry, physics, astronomy and meteorology. The instruments, which were well-crafted, were sourced principally from France and England.

the following case studies within a broader experimental practice characterised by local resourcefulness, sustained instrument use, and supra-local scientific exchange. This brief overview deliberately sets aside three research strands to which Serpieri was particularly committed and which, due to their scientific and historical relevance within Italian physics, will be analysed in detail in the following sections: the studies on Foucault's pendulum (1851), the first research on duplex telegraphy (1855), and the investigations on the first Bell telephones in Italy (1877–1878). Against this background, the three case studies that follow can be read as variations on a single provincial pattern of knowledge-making: locally situated experimental work sustained by supra-regional (and, at times, international) channels of information (journals, correspondence, exhibitions) and consistently engaged with the most advanced European debates. At the same time, the cases span the political rupture of Unification—two episodes in the Papal States (1851; 1854–55) and one in the Kingdom of Italy (1877–78)—allowing a direct comparison of continuities and changes in Serpieri's practice. In the later telephone episode, this pattern also culminates in a more explicit and original analytical contribution, in Serpieri's reflections on the listener and the communicative circuit—that is, the human element in the instrument's effective functioning.

3 Case study I: the first Italian replica of Foucault's pendulum (1851)

3.1 From Paris to Urbino: context and realisation

The first of these cases takes us back to the pre-Unification Papal States, where Serpieri's experimental practice began to take shape under the local material and institutional conditions that would continue to inform his work in later decades. In 1851, Serpieri carried out what is, on present evidence, the earliest documented Italian replication of Foucault's pendulum experiment, originally devised by the French physicist and mechanician Jean Bernard Léon Foucault (1819–1868) to demonstrate the rotation of the Earth. Between January and March of that year, Foucault set up three successive iterations of his pendulum.

The first demonstration took place in the cellar of his home in rue d'Assas, Paris, employing a pendulum only two metres long with a brass bob of 5 kg. After an initial unsuccessful attempt on 3 January, when the wire broke during the experiment, a second attempt, conducted in the early hours of 8 January to minimise external interference, proved successful. Foucault noted: "*le pendule a tourné dans le sens du mouvement diurne de la sphère céleste*" (Gariel 1878, 378, note 2).

On 3 February, Foucault installed a second apparatus in the meridian hall of the Paris Observatory, employing an 11-m pendulum, at the invitation of the director Dominique François Jean Arago (1786–1853). The event was announced with the famous invitation: "*Vous êtes invités à venir voir tourner la Terre, dans la salle méridienne de l'Observatoire de Paris*". The Panthéon phase of the experiment reached its most widely publicised form on 31 March 1851, when Foucault suspended a 67-m pendulum beneath the dome of the Panthéon in Paris, with the support of the President of the Second French Republic, Louis-Napoléon Bonaparte.[22]

The success of Foucault's demonstrations quickly inspired similar experiments across Europe, including George Henry Bachhoffner's public demonstration at the Royal Polytechnic Institution in London in May 1851 (Fig. 9).

In Italy, news of the French experiments spread rapidly through the periodical press of the time. A brief account of the experiment conducted at the Paris Observatory appeared on 8 March 1851 in *Il Diavoletto*, a Trieste-based periodical (Anonymous 1851a, 264).

The experiment was also documented in *La Civiltà Cattolica* (Anonymous 1851b, 140), the journal founded by the Jesuits in 1850. It was against this backdrop of swift informational circulation that Alessandro Serpieri, at the *Collegio dei Nobili* in Urbino, replicated the French experiment.

Although the sources do not allow us to identify with certainty which specific report reached Serpieri concerning the Parisian experiment of 3 February, it is certain that he replicated the pendulum experiment on 30 March at the *Collegio dei Nobili* in Urbino.

This information is documented in the "*Registro delle Osservazioni Meteorologiche*" that Serpieri maintained daily. The document, preserved at the current meteorological observatory of the University of Urbino Carlo Bo (Fig. 10), reports the following annotation dated 30 March 1851: "*The experiment on the deviation of the pendulum's oscillation plane, conducted on a grand scale in the college hall, and the arrival of the Telegraph apparatus at the University, have somewhat disrupted the observations in recent days*". Serpieri's experiment was thus conducted on 30 March 1851, on the eve of the Panthéon demonstration most commonly dated to 31 March, and is, as far as current evidence indicates, the earliest documented Italian replication[23] of Foucault's Parisian experiment.

[22] The chronology of the Panthéon presentation is not entirely uniform in the literature. While several retrospective and institutional accounts retain 31 March 1851 as the date of the most widely publicised Panthéon presentation, some modern accounts point to public announcement or access in the immediately preceding days; see, for instance, Aczel (2005, 180).

[23] Following Serpieri's demonstration, the experiment was replicated in Italy during April by the astronomer Giovanni Plana (1781–1864) in Turin and by the physicist Vincenzo Antinori in Florence. This was followed, from 3 to 10 May 1851,

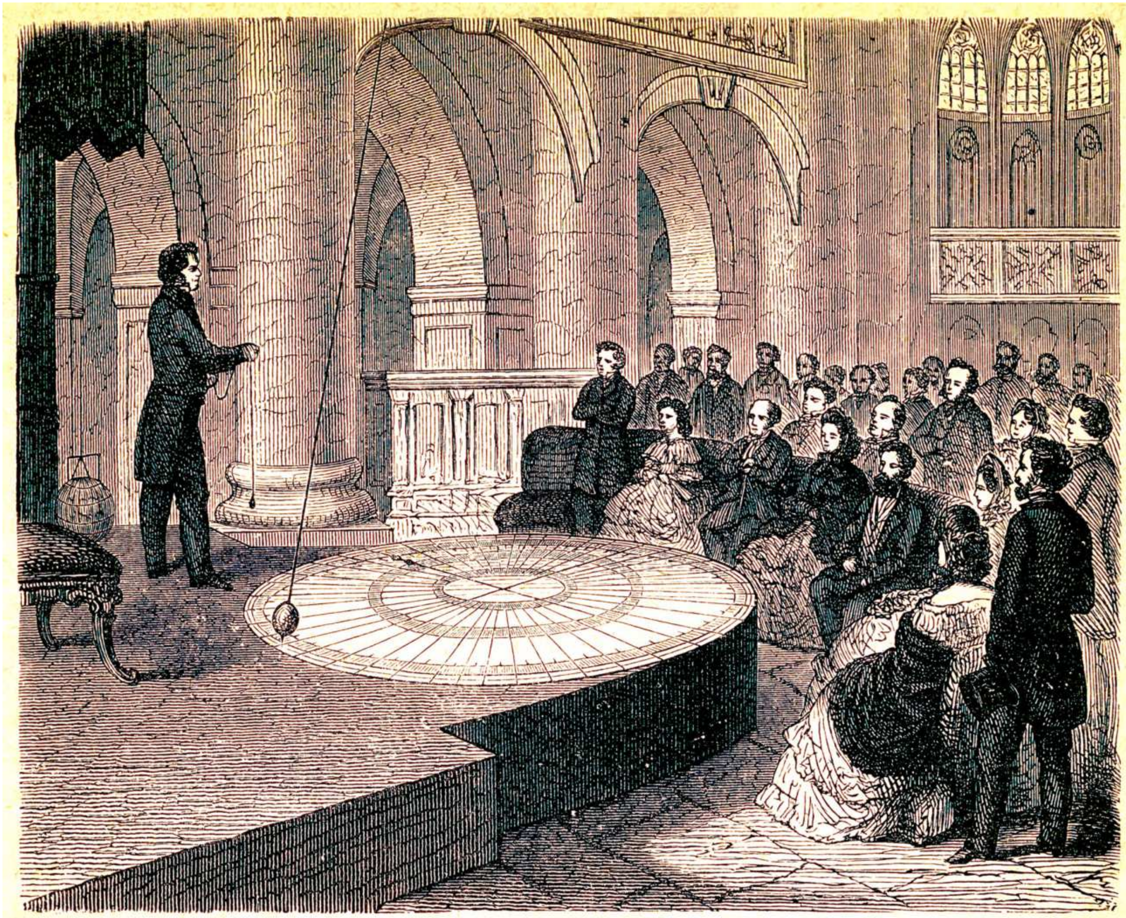


Fig. 9 Foucault's pendulum demonstration by George Henry Bachhoffner at the *Royal Polytechnic Institution*, London, May 1851. Source: Print, inv. no. 1554, *Paris Observatory Library*

The experimental trial took place in the grand "*Raffaello*" hall of the present-day *Collegio degli Scolopi*, also known as *Collegio Raffaello*, situated in the historic centre of Urbino. A "*Note*" authored by Serpieri and published in the *Annali di Scienze Matematiche e Fisiche* of Rome documents that the apparatus consisted of a seven-metre-long iron wire, described as "*ricotto*", from which "*a large marble sphere*" was suspended (Serpieri 1851, 237). The experiment became the object of close analytical scrutiny by the Urbino scientist, who observed an unexpected phenomenon: although the pendulum's plane of oscillation deviated progressively as Foucault's theory predicted, the sphere maintained a fixed orientation relative to the room, without rotating about its own axis (Serpieri 1851, 237).

To understand this behaviour and develop the theory of pendulum motion, Serpieri resolved to consult one of the most eminent Italian mathematicians of the period, Ottaviano Fabrizio Mossotti (1791–1863) (Fig. 11), Professor of Mathematical Physics at the University of Pisa (appointed to the chair in 1841). The correspondence reveals that Serpieri sent at least two letters to Mossotti, containing specific queries regarding the experiment: the first concerned the orientation of the pendulum bob, while the second sought an analytical solution of the pendulum's equations of motion.

3.2 The phenomenon of constant orientation: theoretical analyses and experimental refutations

Mossotti promptly addressed the question of the bob's anomalous orientation. In his letter of 14 April 1851, he offered an interpretation grounded in the torsional behaviour of the suspension wire:

> "The peculiarity you observed—that whilst the pendulum preserves its plane of oscillation and successively more westerly lines traced on the floor pass beneath it, showing the Earth's rotation, the ball instead constantly

by the replication conducted by Angelo Secchi in Rome at the church of Sant'Ignazio, which was annexed to the Collegio Romano.

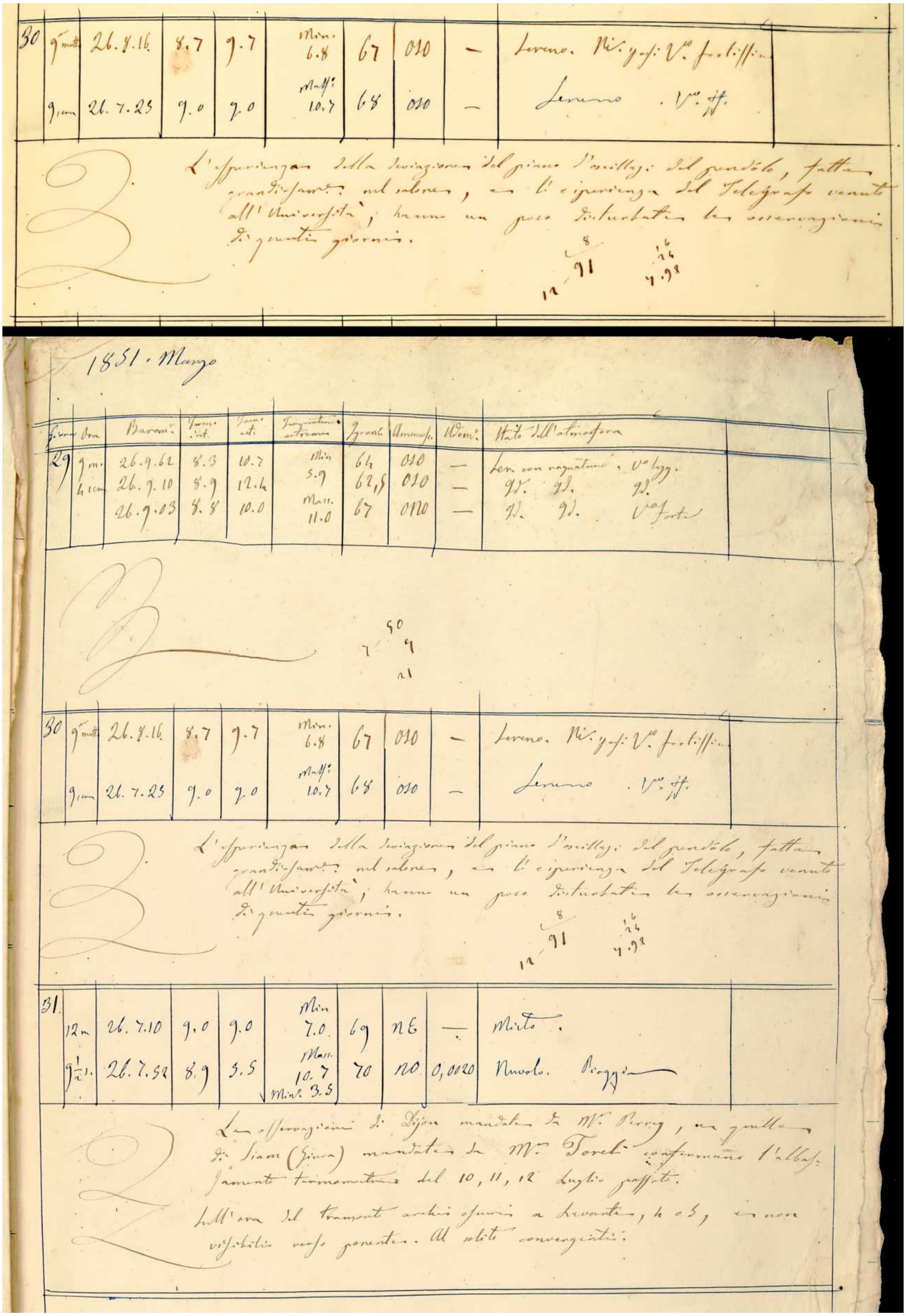


Fig. 10 Page from Alessandro Serpieri's *Registro delle Osservazioni Meteorologiche*, 29–31 March 1851 (below), and detail of the 30 March annotation concerning Foucault's pendulum experiment (above). Source: Courtesy of the Archive of the "*A. Serpieri*" *Meteorological Observatory*, University of Urbino Carlo Bo

Fig. 11 Ottaviano Fabrizio Mossotti. Lithograph. Source: *Wellcome Collection*, London (ref. 7064i), CC BY 4.0

orients itself toward the same point in the room—seems to me to be due to the torsion of the metallic wire. As the Earth rotates relative to the pendulum's plane of oscillation, it induces a rotational movement in the suspension device. The section of the wire at the point of attachment to the device (in your letter, you indicate that the pendulum wire emerged from a hole made in a stationary piece of iron, but you do not specify how it was supported) is constrained to rotate slowly with it. The small torsion that results is unable to produce perceptible changes in the pendulum's plane of oscillation, but is sufficient to overcome the resistance arising from the ball's moment of inertia multiplied by the very small angular velocity that the wire must impart to it in order to twist. The progressive untwisting of the wire is therefore what keeps the ball always oriented toward the same point in the room" (Mossotti 1851a).

Mossotti thus located the phenomenon in the torsional behaviour of the suspension wire rather than in any intrinsic change in the pendulum's plane of oscillation.

Serpieri, apparently satisfied with this reply, published a brief note (Serpieri 1851) reporting the observation and essentially reproducing Mossotti's explanation. In support of the torsional hypothesis, Serpieri suggested that wires with high flexibility and low torsional stiffness might help confirm "*Monsieur Baudrimont's suspicion that even a pendulum at rest manifests after some time a slight rotational motion*" (Serpieri 1851, 237).

This remark, however, points to a conceptual slippage: Serpieri blurred the distinction between the dynamic effect of terrestrial rotation—mediated by the suspension system, as in Mossotti's account—and Baudrimont's hypothesis of torsion at rest, a purely static mechanism. This interpretation was based on a note and a proposed apparatus, published some months earlier by the French chemist Alexandre-Édouard Baudrimont (1806–1880).

3.3 Baudrimont and the "impossible clock"

In a note published in the *Comptes rendus* (Baudrimont 1851, 307–308), Baudrimont advanced two connected yet distinct proposals. First, he argued—explicitly as an *analyse logique*—that Foucault's demonstration of the Earth's diurnal rotation could, in principle, be reduced to a simple plumb line: if it could be suspended at one of the Earth's poles from a point independent of the globe, the Earth would rotate beneath it, and an index would suffice to make that rotation visible. Recast for an observing site at latitude φ with the suspension point fixed to the globe (as in the conditions indicated by Foucault and developed by Binet), the torsion angle of the wire would be given by the Earth's angular rotation over the same interval multiplied by sinφ and would therefore vanish at the equator. Based on this reduction—in which, as he put it, gravity was alien to the phenomenon—he then moved to a second, distinct design: a material mass supported on an axis about which it could rotate freely. If that axis were kept parallel to the Earth's axis at any observing site, inertia would cause one of the mass's meridian planes to remain parallel to a fixed plane in space, so that the mass would appear to rotate although, in reality, it would be the Earth that turned. Baudrimont suggested that such an instrument could serve not only as a demonstration device, but also—by adding a quadrature analogous to that of ordinary clocks, or a worm-and-counter arrangement with several dials—as a "*true clock*" for the exact division of time. Baudrimont's suggestion was soon echoed in England by the mathematician Baden Powell (1796–1860), who remarked that, if torsion in the thread could be eliminated, a simple suspended ball furnished with an equatorial index would appear to rotate—yet "*the torsion destroys the effect*" (Powell 1851, 564).

The first decisive objections to this static-plumb-line proposal were formulated in May 1851 by the Jesuit scientist Angelo Secchi (1818–1878), who deemed Baudrimont's "*clock*" impossible to realise because any suspension point fixed relative to the Earth necessarily transmits the Earth's rotation to the suspended body. Addressing the phenomena observed by Serpieri, Secchi clarified that a suspended body "*participates in the rotational motion of its suspension point*" and therefore, relative to that point "*must remain constantly oriented*" (Secchi 1851, 241). On this basis, he rejected the torsional explanation, arguing that the oscillating sphere was not subject to external torques capable of inducing a spontaneous rotation about the suspension wire; the observed constancy of orientation followed instead from the kinematic constraint imposed by the suspension system (Secchi 1851, 240–241).

Despite Secchi's refutation, the fascination with suspended spheres continued to pique the interest of the scientific community. In 1888, Alexis Boillot (1813–post 1888) independently revived Baudrimont's idea, proposing an apparatus consisting of a sphere suspended in a glass tube by means of a torsion-free wire. According to his theory, the device would complete a full rotation in approximately 31 h and 52 min at Paris, in accordance with the rotation of a Foucault pendulum's oscillation plane.[24] To suppress torsion completely, Boillot suggested employing a vertical cylindrical magnetic bar that would attract a nail with a rounded head without touching it, thereby minimising mechanical coupling (Boillot 1888, 1664–1665).

The theory of Baudrimont and Boillot underwent further analysis and refutation by two eminent Jesuit astronomers: Johann Georg Hagen (1847–1930) and William Francis Rigge (1857–1927). Hagen, using Poinsot's formula, demonstrated the theory's invalidity through rigorous mechanical reasoning. He argued that, in the absence of external forces, the angular velocity of the suspended sphere must remain invariant, as it depended exclusively on the initial angular velocity of the suspension point, which shared the Earth's rotational motion. Consequently, the sphere could not exhibit an apparent rotation independent of the system containing it. Hagen further provided an a priori argument: if the theory of Baudrimont and Boillot were correct, it would lead to a device capable of generating perpetual motion, violating the fundamental laws of physics (Hagen 1911, 101–104). Rigge's 1913 analysis confirmed this line of reasoning, stressing that the sphere's inertia—like that of the surrounding bodies—initially shared the Earth's motion and preserved it, thereby nullifying any relative difference and making the sphere appear stationary (Rigge 1913, 273).

3.4 Mossotti's mathematical formalism

The second question raised by Serpieri concerned the equations of pendulum motion. This inquiry proved consequential in Italy: it helped to trigger a wider debate on the new French experiment. Mossotti responded promptly to Serpieri, and the two scholars agreed that their correspondence should be made public. An extract from Mossotti's letter, accompanied by a "*nota*" drafted by Serpieri, was published in Rome in the *Annali di Scienze Matematiche e Fisiche*.[25] The letter contained the first rigorous analytical solution of Foucault's pendulum ever published in Italy.[26] On 18 April 1851, Mossotti wrote from Pisa:

[24] By way of example, the *Panthéon* in Paris is situated at a latitude of $\varphi = 48.846222°$ N; applying Foucault's formula $T = 24/\sin\varphi$ yields a result whereby the plane of oscillation completes a full rotation in approximately 31 h and 52 min.

[25] The *Annali di Scienze Matematiche e Fisiche*—commonly referred to in Italian academic circles as the *Annali del Tortolini*—was among the most prestigious scientific periodicals of the period. The journal was founded in Rome by Barnaba Tortolini (1808–1874), a priest and distinguished Roman mathematician; the first eight volumes were published between 1850 and 1857.

[26] The dissemination of this publication stimulated a lively scientific discourse among a number of Italian men of science. Indeed, contributions and observations by researchers such as Angelo Secchi, Domenico Chelini (1802–1878), Angelo Vescovali (1826–1895), and Lodovico Ciccolini (1767–1854) appeared in the Annali (Secchi 1851, 238–242; Chelini 1851a, 243–246; Chelini 1851b, 311–317; Vescovali 1851, 301–305; Ciccolini 1851, 409–413, 543–546).

> "To respond also to the second part of your invitation, I have taken advantage of some free moments, which the publication of my Mechanics[27] allows me, to work on the analytical solution of the problem of pendulum oscillations, taking into account terrestrial rotation" (Mossotti 1851b, 232).

In addressing the problem, Mossotti examined the equations formulated by Lagrange, Coriolis and Poisson, all potentially applicable to describing the motion of Foucault's pendulum. Among these, he opted for Poisson's equations, as they were "*already directly prepared for this purpose*" (Mossotti 1851b, 233). His analysis employed a system of differential equations describing the pendulum motion in a reference frame rotating with the Earth. Mossotti adopted a Cartesian coordinate system with the x-axis pointing east, the y-axis north, and the z-axis vertically upwards. The equations accounted for the latitude of the observation site, the coefficient of air resistance, the terrestrial angular velocity and the wire's tension.

Through a series of trigonometric transformations, integrations and approximations (neglecting higher-order terms), Mossotti arrived at the demonstration of the relation governing the slow rotation of the pendulum's oscillation plane (sometimes termed "*Foucault's sine law*"). The Pisan mathematician demonstrated that this plane rotates uniformly with respect to the vertical, with an angular velocity equal to the product of the terrestrial angular velocity and the sine of the local latitude: "*The pendulum's oscillation plane must depart from the initial vertical plane with a uniform rotation, directed from east towards south, with an angular velocity resulting from the combination of terrestrial rotation and the sine of the local latitude*" (Mossotti 1851b, 236). Mossotti concluded that the motion of the pendulum's oscillation plane constitutes an apparent effect: terrestrial rotation does not alter the pendulum's true (or absolute) direction in space, but this variation arises relative to the rotating reference frame of a terrestrial observer.

3.5 The Accademia del Cimento: A historical claim (1661)

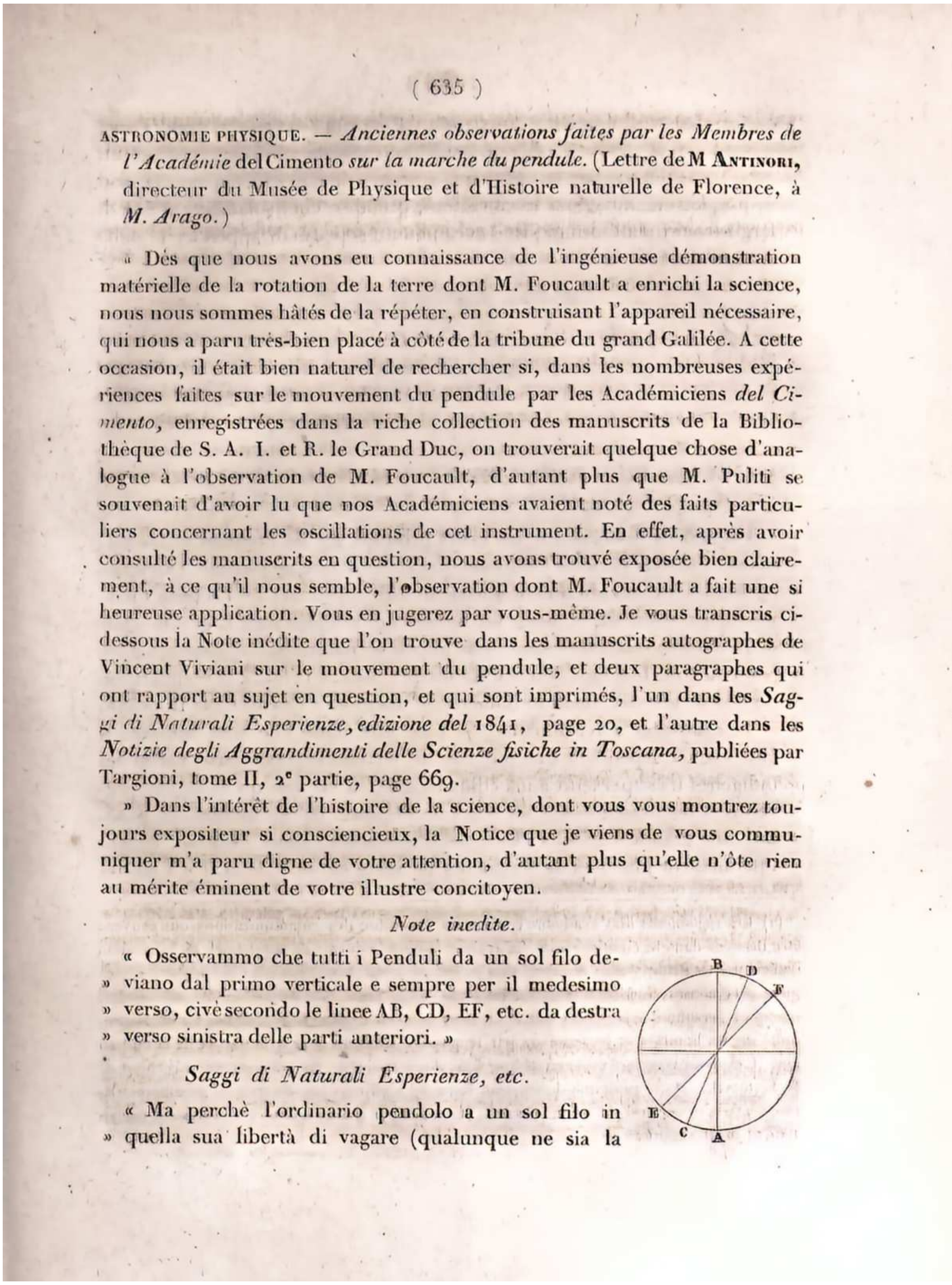
The "*Note*" published by Serpieri, which accompanied Mossotti's letter, went beyond reporting information and observations on the Urbino experiment: it also presented readers with a striking historical claim:

> "It is noteworthy that the distinguished Cavalier V. Antinori has found in an autograph manuscript of Vincenzo Viviani, belonging to the extensive manuscript collection in the library of the Grand Duke of Tuscany, the deviation of the pendulum's plane described verbatim as follows: «We observed that all pendulums consisting of a single wire deviate from the initial vertical plane, and always in the same direction, that is, according to the lines AB, CD, EF, etc. from right to left as viewed from the front.» The same Mr Antinori has also found sufficient evidence of the phenomenon in two published works: Saggi di naturali esperienze, p. 20, ed. 1841.—Notizie degli aggrandimenti delle scienze fisiche in Toscana. T. 2. part 2. p. 669." (Serpieri 1851, 237).

This passage, almost certainly derived from Serpieri's direct reading of the *Comptes rendus* de *l'Académie des Sciences* (Anonymous 1851c), summarised a historical assertion advanced by the Florentine physicist Vincenzo Antinori (1792–1865), then director of the *Imperial and Royal Museum of Physics and Natural History* of Florence. To provide context and clarify the provenance of Antinori's claim, the following concise reconstruction draws on contemporary sources. On 23 April 1851, the Florentine newspaper "*Lo Statuto*" informed its readers of the "*recent discovery of Monsieur Léon Foucault on the movement of the pendulum*" (Anonymous 1851d, 2). An appendix to the article featured a letter from Antinori, in which he, with the assistance of Professor Tito Puliti (1809–1870), announced that he had replicated in Florence the French experiment. Antinori also supplied documents which, he argued, showed that the *Accademia del Cimento* had made the earliest observation of the pendulum-plane rotation from east to west (Antinori 1851a, 2). The perceived significance of this documentary discovery led Antinori to communicate his results by letter to François Arago, *Perpetual Secretary* of the *Académie des Sciences* in Paris. Arago orally reported the contents of the letter at the session of the *Académie des Sciences* on 28 April 1851, and Antinori's letter (Fig. 12) was subsequently published in volume 32 (first semester) of the *Comptes Rendus* de l'*Académie des Sciences* (Antinori 1851b, 635–636). This volume contained both the official announcement of Foucault's discovery and the ensuing scientific debate. In the letter, Antinori described his own experiment, a replication of Foucault's, carried out in the hall of the Royal Museum of Florence, "*à côté de la tribune du grand Galilée*". Antinori further reported that, prompted by Puliti—who recalled some curious annotations on pendular oscillations—he had undertaken research on pendulum experiments conducted by the *Accademia del Cimento*.

The relevant documents were preserved in the Galilean manuscript collection in the *Biblioteca Palatina* of Florence, now part of the *Biblioteca Nazionale Centrale* of Florence. The research led to the discovery of an autograph manuscript by the Academy's secretary, Vincenzo Viviani (1622–1703), which contained an image and a handwritten note clearly attesting to the rotation of the pendulum's plane "*always in the same direction*". In support of his thesis, Antinori also cited two additional sources: the third Florentine edition of the *Saggi di Naturali*

[27] The work in question, mentioned by Mossotti, was *Lezioni di Meccanica Razionale*. Documentary sources indicate that the work was already in press from 1850 but was never completed. However, some fragmentary and incomplete printed copies are documented, generally lacking a title page or date of publication.



(635)

ASTRONOMIE PHYSIQUE. — *Anciennes observations faites par les Membres de l'Académie* del Cimento *sur la marche du pendule.* (Lettre de M **Antinori**, directeur du Musée de Physique et d'Histoire naturelle de Florence, à *M. Arago.*)

« Dès que nous avons eu connaissance de l'ingénieuse démonstration matérielle de la rotation de la terre dont M. Foucault a enrichi la science, nous nous sommes hâtés de la répéter, en construisant l'appareil nécessaire, qui nous a paru très-bien placé à côté de la tribune du grand Galilée. A cette occasion, il était bien naturel de rechercher si, dans les nombreuses expériences faites sur le mouvement du pendule par les Académiciens *del Cimento,* enregistrées dans la riche collection des manuscrits de la Bibliothèque de S. A. I. et R. le Grand Duc, on trouverait quelque chose d'analogue à l'observation de M. Foucault, d'autant plus que M. Puliti se souvenait d'avoir lu que nos Académiciens avaient noté des faits particuliers concernant les oscillations de cet instrument. En effet, après avoir consulté les manuscrits en question, nous avons trouvé exposée bien clairement, à ce qu'il nous semble, l'observation dont M. Foucault a fait une si heureuse application. Vous en jugerez par vous-même. Je vous transcris ci-dessous la Note inédite que l'on trouve dans les manuscrits autographes de Vincent Viviani sur le mouvement du pendule, et deux paragraphes qui ont rapport au sujet en question, et qui sont imprimés, l'un dans les *Saggi di Naturali Esperienze, edizione del* 1841, page 20, et l'autre dans les *Notizie degli Aggrandimenti delle Scienze fisiche in Toscana,* publiées par Targioni, tome II, 2e partie, page 669.

» Dans l'intérêt de l'histoire de la science, dont vous vous montrez toujours expositeur si consciencieux, la Notice que je viens de vous communiquer m'a paru digne de votre attention, d'autant plus qu'elle n'ôte rien au mérite éminent de votre illustre concitoyen.

Note inedite.

« Osservammo che tutti i Penduli da un sol filo de-
» viano dal primo verticale e sempre per il medesimo
» verso, civè secondo le linee AB, CD, EF, etc. da destra
» verso sinistra delle parti anteriori. »

Saggi di Naturali Esperienze, etc.

« Ma perchè l'ordinario pendolo a un sol filo in
» quella sua libertà di vagare (qualunque ne sia la

Fig. 12 Letter from Vincenzo Antinori to François Arago on the observations of the *Accademia del Cimento* regarding the deviation of the pendulum plane (Antinori 1851b, 635). Source: *Biodiversity Heritage Library* (*Natural History Museum Library*, London); not in copyright

Esperienze, in which it was observed that single-wire pendulums, when left to oscillate freely, deviated, tracing an "*oval spiral*" (Accademia del Cimento 1841, 20); and a passage by Giovanni Targioni Tozzetti (1712–1783) in the *Notizie degli aggrandimenti delle scienze fisiche in Toscana*, describing an experiment conducted on 28 November 1661, in which a pendulum, oscillating over marble dust, drew an "*oval*" spiral narrowing towards the centre (Targioni Tozzetti 1780, 669). Nevertheless, these observations were not interpreted by the "*Accademici*" as proof of terrestrial rotation. The Italian physicist Macedonio Melloni (1798–1854) hypothesised that this may have resulted either from their failure to grasp the phenomenon's implications or from a reluctance to disseminate them in a post-Galilean climate still hostile to innovative interpretations (Melloni 1851, 547–548).

With diplomatic caution, Antinori stressed that this archival finding did not diminish Foucault's merit as the first to provide a correct explanation of the phenomenon.

Antinori's revelation resonated strongly within the Italian scientific world, fuelling a sense of patriotic pride. Particularly after Italian Unification, many Italian scientists celebrated this discovery as proof of "*Italian genius*" in experimental physics, incorporating it into their writings. A significant example is provided by the physicist Giovanni Cantoni who, in his *Sommario di un corso di lezioni su la gravità*, adopted Antinori's assertion, affirming that the apparent deviation from east to west of a pendulum's oscillation plane had been "*observed by the Accademia del Cimento, and interpreted and confirmed by Foucault (1851)*". Cantoni corroborated this assertion by directly quoting Viviani: "*We observed that all single-wire pendulums deviate from the vertical plane, and always in the same direction, that is, according to lines from right to left as viewed from the front*" (Cantoni 1867, 56).

4 Case study II: the advent of duplex telegraphy in Italy (1854–1855)

Whereas the pendulum experiment had shown Serpieri's ability to reproduce and adapt a major Parisian demonstration under provincial conditions, the duplex telegraphy controversy placed him in a more openly contested field, in which experimental replication, theoretical interpretation, and questions of priority became more tightly intertwined. Between January and May 1855, in a series of four articles, Serpieri addressed the problem of the simultaneous transmission of oppositely directed electrical currents along a single conductor. This was a long-standing technical challenge, closely tied to the expansion of telegraphic networks and to the emergence of duplex operation. To fully appreciate Serpieri's contribution, one must examine the broader historical and technological landscape in which his work was situated. The advent of duplex telegraphy prompted an intense international debate that engaged numerous European physicists and engineers of the period. At stake was the prospect of significantly increasing line capacity by enabling two-way traffic on a single wire.

By the mid-nineteenth century, telegraphy represented a cutting-edge technology, capable of ensuring rapid and efficient communication over long distances. However, one of the principal technical limitations of the conventional telegraphic system lay in its inability to transmit messages simultaneously in both directions through a single conductor. Consequently, communication between two telegraphic stations was necessarily conducted alternately: sending in one direction precluded the simultaneous reception of another message from the opposite direction. In effect, the line operated as a sequential channel rather than a truly bidirectional one.

This technical and operational constraint imposed significant economic burdens. To manage the growing volume of telegraphic dispatches, network administrations were forced to expand their infrastructure, increasing the number of available lines. This created a pressing demand for engineering solutions that would optimise transmission capacity without multiplying infrastructure. Overcoming this constraint would have permitted, in effect, a near-doubling of transmitted information without a corresponding increase in infrastructural costs.

4.1 The international context and technological innovations

The challenge of "*simultaneous transmission on a single wire*"—as contemporaries technically termed it—lay behind the emergence of duplex telegraphy in Italy as well as elsewhere in Europe. The telegraphic system, developed in the 1830s through the pivotal contributions of innovators such as Charles Wheatstone (1802–1875) in England and Samuel Morse (1791–1872) in the United States, had spread with extraordinary rapidity. Initially adopted in Britain and the United States, this technology swiftly extended to the rest of Europe, giving rise to one of the earliest international communication networks of the modern age.

An early theoretical solution for bidirectional simultaneous transmission is often attributed to the American inventor Moses G. Farmer (1820–1893), who, in 1852, proposed a scheme intended to enable two-way traffic on a single conductor. Although other historical precursors exist, Farmer's work initiated a vigorous scientific debate on the technical feasibility of the system, attracting the attention of the international scientific community. During 1853–1854, the issue fuelled an extensive debate in France, where it was discussed at the Institut de France and, more specifically, within the Académie des Sciences. Numerous scientific journals of the period, including the periodical *Cosmos*, founded by the science populariser François-Napoléon-Marie Moigno (1804–1884), published studies and technical memoirs dedicated to the subject. Prominent scientists participated in the controversy,

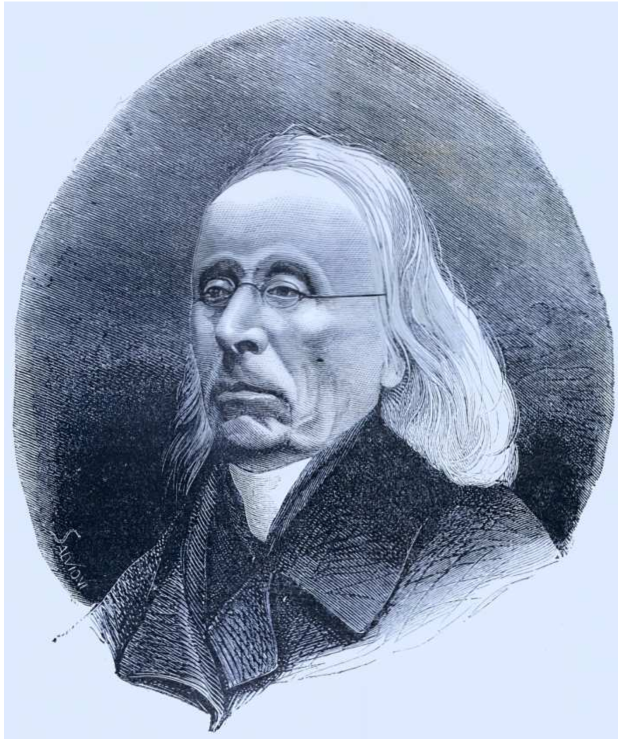


Fig. 13 Francesco Zantedeschi. Source: (Besso 1875, 129), Author's private collection (scan by the author)

including Antoine Masson, Frédéric de La Provostaye, Paul Desains, Jean Bernard Léon Foucault, Auguste De la Rive, Jules Regnault, and Louis Breguet (Zantedeschi 1855a, 4–5). Opinion divided rapidly: Masson, professor of physics at the Lycée Louis-le-Grand (Paris), together with de La Provostaye and Desains, described experiments purporting to demonstrate the passage of two opposing currents in a single conductor. Conversely, Foucault, Regnault, and De la Rive expressed decidedly contrary views (Magrini 1855, 9–11).

Despite the intense theoretical and experimental debate that developed in France, the first practical experiments in simultaneous transmission over short terrestrial distances were conducted by Julius Wilhelm Gintl (1804–1883) in Austria in 1853 and by the engineer Carl Ludwig Frischen (1830–1890) in Germany. Frischen, an inspector of telegraphs in Hanover, developed a differential duplex system on the Hanover-Göttingen line in May 1854. Shortly afterwards, he joined the Berlin firm Siemens & Halske—founded by Werner von Siemens (1816–1892) and Johann Georg Halske (1814–1890)—as chief engineer. This collaboration enabled the system to be refined and subsequently patented.

Comparable experiments were also undertaken in other European settings, including by the physicist Élie Wartmann (1817–1886) in Geneva, the Swedish engineer C. A. Nyström, and the Welsh electrical engineer and inventor William Henry Preece (1834–1913). The pioneering contribution of Gintl, Director-General of Telegraphs of the Austrian Empire, proved crucial in stimulating subsequent debate in Italy, especially in the Habsburg territories of the Italian peninsula. In 1853, Gintl implemented the first practical system of bidirectional simultaneous transmission, testing it on the Vienna–Prague line (approximately 250 km) and refining it the following year. Although Gintl's system had operational limitations, his experiment represented a seminal moment that spurred European research into duplex telegraphy. The rapid dissemination of Austrian and German findings through contemporary scientific journals generated considerable interest within the Italian scientific community, particularly in the territories of Lombardy–Venetia under Habsburg rule, where access to the Empire's technological developments was more immediate. It was in this context that Francesco Zantedeschi emerged as a leading figure in Italy.

4.2 The Italian scientific debate: Zantedeschi and the initial experiments

The scientific debate in Italy was initiated primarily by the intellectual and experimental work of the abbot and physicist Francesco Zantedeschi (1797–1873), then professor at the University of Padua and member of the Imperial-Royal *Istituto Veneto di Scienze, Lettere ed Arti* (Imperial-Royal *Venetian Institute of Sciences, Letters and Arts*). Zantedeschi (Fig. 13) was among the first Italian scholars to recognise the potential of nascent duplex

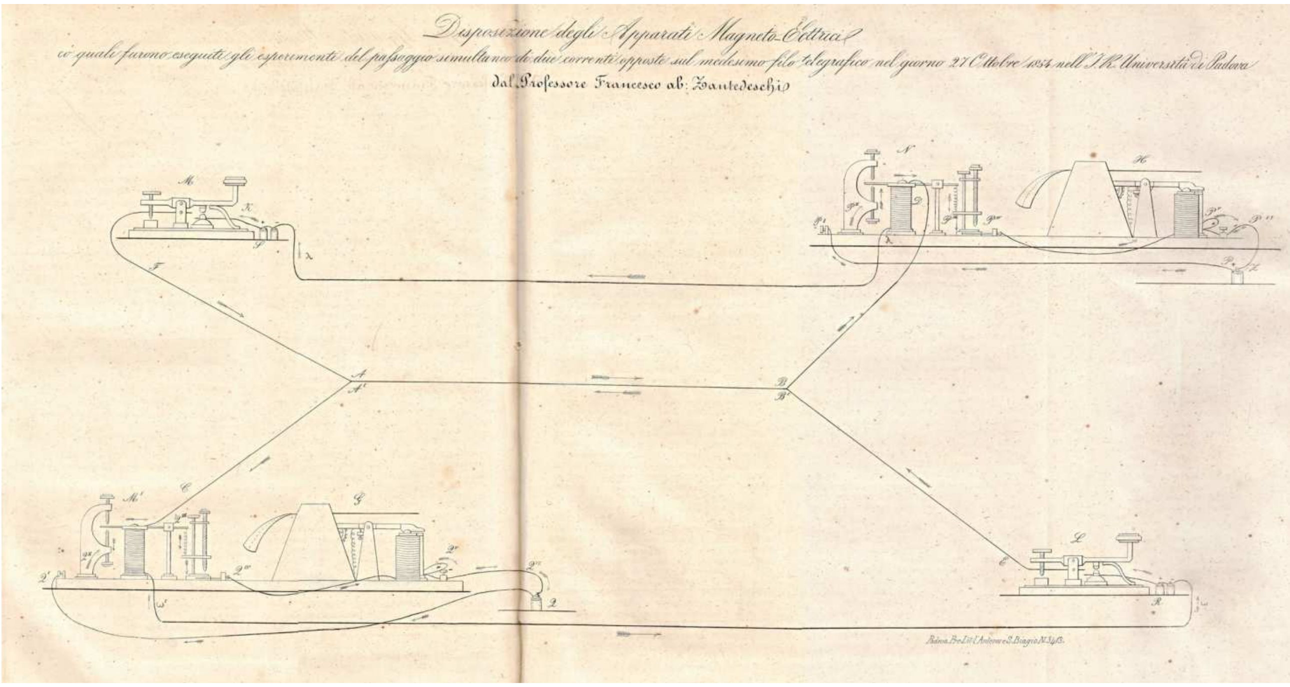


Fig. 14 Diagram of the magneto-electric apparatus used by Francesco Zantedeschi on 27 October 1854 in Padua to test the simultaneous transmission of two opposing currents along a single telegraph wire without earth return. Source: (Zantedeschi 1855e, 238), Author's private collection (photo by the author)

telegraphy. In the preceding years, he had already addressed the matter, though without garnering significant support.[28]

In October 1854, Zantedeschi received an invitation from the physicist Andreas Baumgartner (1793–1865), then *Minister of Commerce* of the Austrian Empire and President of the *Imperial Academy of Sciences* in Vienna, to attend an official demonstration at the *Imperial-Royal Central Telegraph Office* in Vienna.

The experiment, successfully completed, consisted of the simultaneous bidirectional transmission of two dispatches along the Vienna–Linz line, employing the electrochemical telegraphs designed by Gintl in 1853, rather than Morse's electromagnetic telegraph (Zantedeschi 1855c, 140). The effectiveness of the Viennese demonstration encouraged Zantedeschi to undertake new experiments; he chose, however, to employ the more common Morse telegraph, which was more technologically advanced and widely adopted in European telegraphic networks.

Upon his return to Italy, Zantedeschi initiated a series of experiments in Padua, in a fruitful collaboration with Paolo Rocchetti (1814–1897), a precision mechanic and instrument maker at the Astronomical Observatory of the University of Padua. Rocchetti skilfully constructed several Morse telegraph machines and assisted Zantedeschi in the bidirectional transmission trials conducted within his workshop. On 27 October 1854, Zantedeschi performed a first experiment (Fig. 14), using a pair of Morse telegraphs, several Bunsen cells, and two electrical circuits, each 11 m long, sharing a one-metre-long section of wire, through which two electrical currents flowed in opposite directions simultaneously (Zantedeschi 1855e, 238). This methodology was inspired by Gintl's experiments but did not employ the earth as a return conductor.

[28] In 1829, Zantedeschi began investigating the reciprocal interaction of two voltaic currents within the same conductor, corresponding with the Genevan physicist Auguste de la Rive (1801–1873), who held that the coexistence of opposing currents was impossible. In 1839, Zantedeschi published a series of experiments in which he combined what he termed "two heterogeneous currents": one produced by a chemical battery (voltaic current) and the other induced by a magneto-electric machine. Using a Marianini galvanometer, he observed that the needle's deflections appeared to combine in an approximately additive or cancelling manner, depending on whether the two currents were in concordance or opposition. However, these findings were criticised by the physicist Luigi Magrini (1802–1868), who identified three main weaknesses: the imprecision of the instrumentation, insufficient control over the inductor's rotation speed, and the absence of a battery capable of providing a stable electromotive force (Magrini 1855, 6–7).

A few days later, on 4 November, Zantedeschi replicated the experiment, this time using three Morse telegraphs, and announced that he had succeeded in achieving simultaneous transmission. However, the experiment was limited to a closed metallic circuit, without using the earth as a return conductor[29] (Zantedeschi 1855a, 7; 1855c, 142).

As the debate intensified and the prospect of commercial exploitation became apparent, Zantedeschi decided to end his collaboration with Rocchetti and travel to France, where, in January 1855, he embarked on a new series of experiments on the simultaneous transmission of dispatches, utilising French telegraphic lines, which were technologically more advanced and substantially longer than those available in Lombardy–Venetia.[30] In Italy, the controversy sharpened in 1855, focusing primarily on the experiments of Zantedeschi and those of Wilhelm Gintl. In Bologna, the physicist Lorenzo Della Casa (1803–1870) replicated Zantedeschi's experiments in the presence of scholars, such as the mathematician Domenico Chelini, the astronomer Lorenzo Respighi, and Dr Grandi. The experimental apparatus consisted of two Morse telegraph instruments, powered by two Bunsen cells and connected by a common copper conductor six metres long. Although the physical explanation of the phenomenon remained uncertain[31] (Della Casa 1855, 376), Della Casa confirmed that the two electrical currents could travel simultaneously and in opposite directions along the same wire, without detectable mutual interference.

However, these conclusions elicited significant criticism from numerous physicists of the period. Reservations centred on two points: the limited length of the circuits employed, which cast doubt on whether simultaneity could be achieved over realistic operational distances; and the omission of the earth as a return conductor, a practice already established in telegraphy at the time. Moigno, writing in his influential journal *Cosmos*, sharply criticised Zantedeschi's experiments, expressing doubts about whether genuinely simultaneous counter-currents had been achieved. He considered it improbable that the telegraphic keys could be synchronised to within the extremely brief interval of one hundred-millionth of a second[32] imposed by the short length of the wire (Magrini 1855, 14). Another contested aspect was the failure to utilise the earth as a return conductor. In this respect, the experimental configurations adopted by Zantedeschi and Della Casa differed substantially from those of Gintl: the latter incorporated the use of the earth in the circuit, adopting a configuration closer to operational telegraphic systems, whereas the two Italian scientists constructed two distinct circuits interconnected through a shared wire section, thereby creating a three-wire metallic circuit between the two stations. Although theoretically interesting, this solution did not optimise the telegraphic network; on the contrary, it necessitated an increase in lines and entailed a consequent escalation in installation and maintenance costs.

The scientific debate in Italy took on an increasingly acrimonious tone, leading to the formation of two opposing factions. On the one side, scepticism regarding the practical applicability of the new technology[33] was expressed by scholars such as the Jesuit Felice Ciampi (1826–1889), professor of physico-chemistry at the *Collegio Romano*, Giusto Bellavitis (1803–1880), professor of geometry at the University of Padua, and Giuseppe Belli (1791–1860), professor of physics at the University of Pavia. On the other side stood the proponents of simultaneous transmission. These included Dr Cesare Toscani, physics professor at the liceo in Siena, Alessandro Serpieri, Luigi Magrini, and Lorenzo Della Casa. A significant contribution to the debate came from the physicist Luigi Magrini, physics lecturer at the *Regio Liceo di Porta Nuova* in Milan, who presented an important historical memoir on the subject at a meeting of the *Imperial-Royal Lombard Institute of Sciences, Letters and Arts* in Milan on 8 February 1855. Magrini asserted chronological priority for some of his experiments dating back to 1844, while acknowledging the

[29] In 1837, the German physicist Carl August Steinheil (1801–1870) demonstrated that the ground could function as a return conductor, eliminating the need for a second wire. This discovery, fundamental for practical nineteenth-century telegraphy, simplified communication infrastructure, reducing costs and construction times, and accelerated the development of electric communications.

[30] In March 1855, Zantedeschi announced a new electromagnetic telegraph project (Zantedeschi 1855d) designed to function on a single, earthed line. This system would have allowed two stations to communicate bidirectionally using alternating pulses. To develop and commercialise his apparatus, Zantedeschi entered into a collaboration with the French engineers and manufacturers Fabre & Kunemann, successors to the famous *Maison Pixii*. The agreement stipulated joint ownership of the patent and provided that costs would be covered from sales proceeds in various countries. The decision to partner with *Fabre & Kunemann* proved judicious: the company possessed advanced technical expertise and operated in a more dynamic and productive market than that of Italy (Carletti 2014, 204).

[31] Della Casa, while recognising the complexity of the question, analysed two hypotheses then current in the scientific community. The first, based on the theory of an electrical fluid, suggested that opposing currents flowed past one another, much like air currents. The second, by contrast, was founded on wave theory, which likened currents to sound, light, or thermal waves, capable of intersecting without alteration. Zantedeschi adhered to this latter hypothesis, invoking the '*mechanical principle of the superposition of small movements*' formulated by Poisson (Zantedeschi 1855b, 124–125).

[32] This time had been calculated by Moigno, assuming that the propagation speed of electrical current was equal to one-third of its currently accepted value.

[33] According to Matteucci, the same position was held in France by Jean Bernard Léon Foucault, Jacques-Louis Soret, Frédéric de La Provostaye, Paul Desains and Jean-Mothée Gaugain (Anonymous 1855b, 235). However, as already observed, Magrini placed de La Provostaye and Paul Desains in the opposing camp.

scientific validity of Zantedeschi's 1854 demonstrations, which employed a methodology similar to his own (Magrini 1855, 3–18).

The discussion continued with contributions from Giusto Bellavitis and Giuseppe Belli, who addressed the issue in more theoretical terms. Bellavitis criticised Zantedeschi's experiments, maintaining that the lack of cumulative thermal effects on the conducting wire—which should have manifested in the case of the superposition of two opposing currents—demonstrated the absence of genuine superposition. Bellavitis argued that Zantedeschi indirectly confirmed this point by noting in the *Gazzetta Veneta* (17 February 1855) that the wire showed no appreciable heating during the experiments (Bellavitis 1855, 145–146). Giuseppe Belli, for his part, approached the problem from a theoretical perspective, publishing two important memoirs between 1855 and 1857 (Belli 1855; Belli 1857). He linked the matter to the broader debate on the nature of electricity, citing the foundational work of Georg Simon Ohm (1789–1854) and Gustav Kirchhoff (1824–1887), as well as noting the contributions of Italian scholars, including Stefano Marianini (1790–1866), Carlo Matteucci, and Riccardo Felici (1819–1902), who were actively involved in the national debate in various capacities. Belli concluded that the available galvanometric readings were insufficient to resolve the matter, highlighting the limitations of the instrumentation and experimental methodologies of the period.[34] Parallel to this theoretical debate, two practical experiments in simultaneous transmission were conducted along Italian telegraphic lines. Carlo Matteucci performed the first experiment on the Pisa–Livorno line, approximately 20 km long (Anonymous 1855b, 236), while the physicist Giuseppe Domenico Botto (1791–1865) carried out the second on 20 June 1855 along the Turin–Moncalieri telegraphic route (Anonymous 1856, 50). Both experiments yielded positive results, demonstrating that duplex telegraphy was feasible not only in the laboratory but also on operational telegraphic lines.

4.3 Serpieri's experiments at Urbino

On 13 January 1855, Serpieri submitted a communication to Erasmo Fabri-Scarpellini, the director of *La Corrispondenza Scientifica in Roma. Bullettino Universale*,[35] describing a series of experiments carried out in the Urbino physics cabinet (Serpieri 1855a, 373–375). The principal objective of his research was to investigate the behaviour of electrical currents when transmitted simultaneously in opposite directions along a single conductor. Under controlled conditions, the study aimed to determine whether—and to what extent—two currents of equal intensity but opposite direction could interact, neutralise one another, or generate a "derived current"[36] (that is, a residual or diverted current in a secondary branch), a phenomenon that, in Serpieri's view, could bear on both theoretical interpretations and practical applications of telegraphy.

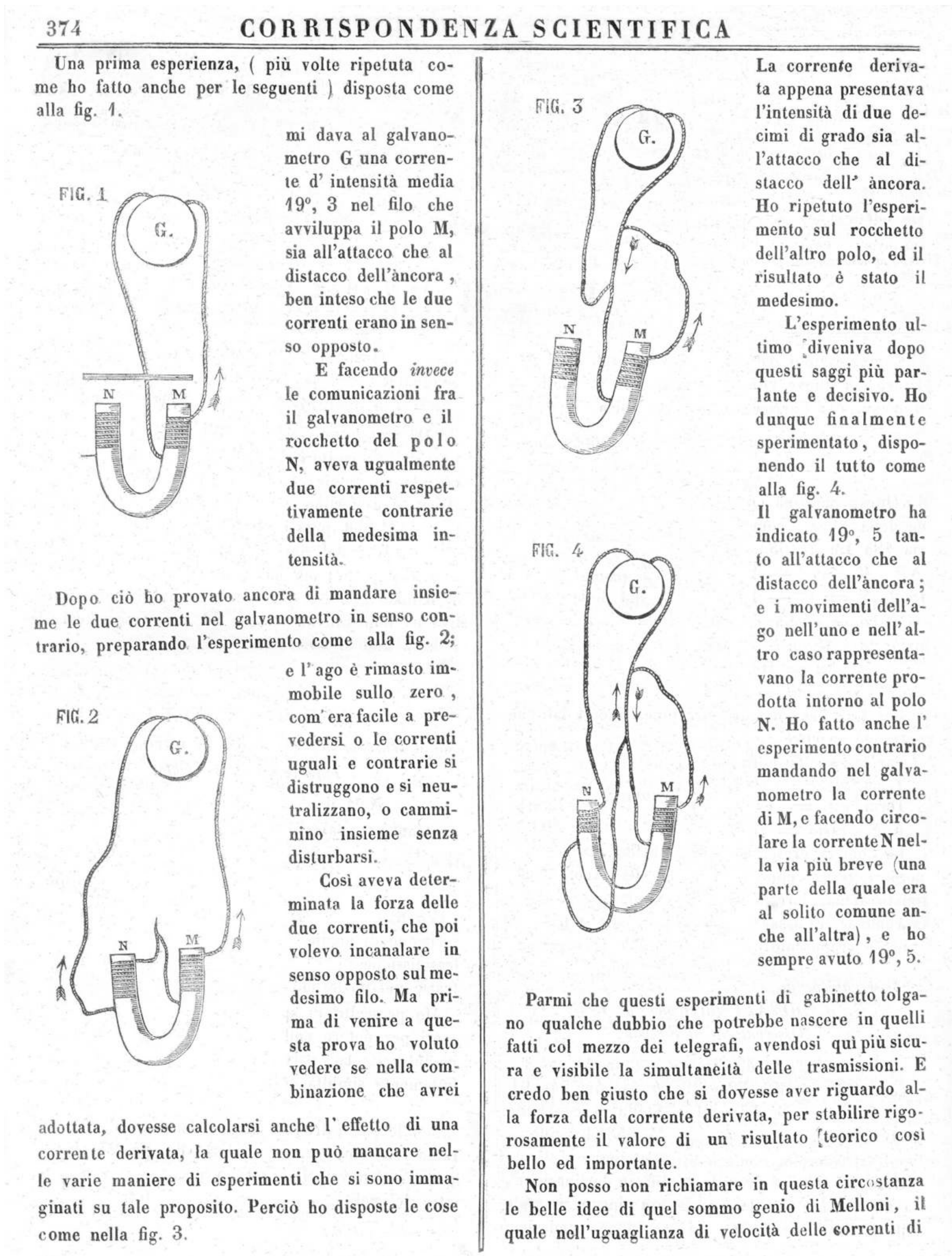
The experimental apparatus comprised a galvanometer and a horseshoe magnet equipped with a soft iron armature. The magnet featured at its poles two coils of copper wire covered in insulating fabric, each containing 27 turns. Serpieri deliberately employed weak currents, precisely measurable using the galvanometer. To generate transient currents of equal intensity but opposite direction, he moved the armature back and forth between the poles of the permanent magnet "*at an approximately constant velocity*", a technique intended to ensure a degree of uniformity. With this simple but ingenious arrangement, Serpieri carried out four experiments (Fig. 15), by progressively varying the circuit arrangements.

In the first experiment, he observed that the two currents, generated separately by each pole and directed in opposite directions, showed identical intensity, as indicated by the galvanometer deflection of 19.3°. In the second, by connecting the wires of the two coils in a single circuit, the currents flowed simultaneously in opposite directions; in this configuration, the galvanometer needle remained at zero, demonstrating their mutual neutralisation or, as Serpieri hypothesised, the ability to "*proceed simultaneously without mutual interference*". In the third experiment, he attempted to detect a possible "*derived current*", recording an extremely weak intensity (two-tenths of a degree) and concluding that such an effect was negligible. In the fourth and final experiment, Serpieri caused two opposing currents, produced by the coils, to circulate simultaneously along a common section of the circuit's wire. By connecting the galvanometer to the coil of the north pole, he observed a stable deflection of 19.5° both on making and on breaking contact with the armature, regardless of the opposite current generated by the other coil and

[34] Belli also expressed reservations about the wave model of electricity—then in competition with fluid models—arguing that the hypothesis of independent currents still presented unresolved conceptual problems.

[35] The Roman periodical was founded in 1847 by Fabri, husband of the astronomer Caterina Scarpellini (1808–1873). This important scientific weekly aimed to disseminate contemporary scientific developments, promoting the work of Italian and foreign men of science, with particular attention to the technical and scientific activities taking place in Rome and throughout the Papal States. The "*Bullettino*" was published regularly until 1856.

[36] In mid-nineteenth-century telegraphy, a "derived current" (courant dérivé/corrente derivata) denotes the portion of current diverted into a secondary (derived) branch of a circuit—either intentionally (via shunts) or parasitically—whenever branches share a conductor segment or an earth return. In the duplex problem, the concern is that two simultaneous opposite currents may not cancel perfectly on the shared segment, leaving a small residual (derived) current capable of disturbing instruments and hence transmission.



374 CORRISPONDENZA SCIENTIFICA

Una prima esperienza, (più volte ripetuta come ho fatto anche per le seguenti) disposta come alla fig. 1.

FIG. 1

mi dava al galvanometro G una corrente d' intensità media 19°, 3 nel filo che avviluppa il polo M, sia all'attacco che al distacco dell'àncora, ben inteso che le due correnti erano in senso opposto.

E facendo *invece* le comunicazioni fra il galvanometro e il rocchetto del polo N, aveva ugualmente due correnti respettivamente contrarie della medesima intensità.

Dopo ciò ho provato ancora di mandare insieme le due correnti nel galvanometro in senso contrario, preparando l'esperimento come alla fig. 2;

FIG. 2

e l' ago è rimasto immobile sullo zero, com' era facile a prevedersi o le correnti uguali e contrarie si distruggono e si neutralizzano, o camminino insieme senza disturbarsi.

Così aveva determinata la forza delle due correnti, che poi volevo incanalare in senso opposto sul medesimo filo. Ma prima di venire a questa prova ho voluto vedere se nella combinazione che avrei adottata, dovesse calcolarsi anche l' effetto di una corrente derivata, la quale non può mancare nelle varie maniere di esperimenti che si sono immaginati su tale proposito. Perciò ho disposte le cose come nella fig. 3.

FIG. 3

La corrente derivata appena presentava l'intensità di due decimi di grado sia all'attacco che al distacco dell' àncora. Ho ripetuto l'esperimento sul rocchetto dell'altro polo, ed il risultato è stato il medesimo.

L'esperimento ultimo diveniva dopo questi saggi più parlante e decisivo. Ho dunque finalmente sperimentato, disponendo il tutto come alla fig. 4.

FIG. 4

Il galvanometro ha indicato 19°, 5 tanto all'attacco che al distacco dell'àncora; e i movimenti dell'ago nell'uno e nell'altro caso rappresentavano la corrente prodotta intorno al polo N. Ho fatto anche l' esperimento contrario mandando nel galvanometro la corrente di M, e facendo circolare la corrente N nella via più breve (una parte della quale era al solito comune anche all'altra), e ho sempre avuto 19°, 5.

Parmi che questi esperimenti di gabinetto tolgano qualche dubbio che potrebbe nascere in quelli fatti col mezzo dei telegrafi, avendosi quì più sicura e visibile la simultaneità delle trasmissioni. E credo ben giusto che si dovesse aver riguardo alla forza della corrente derivata, per stabilire rigorosamente il valore di un risultato teorico così bello ed importante.

Non posso non richiamare in questa circostanza le belle idee di quel sommo genio di Melloni, il quale nell'uguaglianza di velocità delle correnti di

Fig. 15 Circuit configurations of the experiments carried out by Alessandro Serpieri in January 1855 at the physics cabinet in Urbino, aimed at testing the interference between two equal and oppositely directed currents within a single conductor. Source: (Serpieri 1855a, 374), Author's private collection (scan by the author)

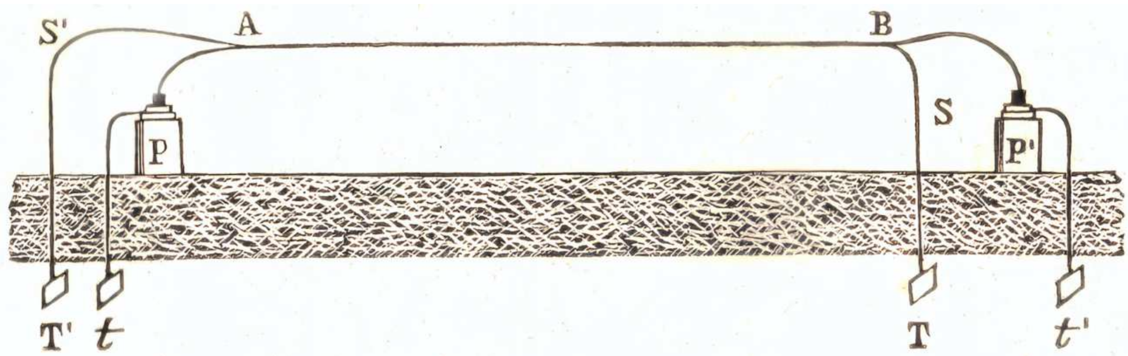


Fig. 16 Diagram of the mixed telegraphic circuit between two telegraph stations (with batteries and pairs of earth electrodes) devised by Serpieri for the simultaneous transmission of opposing currents. Source: (Serpieri 1855b, 398), Author's private collection (scan by the author)

transmitted in the same conductor. The reversal of connections produced analogous results, demonstrating that currents of equal intensity could coexist in opposite directions without reciprocal interference (Serpieri 1855a, 374).

The publication of these results provoked a vigorous response from Zantedeschi. In a letter dated 27 February 1855, published in *La Corrispondenza Scientifica in Roma*, Zantedeschi staked a firm claim to priority concerning three fundamental matters: the method of experimentation with opposite currents on a single wire, which he stated he had first accomplished in 1829; the combined use of voltaic and induction currents, which he had investigated between 1839 and 1840; and the demonstration of the simultaneous passage of opposite currents. Regarding this last point, Zantedeschi criticised Serpieri's methodology, arguing that the manual operation of the armature compromised the precision of synchronism, and asserted the superiority of his own experiments, conducted with greater rigour (Zantedeschi 1855f, 411). Serpieri's response, dated 12 March 1855 and published in the same periodical, was prompt and articulate. Surprised by his colleague's animosity, he replied with subtle irony: "*If Signor Zantedeschi's rights date back to 1829, I defy anyone to contest his priority!*". He clarified that his intent was not to dispute matters of priority, but to address a lacuna in previous studies, focusing on derived currents, an aspect neglected by Zantedeschi but deemed fundamental in light of Felice Ciampi's experiments. In a conciliatory tone, Serpieri emphasised the paradox of the dispute: his study aimed to corroborate, not to refute, Zantedeschi's theses. He further reiterated that his sole purpose was "*to investigate the fascinating phenomena of nature and pursue truth*", declaring himself unconcerned with priority disputes (Serpieri 1855c, 411). In a second communication (24 February 1855), Serpieri expanded the analysis of Zantedeschi's Paduan experiments, extending his investigation from purely metallic circuits to mixed circuits. He specifically investigated a practical telegraph circuit employing the earth as a return conductor. The schematic layout (Fig. 16) involved two telegraphic stations, each equipped with batteries and apparatus, connected by a long telegraph line.

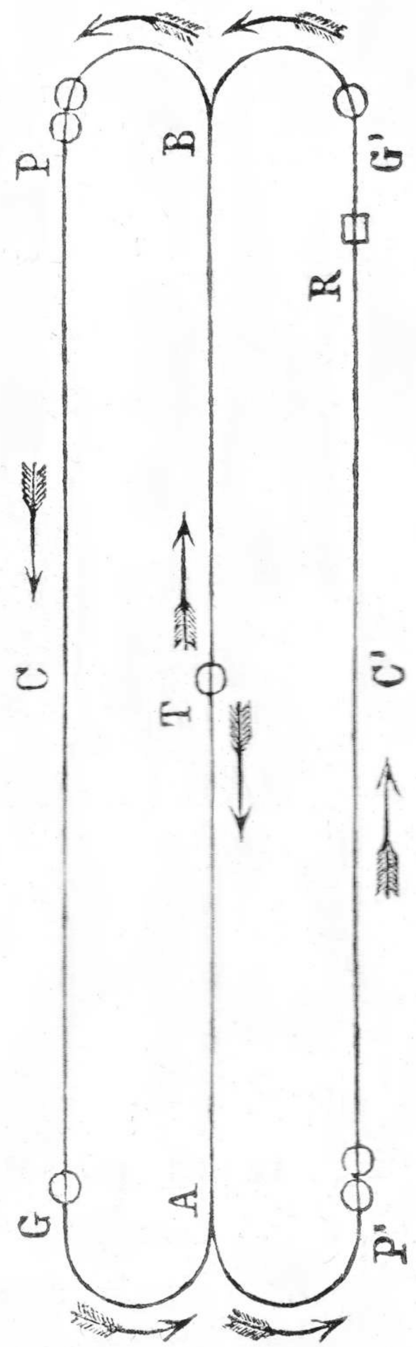
At each station, the battery's negative pole was connected to an earth electrode (typically one or more buried metal plates), while the positive pole was connected both to the line and to a second earth electrode placed "*a few tens of metres*" away from the first electrode—so that the circuit could close through the ground (earth return).

Serpieri analysed the feasibility of simultaneously transmitting opposite currents in this mixed configuration, as Zantedeschi had verified in metallic circuits. His investigation focused on the conductive properties of the earth, noting that, by adjusting the distance between the two buried electrodes at each station, the resistance of the ground path could exceed that of the wire. Such a configuration favoured the flow of currents through the common conductor without mutual neutralisation (Serpieri 1855b, 397–398).

4.4 The analysis of derived currents: the response to Felice Ciampi

Serpieri wrote a third communication in response to an article by Felice Ciampi dated 1 February 1855 and published in *La Corrispondenza Scientifica in Roma*. In that contribution, Ciampi contested the possibility of simultaneously transmitting opposite electrical currents along a single conductor. To verify his thesis, Ciampi designed and conducted experiments utilising two distinct electrical circuits (Fig. 17), interconnected by a common brass wire (diameter 0.15 mm, length 20 m) with a tangent galvanometer inserted in this shared segment.

Each circuit was equipped with its own galvanometer and powered by an independent battery. To ensure equal current strengths in the shared segment, Ciampi introduced a rheostat into the second circuit and adjusted it until the tangent galvanometer inserted in the common wire showed a null (zero) deflection. From his experimental data, he observed that removing the shared segment did not alter the readings of the two galvanometers, and that the current intensity increased relative to the case in which only one circuit was closed. This evidence led him to conclude that the opposite currents did not traverse the shared wire, but circulated exclusively in the external path



Le due pile P e P′ hanno i lor poli collocati in modo che le correnti in esse originate vadano nella direzione delle frecce. Queste formano due circuiti: uno, PCGATBP; l'altro, P′C′G′BTAP′, e che distinguerò coi semplici simboli CT,C′T. Il filo di un galvanometro G fa parte del circuito CT, e quello di un altro G′ è parte del circuito C′T. In T sta una bussola delle tangenti il cui filo è parte del tronco AB comune ai due circuiti; questo tronco poi è formato quasi tutto di un filo di ottone del diametro di 0mm, 15 e lungo circa 20m. Un Reostata R è introdotto nel circuito C′T affine di ridurre la corrente di questo circuito ad una intensità, uguale a quella della corrente C T.

Fig. 17 Schematic diagram of Ciampi's experimental apparatus for the study of simultaneous transmission of opposite electrical currents. Two distinct circuits are connected via a common brass wire AB, into which a tangent galvanometer T is inserted to measure the resultant current intensity. Source: (Ciampi 1855, 393), Author's private collection (scan by the author)

(Ciampi 1855, 393–395). On 12 March 1855, in the same periodical, Serpieri countered Ciampi's empirical and sceptical approach with a more sophisticated theoretical synthesis, supported by experimental observations and mathematical calculations, thereby demonstrating the phenomenon's feasibility. In the article, Serpieri disclosed that he had already examined the question, mentioning an analogous experiment conducted in Florence by Filippo Cecchi (1822–1887), his "*esteemed colleague and friend*". The two had discussed the issue at length, and Cecchi had obtained results comparable to Ciampi's. On the theoretical level, both Cecchi and Serpieri recognised the difficulty of reconciling such experimental evidence with Faraday's prevailing theory, according to which electrical current arose from a "*progressive series of molecular inductions*". Serpieri, in particular, found it conceptually problematic that "*molecular actions*" could "*reverse direction*" to allow for the passage of opposite currents without mutual neutralisation.

He therefore recommended greater caution and flexibility in the application of scientific principles, citing in support the recent research of the physicist Macedonio Melloni on the propagation speed of electrical current (Melloni 1854, 319–325), which had invalidated Faraday's theory of lateral inductions.[37]

Despite these conceptual difficulties, and while acknowledging the critical approach and courtesy of the Roman physicist, Serpieri proposed an alternative interpretation of Ciampi's results, based on the theory of derived currents. According to this theory, each circuit could be considered a "*derived branch*" of the other, allowing opposite currents to coexist and flow in the common wire without neutralisation. To validate his interpretation, Serpieri developed a mathematical analysis and applied the standard formulae for derived circuits outlined in Abbé Moigno's *Traité de télégraphie électrique* (Moigno 1852, 219) to calculate the expected galvanometric changes under Ciampi's conditions. Using these relations, and by combining the relevant resistances and electromotive forces, Serpieri showed that the increase measured by Ciampi in the galvanometers was consistent with the hypothesis that opposite currents could coexist on the shared segment (Serpieri 1855d, 413–415). Serpieri's response thus shifted the discussion from the empirical registration of a disputed effect to the theoretical and mathematical analysis of the common wire as a circuit of derived currents, thereby redefining the problem in both epistemological and practical terms.

4.5 The synthesis on Gintl's telegraph

Serpieri's final article on this technology was written at the request of the director of *La Enciclopedia contemporanea*[38] to describe and validate Gintl's duplex telegraph. Dated 12 May 1855, this text (Serpieri 1855e) combines expository clarity with technical rigour, reducing the complexity of the circuit to a schematic diagram that conceptually linked the stations of Rome and Ancona (Fig. 18). For each station, Serpieri reduced the system to four essential components: a local battery, a telegraph key, an electromagnet of Prussian design,[39] and a wire rheostat—the latter designed to balance the circuit's resistance.

Serpieri had become acquainted with the technical details of the new telegraphic system through reading articles published in *Il Nuovo Cimento* (Anonymous 1855a; Anonymous 1855b), in which Matteucci and his collaborators had described, among the first in Italy, the principle and operation of the Gintl telegraph. Analysing the current path in different operational configurations, Serpieri illustrated how signals were transmitted utilising the earth as a return conductor. In unidirectional mode, the device reproduced the performance of traditional telegraphs, circulating the current along the main wire to the receiving station, then returning via the earth, generating the desired signal.

The principal interpretative challenge, however, arose in explaining synchronous operation, when both stations simultaneously activated the keys. In this scenario, Serpieri, revisiting and further clarifying the previous analysis (Anonymous 1855b, 237–239), proposed the following explanation: the system did not necessarily require the hypothesis, which he himself had previously supported, that opposite currents could coexist in the main wire. He argued instead that the receiving action of the electromagnets depended chiefly on local currents, whose distribution was determined by the configuration of the circuit during synchronous keying. Although the machines appeared

[37] Faraday had observed that submarine telegraph cables transmitted electrical signals more slowly than terrestrial cables, hypothesising that the potential of a wire diminished along the direction of propagation due to lateral inductions. According to Serpieri, this concept could explain the simultaneous passage of opposing currents, but the telegraphic experiments devised by Melloni and conducted by Latimer Clark (Melloni 1854, 321) had refuted Faraday's theory, thereby casting doubt upon his conclusions.

[38] This scientific periodical, published in Fano, was founded and directed in 1855 by Gabriel Angelo Gabrielli. It presented itself as a "*Universal repertory and handbook of technical knowledge and all important current events, discoveries and useful applications*". It was published until 1858.

[39] This crucial component, based on a differential winding (two identical windings arranged in opposite directions), was initially introduced by Frischen and subsequently perfected by *Siemens & Halske*. Thanks to this configuration, the local current did not interfere with the reception of remote signals, making feasible the simultaneous use of a single line for both stations (Anonymous 1877d, 181).

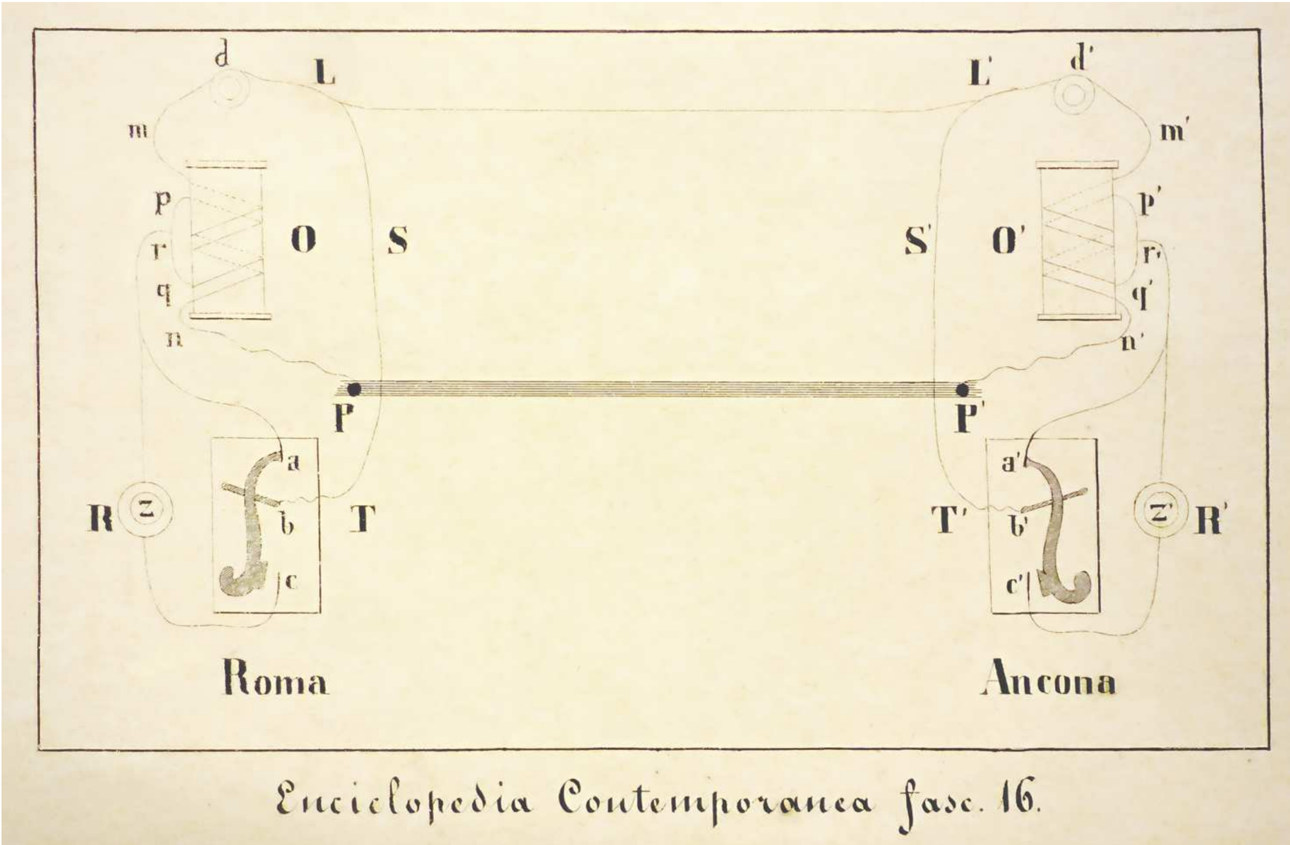


Fig. 18 Diagram of Gintl's duplex telegraph, reproduced by Serpieri to illustrate the simultaneous transmission between Rome and Ancona. Highlighted are the local battery, the key, the electromagnet, and the rheostat–key components for understanding the role of local currents in synchronising transmissions. Source: (Serpieri 1855e, 244), Author's private collection (scan by the author)

to respond to the remote current, they operated in reality thanks to the local circuit, thereby relegating to a secondary role the theoretical controversies on the coexistence of opposite currents.

Nevertheless, Serpieri initially expressed technical misgivings,[40] fearing that Gintl's machine might prove imprecise owing to the possible presence of opposing currents that could not be fully neutralised (Serpieri 1855e, 247). Shortly thereafter, however, he acknowledged that such concerns had been allayed by the success achieved by the Pisan experimenters in testing the system along the Pisa–Livorno telegraphic line. Synchronism, Serpieri concluded, did not require the perfect neutralisation of opposing currents, but rather relied on the predominance of local currents, thereby rendering it unnecessary to invoke still-contested physical theories, such as that of the simultaneous coexistence of opposing currents within the same conductor. Serpieri concluded with a trenchant observation: "*Considering the division to which the current is subjected, one might almost affirm the principle: what is gained in time is equally lost in power*" (Serpieri 1855e, 249), thereby highlighting the inherent trade-off in the innovation proposed by Gintl.

4.6 Epilogue: commercial developments and technological legacy

Despite the intense debate and encouraging experimental results, duplex telegraphy became commercially viable on a large scale only from the late 1860s, owing to the innovations introduced by Joseph B. Stearns (1831–1895) of Boston. His current-balancing system saw its first practical implementation on the New York–Boston line in 1872, where it proved commercially successful and was subsequently adopted in submarine cable telegraphy. In 1874, Thomas A. Edison (1847–1931) further refined the technology with the development of the quadruplex system,

[40] See his critical letter (Serpieri 1855f, 373) addressed to Carlo Matteucci and the compilers of *Il Nuovo Cimento*, in which he highlighted an error in the description of the current distribution. This observation was subsequently deemed pertinent and correct by the journal's compilers and published as an appendix to the letter (Serpieri 1855f, 373–374; see 'Nota dei Compilatori').

which enabled the simultaneous transmission of four messages over a single wire, significantly enhancing the efficiency of telegraphic communication. These innovations profoundly transformed the economics of long-distance communication, reducing operating costs while expanding the capacity of existing lines.

In retrospect, the mid-century controversy over simultaneity—line balancing, signal separation, and the management of interference on a shared conductor—also clarifies the broader significance of the Italian debate of 1855, by showing that what was then at stake was not merely a local technical dispute, but a wider nineteenth-century problem of line economy, current distribution, and signal control, addressed through a combination of theoretical reasoning, experimental practice, and instrumental ingenuity.

5 Case study III: the introduction of the Bell telephone in Italy (1877–1878)

The third case shifts to post-Unification Italy, but it also shows how features already visible in Serpieri's earlier practice—local experimentation, close analysis of instruments, and sustained engagement with wider scientific debates—continued to shape his work under new political and communicative conditions. In the early months of 1878, Serpieri showed a keen interest in the "extraordinary effects" of the telephone devised by the Scottish-born inventor Alexander Graham Bell (1847–1922), and investigated its operation both theoretically and experimentally. Before examining Serpieri's specific contributions in detail, it is useful to outline the broader context of this new technology's reception within Italy. Such a reconstruction requires attention to the role played by the nation's scientific and technical communities and contemporary channels of communication—including specialised periodicals and the general press—in analysing, testing, and disseminating the invention. Bell filed a patent application for his "speaking telegraph" in February 1876 and refined the apparatus in the months that followed. In the earliest configurations reported in the technical press, the telephone still appeared as a battery-fed electromagnetic system: a battery supplied the line current (Fig. 19, battery labelled h), while the transmitter and receiver relied on coils—that is, electromagnets—and a vibrating diaphragm and armature to convert voice vibrations into "undulatory" current variations and back into sound.

This context helps clarify the later shift to "magneto" instruments, in which a permanent magnet provided the magnetic field, allowing the receiver to operate without an external battery. In 1877, the Bell Telephone Company was established in Boston to commercialise the invention both in the United States and abroad.

In Italy, the first accounts of Bell's device appeared in February 1877 in the pages of the monthly journal *L'Elettricista* (Cardarelli 1877), edited by the engineer Lamberto Cappanera.[41] This periodical, established in Florence in January 1877 and initially focused primarily on electric telegraphy applications, was the first Italian journal entirely dedicated to electrotechnology. Its primary objective was to keep physicists and engineers abreast of developments in electrical technology and its application to industry and society.[42] The periodical hosted technical and popular articles of a high standard, a feat attributable to the capable editorship of Cappanera, who secured contributions from numerous Italian and foreign scientists. The journal also regularly published bibliographical reviews and a selection of abstracts and notices from international scientific publications. It was through these accounts—sourced either from foreign correspondents or directly from British, French, and American journals—that the first technical details regarding Bell's pioneering research on the remote transmission of sound reached Italy. Throughout 1877, the articles published in *L'Elettricista* documented the principal applications and technical refinements to the telephone, offering detailed descriptions of its components and principles of operation, while situating these developments within the broader history of acoustic telegraphy. In the course of 1878, this flow of information gave rise to an extensive debate within the Italian scientific community, which in turn stimulated Serpieri's interest and prompted him to undertake his own investigations into the instrument. A reconstruction of the intellectual climate and the initial responses to the telephone's arrival in Italy, therefore, requires an analysis of the most significant articles appearing not only in the first volume of *L'Elettricista* but also in other contemporary Italian periodicals.

---

[41] Lamberto Cappanera († Naples, 31 August 1880), an Italian engineer specialising in telegraphy, held a commission in the Italian Telegraph Corps. He supervised the fifth (1873) and sixth (1876) Italian editions of Richard Spelman Culley's *Manual of Practical Telegraphy*, which he augmented with his own original annotations. In 1877, he translated and annotated the third English edition of *Electricity and Magnetism* by Fleeming Jenkin (1833–1885), the British engineer and academic. He was a member of both the *Society of Telegraph Engineers* of London and the *Société Scientifique et Industrielle* of Marseille.

[42] The journal ceased publication at the end of 1878, only to be re-established in 1879 with an expanded editorial remit and the new title *La Natura*, extending its scope to encompass related sciences and the applications of the physical sciences in the fields of art and industry. Following Lamberto Cappanera's death in August 1880, the editorship passed to his brother Rodolfo; however, the venture proved unsuccessful, and the journal ceased publication permanently in 1882.

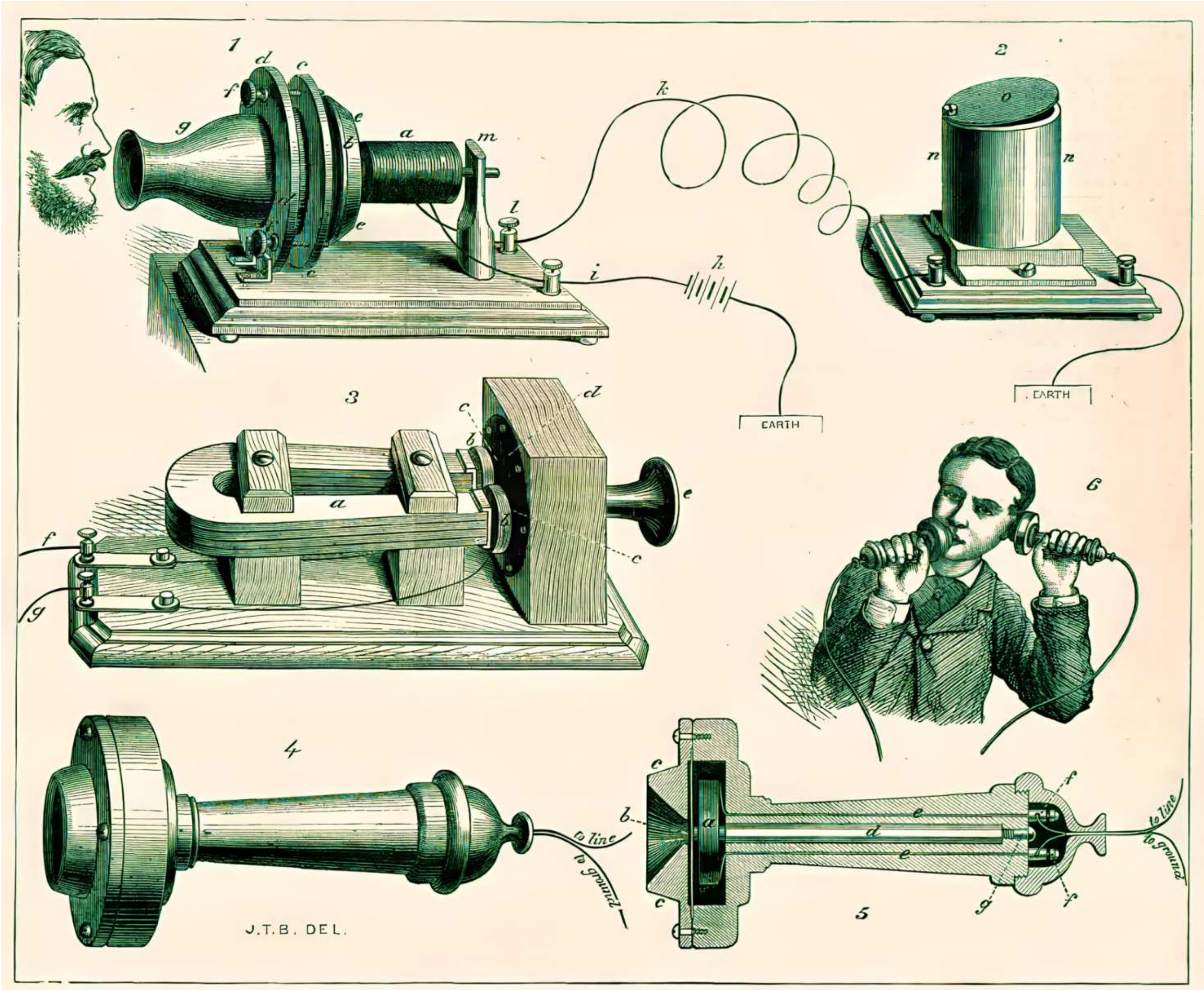


Fig. 19 Illustrations of Alexander Graham Bell's early telephone apparatus published in December 1877, less than two years after the original patent (1876). In the upper diagram, element h indicates the battery required in the early electromagnetic configuration. Source: *The Illustrated London News*, Vol. 71, 15 Dec. 1877, p. 581; accessed via *HathiTrust Digital Library*

5.1 The telephone's media reception: technical and popular press (1877)

News of Alexander Graham Bell's "*articulating telephone*" began to circulate in Italy during 1877, eliciting considerable interest both among the educated public and within technical and scientific milieu. These initial reactions, however, were far from uniform. As the engineer Giuseppe Colombo (1836–1921) observed in the Milanese monthly journal *Il Politecnico* in a contribution dated 13 December 1877, the American origin of the apparatus initially engendered a degree of scepticism, linked to the United States' reputation as the homeland of spiritualism and related "mystifications", associated—among others—with celebrity mediums such as Daniel Dunglas Home (often rendered "Hume" in Italian sources) and the Davenport brothers (Colombo 1934b, 476).

This climate of mistrust, however, rapidly dissipated in light of the growing body of technical documentation and, above all, the first practical demonstrations, which revealed the device's genuine scientific value. In this context, the journal *L'Elettricista* established itself as the first publication to offer a systematic and up-to-date treatment of the invention (see, for instance, the first two notes: Anonymous [L'Elettricista] 1877a, 54–55; Cardarelli 1877, 55–56), publishing numerous reports based on American, French, and British sources. It was not, however, the sole voice to attribute significance to the discovery. Other periodicals—popular, didactic, and institutional—contributed to extending the reach of the innovation and to stimulating interest in what was perceived as a "*technical marvel*". This plurality of channels of communication, each with its own tone and purpose, played a complementary role in shaping the Italian reception of Bell's telephone.

This complex media landscape, however, was not monolithic; it also featured dissonant or cautious voices. A significant example is found in the institutional press. In March 1877, the *Bullettino Telegrafico del Regno d'Italia*—the official organ of the *Directorate-General of Telegraphs*—reprinted an article from the *Journal des Débats* that adopted a more measured and reflective tone. While recognising the feasibility of transmitting sounds at a distance via electricity, the article sought to minimise the impact of recent news linked, albeit implicitly, to Bell's invention. It did so by recalling the prior experiments of the German physicist Johann Philipp Reis (1834–1874),[43] erroneously cited in the *Bullettino* as "*Reuss*", and misdated to 1863. According to the author, the technical principle of the so-called *speaking telegraph* was by no means new, and the successes achieved in the United States represented merely the refinement of an idea already known to the European scientific community for over a decade (Anonymous 1877a, 69–72). This therefore represented a cautious and rational evaluation that, as early as March 1877, recognised the theoretical potential of acoustic-electrical transduction, while not yielding to the uncritical enthusiasm that would characterise a segment of the press in the following months.

Despite this prudent analysis, the overall reception of the invention in Italy was markedly positive and enthusiastic, buoyed by reports of public demonstrations and by increasingly detailed descriptions. Already in February 1877, Lamberto Cappanera's recently founded periodical published its first technical account of Alexander Graham Bell's "*articulating telephone*", one of the earliest to appear in Italy. The dispatch, signed by the engineer Fedele Cardarelli and composed in London on 22 January 1877, offered a clear and detailed description of the apparatus. Cardarelli illustrated the essential structure of the device, which he judged to be surprisingly simple, comprising two principal components: the transmitter and the acoustic–electric receiver. The transmitter consisted of a brass drum across which a thin membrane was stretched. At the centre of this membrane, a small disc of soft iron was affixed. When one spoke into the mouthpiece of the drum, the membrane and disc vibrated in proximity to a magneto-electric inductor (a magnet wound with conducting wire). The vibrations produced a continuous series of induced currents, whose intensity varied proportionally to the amplitude of the acoustic oscillations. The receiver contained an electromagnet enclosed in a soft iron tube, which concentrated its magnetic field. Above this tube was fixed a thin circular iron plate designed to vibrate under the influence of the transmitted currents. The rapid magnetisations and demagnetisations induced by the current caused the plate to vibrate; it operated simultaneously as a vibrator and resonator, reproducing with remarkable fidelity the timbral qualities of the original sound. From this description, the innovative principle of Bell's telephone emerges clearly: the capacity to achieve a continuous, modulated electromagnetic transduction, capable of reproducing not only the frequency but also the intensity and quality of the vocal signal. This mechanism radically distinguished Bell's device from the antecedent apparatuses of Reis and Elisha Gray (1835–1901), which were based on periodic interruptions of the current (make-and-break) or, in Gray's case, on vibrating reeds tuned to fixed frequencies.[44]

Cardarelli's contribution also included a brief historical contextualisation of acoustic telegraphy, with references to Charles Grafton Page's (1812–1868) "*galvanic music*" (1837), Charles Wheatstone's (1802–1875) experiments in sound transmission through metallic conductors, and the pioneering devices of Reis and Gray (Cardarelli 1877, 55–56).

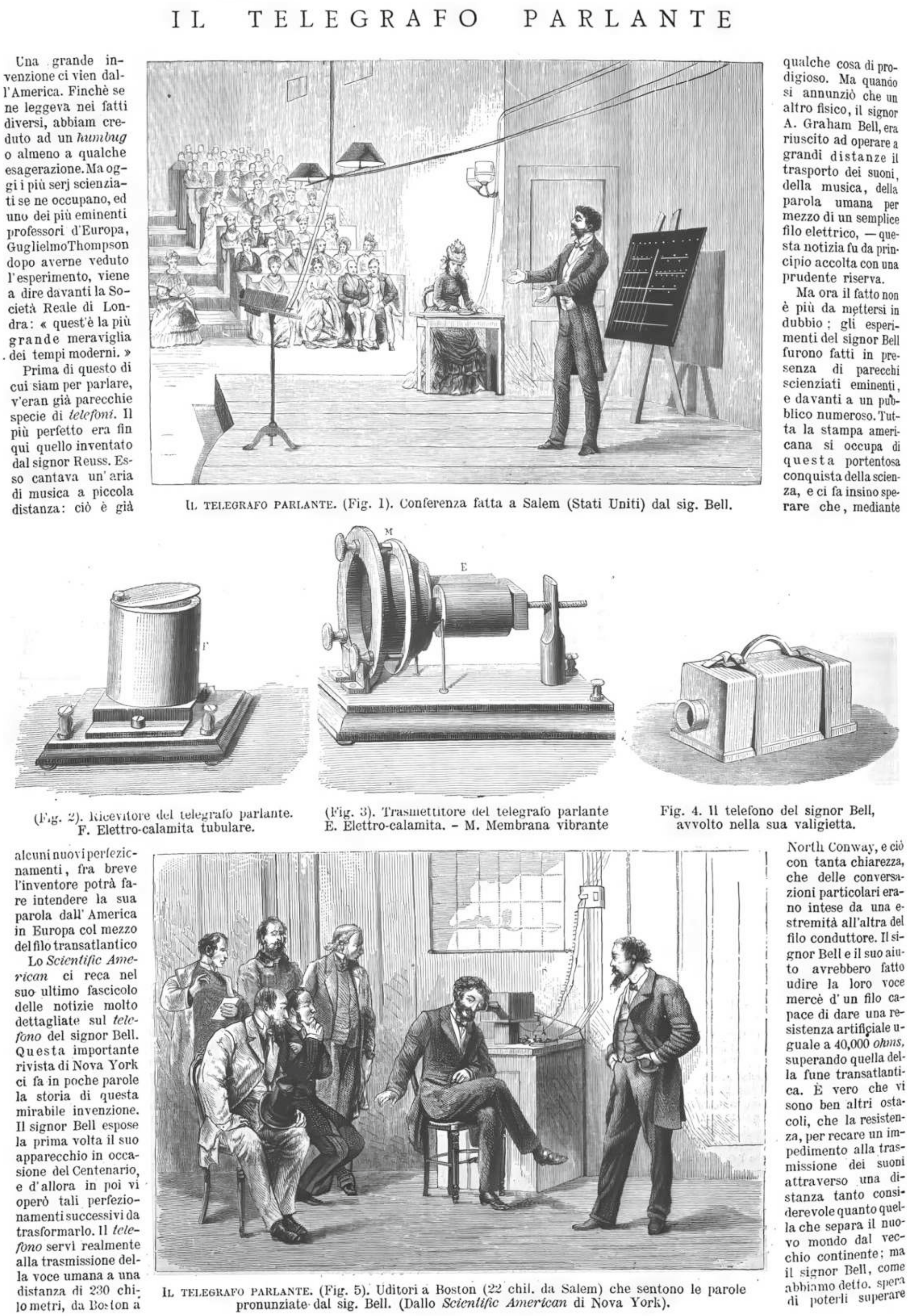
Supplementing Cardarelli's article, *L'Elettricista* also reported the results of the first practical experiments conducted in the United States (August–November 1876) over increasing distances between Boston, Cambridgeport, Salem, and North Conway. These reports highlighted both the successes achieved in sound transmission up to 143 miles and the difficulties encountered beyond that limit, emphasising the apparatus's capacity not only to transmit sounds but also to render articulated words intelligible (Anonymous [L'Elettricista] 1877a, 54–55).

The technical and scientific coverage offered by *L'Elettricista* was complemented in the following months by the dissemination of news regarding the so-called *speaking telegraph* through widely circulated general-interest periodicals. In May 1877, *L'Illustrazione Italiana*, a popular illustrated weekly published in Milan, featured an article accompanied by a series of engravings reproduced from the American journal *Scientific American,* and aptly entitled "*The Speaking Telegraph*" (Fig. 20). The text stressed the "*marvellous*" character of the discovery and highlighted the astonishing capacity for long-distance transmission of the human voice, describing in detail experiments conducted between Salem and Boston, during which the device demonstrated its ability to transmit clearly articulated words and phrases over distances exceeding twenty kilometres (Anonymous [L'Illustrazione Italiana] 1877a, 300, 302).

---

[43] It is noteworthy that while the Reis device conceptually anticipated the principle of acoustic-electrical transduction and indeed succeeded on several occasions in transmitting articulated words, its performance was both limited and highly inconsistent. The difficulties in achieving intelligible voice reproduction stemmed from a combination of the receiver's limited sensitivity and the weakness of the generated current; consequently, the system was more suited to transmitting musical sounds or simple sung phrases (Coe 1995, 16–24; Shulman 2008, 117–125).

[44] Cardarelli's account was substantially correct. The decisive innovation lay in the replacement of the "*liquid transmitter*," initially employed by Bell, with a magnetic induction model capable of generating continuous currents modulated by the amplitude of acoustic vibrations. This principle surpassed the discontinuous 'make-and-break' impulse devices of Reis and Gray, which were unsuited to the intelligible transmission of the human voice (Shulman 2008, 12–15).



IL TELEGRAFO PARLANTE

Una grande invenzione ci vien dall'America. Finchè se ne leggeva nei fatti diversi, abbiam creduto ad un *humbug* o almeno a qualche esagerazione. Ma oggi i più serj scienziati se ne occupano, ed uno dei più eminenti professori d'Europa, Guglielmo Thompson dopo averne veduto l'esperimento, viene a dire davanti la Società Reale di Londra: « quest'è la più grande meraviglia dei tempi moderni. »

Prima di questo di cui siam per parlare, v'eran già parecchie specie di *telefoni*. Il più perfetto era fin qui quello inventato dal signor Reuss. Esso cantava un'aria di musica a piccola distanza: ciò è già qualche cosa di prodigioso. Ma quando si annunziò che un altro fisico, il signor A. Graham Bell, era riuscito ad operare a grandi distanze il trasporto dei suoni, della musica, della parola umana per mezzo di un semplice filo elettrico, — questa notizia fu da principio accolta con una prudente riserva.

Ma ora il fatto non è più da mettersi in dubbio; gli esperimenti del signor Bell furono fatti in presenza di parecchi scienziati eminenti, e davanti a un pubblico numeroso. Tutta la stampa americana si occupa di questa portentosa conquista della scienza, e ci fa insino sperare che, mediante alcuni nuovi perfezionamenti, fra breve l'inventore potrà fare intendere la sua parola dall'America in Europa col mezzo del filo transatlantico

IL TELEGRAFO PARLANTE. (Fig. 1). Conferenza fatta a Salem (Stati Uniti) dal sig. Bell.

(Fig. 2). Ricevitore del telegrafo parlante. F. Elettro-calamita tubulare.

(Fig. 3). Trasmettitore del telegrafo parlante E. Elettro-calamita. – M. Membrana vibrante

Fig. 4. Il telefono del signor Bell, avvolto nella sua valigietta.

Lo *Scientific American* ci reca nel suo ultimo fascicolo delle notizie molto dettagliate sul *telefono* del signor Bell. Questa importante rivista di Nova York ci fa in poche parole la storia di questa mirabile invenzione. Il signor Bell espose la prima volta il suo apparecchio in occasione del Centenario, e d'allora in poi vi operò tali perfezionamenti successivi da trasformarlo. Il *telefono* servì realmente alla trasmissione della voce umana a una distanza di 230 chilometri, da Boston a North Conway, e ciò con tanta chiarezza, che delle conversazioni particolari erano intese da una estremità all'altra del filo conduttore. Il signor Bell e il suo aiuto avrebbero fatto udire la loro voce mercè d'un filo capace di dare una resistenza artificiale uguale a 40,000 *ohms*, superando quella della fune transatlantica. È vero che vi sono ben altri ostacoli, che la resistenza, per recare un impedimento alla trasmissione dei suoni attraverso una distanza tanto considerevole quanto quella che separa il nuovo mondo dal vecchio continente; ma il signor Bell, come abbiamo detto, spera di poterli superare

IL TELEGRAFO PARLANTE. (Fig. 5). Uditori a Boston (22 chil. da Salem) che sentono le parole pronunziate dal sig. Bell. (Dallo *Scientific American* di Nova York).

Fig. 20 Components and testing of Alexander Graham Bell's telephone (1877): tubular electromagnet receiver, transmitter with vibrating membrane, portable model, and demonstration of voice transmission between Salem and Boston (detail numbers as in the original illustration). Source: *L'Illustrazione Italiana*, Year IV, no. 19 (13 May 1877), p. 300; accessed via *Internet Archive*

A more thorough technical commentary appeared in the June 1877 issue of *Il Politecnico*, authored by Giuseppe Colombo, a physicist, engineer, and prominent figure in Italian applied science, as well as Professor of "*Industrial Mechanics"* at the *Regio Istituto Tecnico Superiore* di Milano (*Royal Higher Technical Institute* of Milan). Colombo described in enthusiastic tones the results of the first practical applications of Bell's telephone, reporting accounts of trials conducted between Boston and Malden (approximately nine kilometres apart), during which not only were conversations transmitted, but also stock-market information, greetings, invitations, and even a serenade. While maintaining a prudent tone, Colombo did not hesitate to acknowledge that, if confirmed, such results could elevate the apparatus to the rank of an invention "*amongst the most marvellous of our century*" (Colombo 1877a, 377).

The reception of the discovery rapidly stimulated new research and the development of alternative technologies. In August 1877, *L'Illustrazione Italiana* reported on a device developed by Elisha Gray, the American engineer who, almost contemporaneously with Bell, had devised his own system of acoustic transmission. The article clearly delineated the difference between the two paradigms: while Bell aimed to reproduce the human voice in its continuity and timbral complexity, Gray adopted an analytical paradigm, based on the decomposition of sound into elementary frequencies through vibrating reeds and tuned resonators (Anonymous [L'Illustrazione Italiana] 1877b, 121–122). From a historiographical perspective, the article allows one to identify two technical and conceptual paradigms: one of a "*mimetic*" type (Bell), the other of a "*modular*" type (Gray). In the same period, *La Civiltà Cattolica* also contributed to the debate, publishing an enthusiastic article that not only chronicled Bell's experiments but also introduced the idea—still purely speculative—of a "*telectroscope*", namely a hypothetical apparatus for the remote transmission of images, based on a direct analogy between luminous and sound vibrations, and conceived according to a principle similar to the acoustic one (Anonymous 1877b, 464–465). Concurrently, throughout the year, *L'Elettricista* monitored developments closely, publishing updates on public demonstrations, the transmission of musical pieces, conferences, the first private lines activated in the United States, and the introduction of the telephone to England (Anonymous [L'Elettricista] 1877b, 135; Anonymous [L'Elettricista] 1877c, 166; Anonymous [L'Elettricista] 1877d, 192). The Florentine journal reported the acclaim from figures such as Sir William Thomson (1824–1907), who had personally witnessed telephone demonstrations and attested to its effectiveness. *L'Elettricista* further explored the historical context, citing among the pioneers the Danish engineer Poul La Cour (1846–1908) and the English physicist Sir Charles Wheatstone (1802–1875), alongside the previously mentioned figures (Page, Reis, Gray), and emphasising that only Bell had succeeded in obtaining an intelligible and tonally faithful transmission of the voice. The journal also documented the technical functioning of Bell's device, emphasising the apparatus's capacity to convert, not only the frequency but also the amplitude of vocal vibrations into corresponding variations in electric current intensity. This enabled the continuous reproduction of timbre and vocal modulations, surpassing the simple sequence of electric impulses (Anonymous [L'Elettricista] 1877e, 258–260). Gradually, *L'Elettricista* expanded its accounts to include technological variants designed to overcome the limitations (particularly of a sonic nature) of Bell's telephone. The journal described research conducted by Thomas Alva Edison (1847–1931) on his "*electro-motograph*" telephone, designed on the principle of the variation in the resistance of graphite under pressure (transmitter), and a recording device in which a stylus, in contact with a strip of paper moistened with chemical solutions, traced the variations in the electric signal as a function of the transmitted sound (Anonymous [L'Elettricista] 1877f, 289–291). In October, *L'Elettricista* described a significant refinement of Bell's telephone, supplementing the discussion with technical illustrations reproduced from the English journal *Nature*. The innovation consisted of a single reversible instrument that served for both transmission and reception, eliminating the need to employ two separate units. Unlike the earlier battery-fed, electromagnet-based configurations (see Fig. 19, the battery labelled "h"), the apparatus utilised a permanent magnet to induce and detect variable currents and could operate without an external battery (Anonymous [L'Elettricista] 1877g, 311–312). The journal also published extensive accounts of the lectures by William Henry Preece (1834–1913) and Graham Bell himself at the meeting of the *British Association for the Advancement of Science* (Plymouth). Preece retraced the history and development of the invention while Bell illustrated the conceptual origins of his apparatus, derived from the study of the structure of the human ear (Anonymous [L'Elettricista] 1877h, 312–314; Anonymous [L'Elettricista] 1877i, 314–315). The first practical applications were documented both by *L'Illustrazione Italiana* (September 1877) and *L'Elettricista* (October and December 1877) through accounts of the use of the telephone in English mines (Saint-Austell, Liverpool), where vocal communications between galleries and the surface were tested using simple insulated wires. The experiments, conducted in the presence of leading mining engineers and entrepreneurs, demonstrated the clear superiority of the telephone over traditional signalling systems and facilitated its integration with measuring instruments employed for remote monitoring of ventilation. The reliability of transmission, confirmed even with non-specialist personnel, aroused widespread interest, consolidating the image of the telephone as a "*democratic*" technology, destined to revolutionise the safety and efficiency of the mining environment (Anonymous [L'Illustrazione Italiana] 1877c, 202; Anonymous [L'Elettricista] 1877j, 315–316; Anonymous [L'Elettricista] 1877m, 383–384).

Finally, the December 1877 issue of *L'Elettricista* reported the outcomes of the first experimental applications of the telephone in Europe. Tests conducted in Germany, for instance, indicated good results over short distances but showed a marked deterioration of articulated sounds beyond 150 km. Concurrently, the first experiments conducted on submarine cables across the Strait of Dover yielded results deemed promising. In the same issue, the journal analysed the problems of induced currents in parallel wires, along with the first attempts to devise a technical solution. It also featured an account of a lecture given by Bell and the description of a new telephone model developed by the French inventor Gustave Pierre Trouvé (1839–1902). In his lecture, Bell retraced the complex process of refining the apparatus, from the analysis of vowels to the development of undulatory currents and metallic diaphragms. Trouvé, by contrast, presented a new telephone with multiple membranes, designed to sum the generated currents and increase transmission power, thus overcoming limitations over long distances (Anonymous [L'Elettricista] 1877k, 378–380; Anonymous [L'Elettricista] 1877l, 380–383; Anonymous [L'Elettricista] 1877n, 384). This ensemble of contributions constituted the first major "*Italian echo*" of Bell's discovery: a resonance varied in its tones but unified in its capacity to elicit attention, debate, and experimentation. The extraordinary nature of the invention lay not only in the underlying physical principle, but also in the cultural imaginary it activated, generating theoretical reflections, practical applications, and even technological utopias.

5.2 Early Italian experiments: practice and theory (1877–1878)

While reports from abroad fuelled growing interest in Bell's electromagnetic telephone, the Italian technical-scientific community began to engage directly with the new technology in November–December 1877. Milan, Padua, and Turin rapidly emerged as among the earliest centres of reception, adaptation, and experimentation. The telephone thus ceased to be merely an object of admiration and became an instrument of study, verification, and discussion, thereby entering the circuits of practical knowledge and Italian experimental culture.

5.2.1 Milan: practical demonstrations

The first documented public experiment took place in Milan on 29 November 1877 (Fig. 21), at Palazzo Litta, then the headquarters of the *Società per le Strade Ferrate dell'Alta Italia* (Upper Italian Railway Company), on the initiative of the engineer Marco Maroni (1829–1892),[45] director of the *Company's telegraph office*. Using a self-constructed apparatus, Maroni conducted a series of experiments, transmitting musical pieces, words, and phrases over a distance, with a level of intelligibility sufficient to enable recognition of the speakers' voices.

To simulate performance over long distances without resorting to extensive physical cabling, Maroni inserted into the circuit a variable-resistance rheostat manufactured by *Siemens & Halske*: a device that allowed for the replication of signal attenuation equivalent to distances ranging from 100 to 1000 km (Anonymous [Corriere della Sera] 1877a). The demonstrations were repeated on 1 December in the Company's boardroom, before a larger audience (Anonymous [Corriere della Sera] 1877b), and again on 6 December in the same boardroom, in the presence of approximately 40 guests, primarily journalists[46] (Anonymous [Corriere della Sera] 1877c). The demonstration of 1 December was described by Giuseppe Colombo in a letter sent to the Milanese daily journal *La Perseveranza* (4 December 1877), later collected in *Scritti e discorsi scientifici* (Colombo 1934a, 474–475). A more comprehensive technical account was drafted by the telegraph operator Carlo Pianta (dated 10 December 1877) and published in the journal *L'Elettricista* (Pianta 1878, 19–23), although it is not explicitly indicated which demonstration he attended.

Both accounts praised Maroni's technical skill, highlighting his ability to construct a functioning telephone from incomplete sources, namely "*from the imperfect and inaccurate descriptions and the even more imperfect and inaccurate drawings that newspapers have provided of Bell's telephone*" (Colombo 1934a, 474–475). The device, as described by Pianta, consisted of a wooden cylinder approximately 13 cm high, fitted on one side with an acoustic mouthpiece shaped like a hat brim and on the other with a pair of metallic terminals. Inside was a vibrating soft iron diaphragm positioned opposite a copper wire coil with a magnetic core, whose ends were connected to the pair of terminals. The two identical apparatuses were linked by copper wires covered with gutta-percha, an insulating material essential for signal transmission. The system, pocket-sized and completely reversible, functioned as both receiver and transmitter, required no batteries, and relied entirely on magneto-electric induction (Pianta 1878, 20).

The apparatus's performance was judged remarkable. Colombo reported that "*singing, the sound of the flute, the accordion, the drum, phrases spoken even in a low voice reach the ear with surprising clarity*" (Colombo 1934a, 474). Pianta confirmed the timbral fidelity, whilst observing that voices assumed a metallic or nasal tone (Pianta 1878, 21), probably owing to the limited frequency response of the diaphragm.

---

[45] In 1860, Maroni modified the Morse apparatus by replacing the standard soft iron armature with an electromagnetic one. For this technical innovation, he was awarded two silver medals: one in 1861, conferred by the *Royal Lombard Institute of Sciences, Letters and Arts*, and the other in 1872 at the *Moscow Exhibition* (Anonymous [L'Elettricista] 1892, 96).

[46] The daily newspaper *Corriere della Sera* of 15 December 1877 documents that Maroni conducted further "*experiments with his telephone to ascertain the effect of a new modification of the instrument, by which the clarity and intensity of the transmitted sounds are notably increased*" (Anonymous [Corriere della Sera] 1877d).

maggioranza i dissidenti di Napoli, e più specialmente d'impedire che ne esca l'on. Sandonato.

Corriere della città

Il Telefono a Milano. — Ieri sera, 29, presso l'ufficio della Divisione dei telegrafi delle ferrovie dell'Alta Italia furono fatte dal cav. Maroni, capo di quell'ufficio, delle esperienze sul Telefono. L'apparecchio era ideato e costrutto dallo stesso signor Maroni. Ignorasi se sia conforme a quello di Bell, il quale pare non sia entrato ancora nè in Francia, nè in Italia. Le esperienze riescirono ottimamente. Non solo i suoni e le parole, ma interi motivi di musica e intere frasi come erano trasmessi venivano ricevuti, distinguendo anche la persona che li pronunciava. La trasmissione si faceva ad una distanza abbastanza considerevole, e coll'apparecchio Siemens le resistenze furono ragguagliate a distanze di 100 e fino a 1000 chilometri. L'impressione che se ne riceveva era quella che i suoni giungessero da distanze indefinite, e che fossero ridotti a dimensioni infinitesimali. Ritorneremo su questo importante e curioso argomento.

Onorificenza. — Il nobile cav. Giovanni Casati, maestro dirigente la nostra Accademia di ballo, venne nominato socio onorario del Circolo del progresso per le

Fig. 21 First public telephone experiment in Milan. Excerpt from *Corriere della Sera*, 30 November 1877, reporting Marco Maroni's demonstration of voice and music transmission using a self-built apparatus and Siemens resistances simulating long-distance lines. Source: Courtesy of *Historical Archive*, *Corriere della Sera* (*Fondazione Corriere della Sera*), Milan

The simulated long-distance tests were also significant. Colombo reported not having noticed "*the slightest difference in intensity [...] whilst with a rheostat the line resistance was gradually varied from 150 to 1500 km*" (Colombo 1934a, 474). In a particularly evocative demonstration, Maroni connected twelve people in series in the telephone circuit, further increasing the overall resistance, which Pianta estimated at approximately 800 km. Nevertheless, the transmitted sound—particularly the trill of a railway whistle—remained clearly perceptible, albeit somewhat attenuated (Pianta 1878, 22). Colombo published a second contribution on 13 December 1877 in *Il Politecnico* (Colombo 1877b, 685–688; Colombo 1934b, 476–482), presenting a synthesis of Bell's invention and a detailed description of the technical functioning of the telephone constructed by Maroni. This was accompanied by an explanatory illustration (Plate XXXIII, see Fig. 22), probably drawn by Maroni himself and considered the

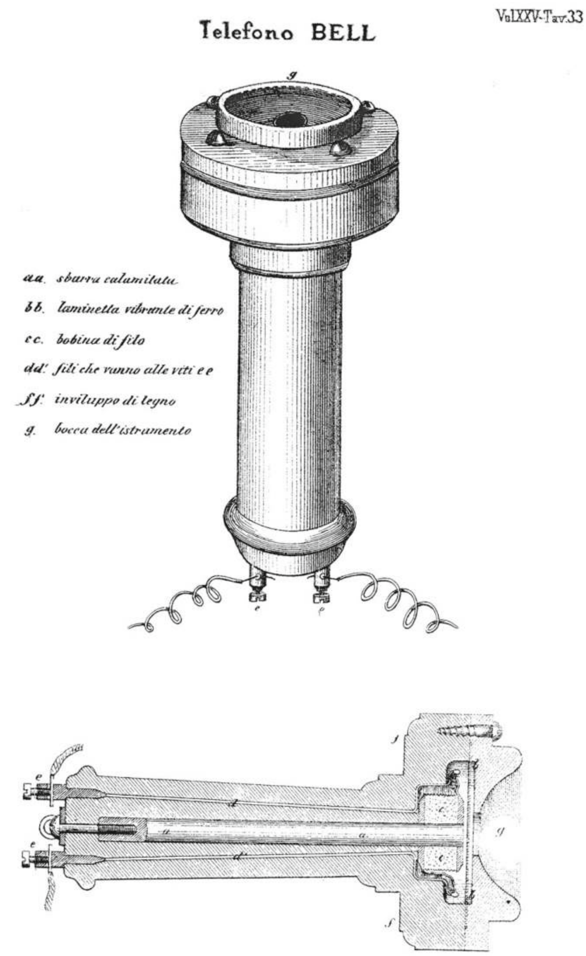


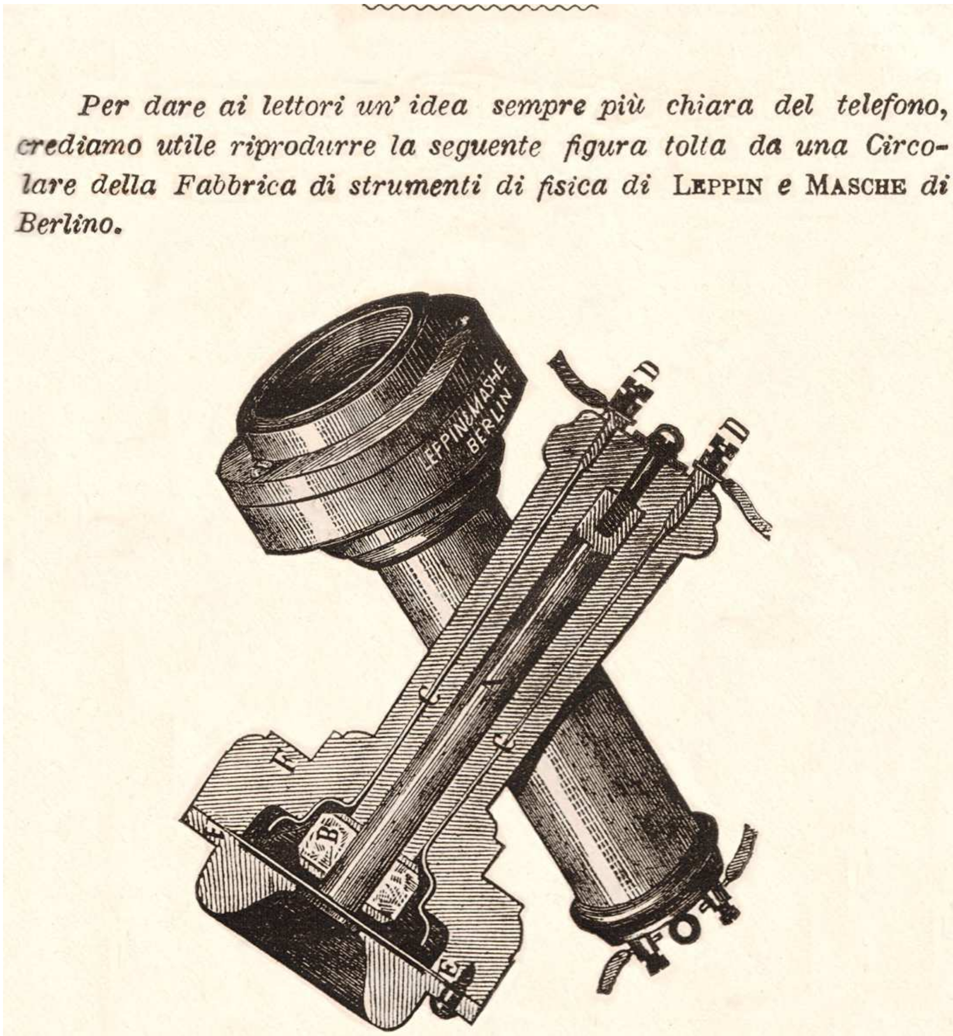
Fig. 22 Homemade Bell telephone. Illustration published by Colombo on 13 December 1877 and attributed to Marco Maroni. It is the earliest known technical depiction published in Italy of a homemade Bell-type telephone, showing both a frontal and longitudinal section of the electromagnetic induction device. Source: (Colombo 1877b, Plate XXXIII), Author's private collection (scan by the author)

earliest technical representation published in Italy of a self-constructed Bell-model apparatus.[47] This illustration (Fig. 22) presents a longitudinal cross-sectional view and a frontal view of the instrument.

In the cross-section, the vibrating diaphragm, the permanent magnetic bar, and the copper wire coil wound near the pole were clearly visible: a configuration that exemplified the principle of electromagnetic induction (Colombo 1934b, 478). The frontal view highlighted the "*hat-brim-shaped*" mouthpiece also mentioned by Pianta (Pianta 1878, 20), as well as the simplicity of the circuit: two binding posts, one designated for earth and the other for the line, completed the connection between the twin instruments. The apparatus, as previously described by Pianta, was completely reversible and required no galvanic batteries. Colombo emphasised its portability—it weighed little more than a common pocket watch—and noted that *Siemens & Halske* in Berlin marketed an analogous model, "*at fifteen lire per pair, with twenty-five metres of wire*", a price judged competitive when compared with Morse systems (Colombo 1877b, 687).

In January 1878, *L'Elettricista* published a new image of Bell's telephone, taken from a promotional circular of the Berlin manufacturers Georg Leppin (1835–1892) and Louis Masche (1841–1904). The illustration (Fig. 23) presented a cross-sectional view and an external view, accompanied by a brief description. It depicted a model already in industrial production, manufactured in fir-wood, which was more compact and refined, equipped with two terminals and a simple frontal opening for speaking or listening.

[47] On 23 December 1877, the *Corriere della Sera* published an article titled "*Il telefono*" which featured an image of the apparatus substantially identical to that shown in plate XXXIII, albeit lacking the sectional view.



Per dare ai lettori un' idea sempre più chiara del telefono, crediamo utile riprodurre la seguente figura tolta da una Circolare della Fabbrica di strumenti di fisica di Leppin *e* Masche *di Berlino.*

Fig. 23 Sectional and external view of a Bell telephone manufactured by the firm *Leppin & Masche* in Berlin. The illustration, reproduced from a commercial circular, was published in *L'Elettricista* (January 1878) with a brief accompanying description. Source: (Anonymous [L'Elettricista] 1878b, 23), Author's private collection (scan by the author)

Maroni's initiative with the self-constructed prototype likely represented a crucial stimulus for the emergence of local entrepreneurial activities. In Milan, the brothers Edoardo and Emilio Gerosa, proprietors of an *electro-telegraphic* workshop,[48] were the first to manufacture Italian telephones under Bell licence. The Gerosa brothers, who had represented Italy at the *International Exhibition* of Philadelphia in 1876 (Department III–Education and Science, Class: *Scientific and Philosophical Instruments and Methods*), exhibiting telegraphic instruments (Anonymous 1876, 365), had the opportunity to establish contact with Alexander Graham Bell. Upon their return to Milan, they obtained the licence to commercialise the Bell telephone. Their pioneering public experiments with Bell-system telephones, of their own manufacture, commenced in December 1877. On 23 December, the Gerosa brothers organised an initial public experiment at *Palazzo Marino* (then Milan's Town Hall), connecting the *Municipal Council Chamber* with the tower of *Piazza Mercanti* via the electric clock wire over a distance of approximately one kilometre. The experiment, conducted in the presence of municipal authorities, officials, and numerous citizens, achieved "*excellent results*" and enabled the clear transmission of singing, whistling, and shouting, eliciting congratulations from those present (Anonymous [Corriere della Sera] 1877e; Anonymous 1877c, 870). Building upon this success, on 26 December, the Gerosa brothers established a new connection, again utilising the electric clock wire, between the fire guard at *Palazzo Marino* and the Fire Station at *San Gerolamo*. This experiment also yielded "*positive results*", ensuring the clear transmission of various commands and even trumpet calls (Anonymous [Corriere della Sera] 1877f). An engraving published in the weekly *L'Illustrazione*

[48] The workshop was founded in Milan in 1873, specialising in the construction of telegraphic instruments and electric clocks.

Fig. 24 Telephone demonstration in Milan at Palazzo Marino's fire district, 30 December 1877. Source: (Anonymous [L'Illustrazione Italiana] 1878, 24), Author's private collection (scan by the author)

Italiana (Fig. 24) documents a further telephonic demonstration on 30 December 1877, previously announced by the newspaper *Corriere della Sera* on 27 December 1877.

The success of these preliminary trials attracted the interest of the military authorities, who were eager to verify for themselves the potential of the new technology. On 2 January 1878, at their invitation, the Gerosa brothers repeated the experiment of 26 December, this time in an official capacity, in the presence of representatives of the *Third Military Division*, including Lieutenant General Dezza and Colonel Besozzi. The connection was established between the fire guard post at *Palazzo Marino* and the *San Gerolamo* Barracks, utilising the telegraph wire used for fire communications, over an estimated distance of approximately three kilometres. Military orders, trumpet calls, and even the sound—though faint—of a small carillon were transmitted with clarity (Anonymous [Corriere della Sera] 1878).

5.2.2 Padua: experimental practice and technical refinement

While the experiments conducted in Milan by Marco Maroni and the Gerosa brothers represented the first practical demonstrations of the telephone in Italy, interest in Padua shifted to a more theoretical and systematic line of enquiry. Here, the physicist Francesco Rossetti (1833–1884), then Professor of *Experimental Physics* at the University of Padua, adopted a methodical approach, combining theoretical analysis and experimental verification to systematically probe the potential and limitations of the new technology. This interest in what he termed an "*extraordinary invention*" took concrete form on 16 December 1877, when, at a session of the *Reale Istituto Veneto di Scienze, Lettere ed Arti* in Venice, he presented two pairs of Bell telephones, manufactured in Berlin by the firm *Leppin & Masche*[49] (Anonymous 1878a, 218), stating that he had received them only two days earlier. In his presentation, subsequently published in the Proceedings of the *Veneto Institute*, Rossetti illustrated the physical principles of sound and its transmission, drawing on an inaugural lecture delivered on 19 November 1877 to open

[49] By the end of 1877, the firm *Leppin & Masche* was among the few companies marketing the Bell telephone in Italy, as demonstrated by Rossetti's purchase and by the publication, in January 1878, of a related illustration in *L'Elettricista*.

the academic courses at the University of Padua. In this theoretical introduction, Rossetti elucidated how Bell's telephone was founded upon the principle of reversibility (functioning as both transmitter and receiver) and upon variations in the magnetic field, which enabled the reproduction of the human voice with all its modulations. He was also among the first in Italy to identify its limitations: namely the weakness of the currents and the instrument's sensitivity to interference. Having concluded the theoretical exposition, Rossetti focused on the technical characteristics of the apparatuses he had presented, highlighting how they already incorporated certain modifications compared to the initial models: the "*soft iron appendage*" had been eliminated, and the copper wire was wound directly around one of the magnet poles.

As a demonstration of the efficacy of the apparatus, Rossetti reported on experiments conducted the previous day at the University of Padua, during which he had verified the faithful transmission of sounds and words even with resistances as high as "10,000 Siemens units"—equivalent to more than one thousand kilometres of ordinary electric wire. To conclude his presentation, Rossetti conducted practical demonstrations before the assembled audience, enabling the Institute members to witness directly the functioning of the new technology (Rossetti 1878a, 291–297). In the subsequent weeks, Rossetti's experimental investigations extended beyond laboratory demonstrations. Commencing in January 1878, he conducted a systematic series of trials on operational telegraph lines, initially between Padua and Venice and subsequently on the Cittadella–Padua route (33 km) and the Padua–Venice section (exceeding 40 km), utilising telegraph wires made available by the *Directorate-General of Telegraphs*. In these trials, Rossetti implemented several innovative configurations. He employed a double telegraph wire configuration, thereby eliminating the earth connection, which he regarded as a source of interference and signal attenuation. This solution significantly enhanced transmission quality by reducing distortions. To amplify the signal, he introduced induction coils (Ruhmkorff coils), connected in series along the telephone lines. In this configuration, the telephone transmitter was connected to the primary circuit of an induction coil and the receiver to the secondary circuit. The electromagnetic induction thus generated enabled voltage amplification of the signal, ensuring clear communication even across extended distances. His trials demonstrated that the optimal configuration comprised multiple telephones connected in parallel, a solution that enhanced signal perception and enabled more stable communication. A principal advantage of this configuration was the reduction of "*crackling*" in telephone conversations, a parasitic noise caused by induced currents in adjacent telegraph wires, which interfered with voice transmission. Whilst the induction coils did not entirely eliminate this crackling, they significantly attenuated its effect. Rossetti observed that over extended distances, such as the Padua–Venice section, communication remained clear and stable for two consecutive hours without necessitating any raising of the voice (Rossetti 1878b, 351–353; Rossetti 1878c). Rossetti further conducted experiments investigating the possibility of transmitting sounds with diaphragms other than the standard iron one. In a communication dated 10 February 1878 (Rossetti 1878b), he had already reported sound transmission by substituting the iron diaphragm with one made of copper, whilst observing a drastic reduction in induced current intensity and the absence of any effect with non-conducting diaphragms in that initial phase. Pursuing these investigations, as presented on 27 February (Rossetti 1878d), he confirmed word reception with copper diaphragms and musical sound transmission even when both telephones were equipped in this way. Having become aware of analogous observations by Blyth, reported by Tait—who used even cardboard or other elastic insulating substances—Rossetti verified the possibility of perceiving sounds with a receiving telephone entirely devoid of a diaphragm. He identified the key to this phenomenon in the potential mobility of the electromagnetic coil relative to the permanent magnet: sound waves could induce minute relative displacements of the coil itself, thereby generating the currents necessary for transmission—an effect distinct from, and occasionally cumulative with, that produced by metallic diaphragm vibrations. This intuition was corroborated by the observation that a telephone with an accidentally mobile coil exhibited behaviour distinct from that of one with a fixed coil, and by the subsequent inoperability of the former once the component's stability was secured (Rossetti 1878d, 661–665).

5.2.3 Turin: experimental practice and theoretical analysis

While Francesco Rossetti combined theory and experimentation in Padua to investigate the physical principles of Bell's telephone, Galileo Ferraris (1847–1897) pursued an equally rigorous approach in Turin, rooted in the traditions of electrical engineering and mathematical analysis. An engineer, mathematical physicist, and Professor of *Technological Physics* at the *Reale Museo Industriale Italiano* (*Royal Italian Industrial Museum)*, Ferraris not only analysed the telephone's functioning but transformed it into an instrument of scientific research, laying the foundations for the future development of Italian electrical engineering. He presented his research on the telephone on two closely following occasions: on 27 January at a session of the *Turin Academy of Sciences* and on 2 February at a conference held at the *Society of Engineers and Industrialists* of Turin, addressing the subject from complementary perspectives. In his communication to the *Academy of Sciences*, Ferraris presented a novel experimental demonstration of Hermann von Helmholtz's principle concerning the timbre of sounds (what Ferraris termed "*tempera dei suoni"*), according to which the quality of a sound depended exclusively on the relative intensity of its harmonic components and not on their phases. He demonstrated that, although the phases of harmonics were modified without altering their amplitudes, the perception of timbre remained unchanged. Helmholtz had already demonstrated this principle utilising complex apparatuses comprising magnetised tuning forks and acoustic resonators; however, such instruments were expensive, delicate, and available to only a few laboratories. Ferraris proposed an elegant and effective alternative. He employed Bell's telephone, an inexpensive instrument undergoing rapid dissemination, not merely as a communication device but as a genuine scientific detector for acoustic analysis: a form of "*electromagnetic stethoscope*". The experiment consisted of connecting a transmitting telephone to two identical receiving telephones, each connected through a distinct configuration: the first was connected directly to the principal circuit, while the second utilised inductive coupling achieved by winding two wire spirals, one within the other. In the direct circuit, the electric current transmitted sound signals directly, while in the inductive circuit, the generated current was proportional to the time derivative of the original current, thereby modifying the phases of the signal's harmonic components. In modern terms, the inductively coupled receiver preserved the same frequency spectrum as the direct receiver, but progressively emphasised higher-order harmonics and, crucially, imposed a uniform phase shift on all components. Ferraris tested the transmission of vowels and musical notes through both circuits, selecting sounds whose timbre was determined by a few dominant harmonics.

When vowels were uttered before the transmitting telephone, these were recognised without hesitation by both the direct receiver and the inductively coupled receiver, confirming that phase displacement did not alter their perceptual quality (Ferraris 1878a, 287–298).

At the conference on 2 February (Fig. 25), Ferraris developed his analysis of Bell's telephone, elucidating its functioning as a bidirectional converter between sound vibrations and electrical signals.

He began with an analysis of the physical and physiological nature of sound, clarifying how each sound wave, however complex, was decomposable into a series of elementary oscillations, or "*pendular sounds*", in accordance with Ohm's acoustic law. The human ear, unlike the eye, which perceives the waveform in its entirety, executes an "*unconscious*" mechanical decomposition of such components. This analysis, grounded in the "*anatomical structure of the organ*", enables the distinction between sound intensity (determined by oscillation amplitude), its pitch (related to period), and, crucially, its timbre (*tempera*), defined by the relative pitches and intensities of the individual component pendular sounds. This analytical capacity of the auditory organ, whose mechanics were elucidated by Helmholtz, resides in the transverse fibres of the basilar membrane within the cochlea: these, comparable to harp strings of varying length, vibrate selectively in resonance with the frequencies of pendular sounds, thus enabling the brain to decode the complex harmonic structure of perceived sound. Turning to the telephone, Ferraris described with precision the electromagnetic functioning of Bell's apparatus, demonstrating mathematically how air pressure variations acting on the soft iron diaphragm of the transmitting telephone generated, through induction, currents proportional to the velocity of the diaphragm's displacement. These currents, propagating along the line, produced synchronous variations of magnetic attraction in the receiving telephone, which induced movements in the second diaphragm that reproduced the original sound. Ferraris formulated the equations correlating the transmitting diaphragm's movement to the induced currents and these latter to the receiving diaphragm's movement, demonstrating that, although the received waveform differed from the originally transmitted one, it preserved the same harmonic components, though with different relative intensities. In the experimental section, crucial for corroborating the theory, Ferraris utilised the high-resistance telephones that the engineer Marco Maroni had skilfully constructed. With these instruments, he demonstrated that voice could be transmitted clearly even across simulated lines of considerable length, equivalent to over ten thousand kilometres of telegraph wire, by inserting variable resistances into the circuit. In these experiments, he observed that the telephone tended to emphasise the higher harmonics relative to the lower fundamental sounds, imparting to the transmitted voice a "*more brilliant and metallic timbre*". By varying the circuit resistance with a rheostat, he confirmed that this timbral alteration was not attributable to the material of the vibrating membrane, but rather to the very nature of electromagnetic transduction, which was more sensitive to the rapid variations of magnetic field associated with high-frequency sounds. Ferraris concluded his analysis by highlighting certain practical limitations of the telephone, particularly its excessive sensitivity to electromagnetic interference emanating from adjacent telegraph lines (Ferraris 1878b, 53–78). A detailed account of this conference, drafted the following day (3 February 1878) by the Piedmontese physicist Giovanni Luvini (1818–1892), was published in *L'Elettricista* (Luvini 1878).

5.3 Public engagement and popularisation

The intense debate surrounding these new experiments and theories prompted several Italian physicists to write popular accounts of the telephone. In February 1878, Pietro Blaserna, Professor of Experimental Physics at the University of Rome, published an article in the Florentine fortnightly journal *Nuova Antologia* that combined scientific rigour with attentiveness to the demands of public outreach. Blaserna analysed the telephone, highlighting the transition from initial scepticism—which cast it as an "*American deception*"—to widespread acceptance secured through convincing demonstrations, and situated Bell's invention within the earlier tradition in acoustics.

53

SUL TELEFONO DI GRAHAM BELL

Conferenza fatta nella Società degli Ingegneri e degli Industriali

DI TORINO

nella seduta del 2 febbraio 1878

dell'Ingegnere Professore GALILEO FERRARIS

Un benevolo voto del nostro Comitato stabilì che in questa adunanza io intrattenessi la Società sul Telefono dell'americano GRAHAM BELL. Ubbidiente a questo voto, io mi propongo: 1° di spiegare ai miei colleghi, come i suoni e le parole si possano trasmettere fra due luoghi lontani, congiunti fra loro per mezzo di un semplice filo telegrafico; 2° di ricercare con loro le leggi di questa trasmissione, e di indagare le relazioni che sussistono tra i suoni prodotti in una stazione, e quelli ricevuti col telefono nella stazione compagna.

Per riuscire nel mio intento, egli è naturale che io cominci a ricordàre in che cosa consistano i suoni articolati: soltanto quando conosceremo ciò che si vuole trasmettere, noi potremo studiare i mezzi di trasmissione.

Il suono, prendendo la parola nel suo senso più generale, e comprendendo con questa denominazione tutto ciò che può essere sentito dall'orecchio, è l'effetto di una rapida successione di condensazioni e di rarefazioni, di aumenti e di diminuzioni di pressione nell'aria, che riempie il *foro uditivo*. Invece delle variazioni di pressione possiamo anche considerare gli spostamenti delle particene dell'aria, dei quali quelle sono la conseguenza, e dire che

Fig. 25 Frontispiece of Galileo Ferraris's lecture *Sul telefono di Graham Bell. Conferenza fatta nella Società degli Ingegneri e degli Industriali di Torino* [*On Graham Bell's telephone. Lecture delivered at the Society of Engineers and Industrialists of Turin*], 2 February 1878. Source: Courtesy of *Politecnico di Torino Library System*, *DIGIT digital repository*

He maintained, however, a cautious stance on the potential for large-scale application, citing obstacles such as coexistence with telegraph lines (interference) and the necessity for silent environments. He further criticised the tendency to disseminate scientific news through non-specialist daily newspapers rather than technical journals, thus highlighting a key epistemological tension of the period: the growing divide between expert knowledge and public debate (Blaserna 1878, 687–696). A few days later, on 20 February, the physicist Pietro Maria Garibaldi (1823–1902), Professor of *Experimental Physics* at the University of Genoa, delivered a lecture at the *Society of Scientific Readings and Conversations* in Genoa, where he explained the telephone through practical experiments and a historical overview. Garibaldi situated Bell's device within the European scientific tradition (Volta, Ørsted, Arago), presenting the telephone as a symbol of the technological achievements of the nineteenth century (Garibaldi 1878, 162–180).

This dual approach, at once critical and celebratory, reflected the duality of scientific popularisation in the post-Unification era: on the one hand, the demand for methodological rigour, and on the other, the desire to legitimise technological progress as a central element of national and civic identity.

5.4 Serpieri and the telephone: experimental investigations and the epistemology of acoustic perception

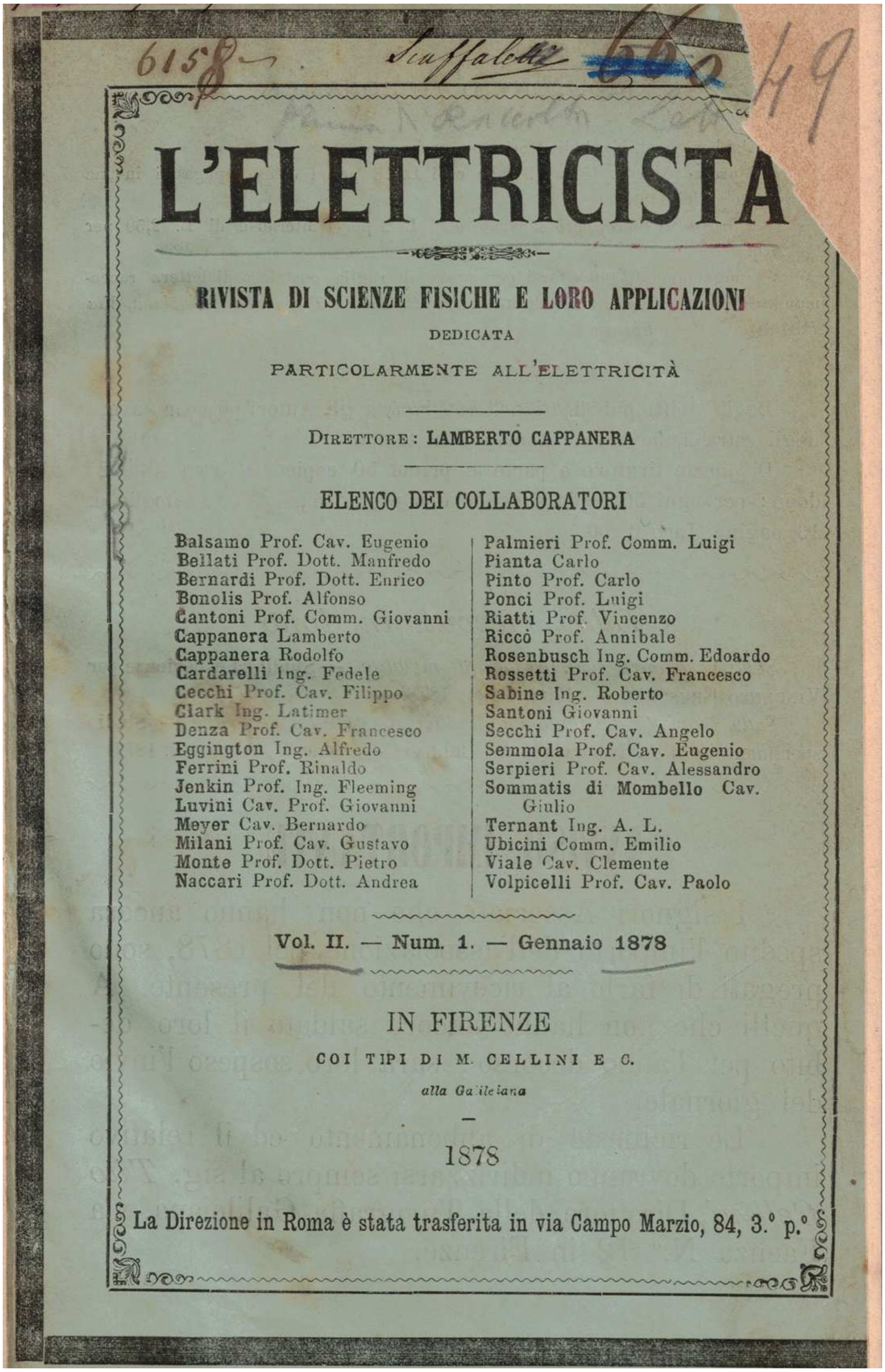
In the early months of 1878, the journal *L'Elettricista* featured contributions from international figures such as the British engineers Latimer Clark and Fleeming Jenkin—pioneers of nineteenth-century electrical engineering and telecommunications—alongside a substantial group of prominent Italian men of science. Among these were Angelo Secchi, Francesco Denza (1834–1894), Luigi Palmieri (1807–1896), Giovanni Luvini, Giovanni Cantoni (1818–1897), Andrea Naccari (1841–1926), Rinaldo Ferrini, Paolo Volpicelli (1804–1879), and Francesco Rossetti (Fig. 26). Within this context of scientific exchange and specialist dissemination, Alessandro Serpieri also began to contribute to *L'Elettricista*, a periodical that served as his principal source of information on the new telephone apparatus, its ongoing technical developments, and the experiments conducted in Italy and abroad.

During 1878, the journal hosted an intense debate on the telephone, fuelled by numerous theoretical and experimental contributions. Serpieri contributed to this scientific discussion through two complementary pieces published in the early months of the year: a letter addressed to Lamberto Cappanera, dated 8 February 1878, in which he critically analysed the limitations and potential of the device with particular attention to the phenomenology of auditory perception (Serpieri 1878a); and a second letter, dated 11 March 1878, sent to the engineer Rinaldo Ferrini and subsequently published in the *Proceedings of the Royal Lombard Institute of Sciences and Letters*, in which he examined in detail both the functioning of the apparatus and its experimental trials (Serpieri 1878b). Through these two publications, Serpieri outlined a methodologically novel approach based on the systematic analysis of the new instrument, integrating controlled phonetic experiments, theoretical considerations, and experimental verification. Read through the lens of the epistemology of the province, these two interventions show how a locally situated experimental practice, grounded in the apparatus available in Urbino, could generate original analytical results while remaining embedded in supra-local circuits of information, discussion, and validation.

5.4.1 The cognitive and phonetic perception of the telephone

In the letter of 8 February (Fig. 27), after personally experimenting with the telephone at the Cabinet of Physics of the University of Urbino, Alessandro Serpieri, with characteristic intellectual rigour, posed a searching question: "*Is the telephone truly as perfect and marvellous as it appears to those who use it and listen to its transmissions?*" (Serpieri 1878a, 95). With this query, he did not intend to question the technical components of the apparatus or any mechanical defects, but rather its apparent fidelity of vocal reproduction, which he found "*superior to all expectation*".

This very perfection, perceived as almost suspect, prompted him to formulate a refined epistemological critique: his doubt arose not from evident errors, but from its very effectiveness. The apparatus functioned too well, to the point of raising questions concerning the respective roles of the device and the human interpreter. Serpieri thus addressed the problem of the telephone's acoustic fidelity from a perspective that was not purely technical, but profoundly psychological and cognitive. "*This device*", he noted with precision, "*works all too effectively [...] I fear it might be credited with merits not its own*". This insight led him to formulate a central hypothesis: much of the precision attributed to the apparatus was in fact due "*to the skill of the listener*". According to Serpieri, the recipients of a telephone message were no mere passive receivers, but contributed actively through "*their own discernment, [...] the influence of their own cognitive habits, [and] intellectual capacities to lend precise and correct form to telephonic sounds*". From this framework there emerges an unusually explicit nineteenth-century analysis of technologically mediated phonetic perception, which anticipates by decades twentieth-century investigations into active perception, particularly in the fields of cognitive psychology and linguistics. The listener, intelligently processing indistinct sounds and interpolating missing ones, in effect decodes and interprets them, and "*completes and perfects the machine's dictation*".


L'ELETTRICISTA

RIVISTA DI SCIENZE FISICHE E LORO APPLICAZIONI

DEDICATA

PARTICOLARMENTE ALL'ELETTRICITÀ

DIRETTORE: LAMBERTO CAPPANERA

ELENCO DEI COLLABORATORI

Balsamo Prof. Cav. Eugenio
Bellati Prof. Dott. Manfredo
Bernardi Prof. Dott. Enrico
Bonolis Prof. Alfonso
Cantoni Prof. Comm. Giovanni
Cappanera Lamberto
Cappanera Rodolfo
Cardarelli Ing. Fedele
Cecchi Prof. Cav. Filippo
Clark Ing. Latimer
Denza Prof. Cav. Francesco
Eggington Ing. Alfredo
Ferrini Prof. Rinaldo
Jenkin Prof. Ing. Fleeming
Luvini Cav. Prof. Giovanni
Meyer Cav. Bernardo
Milani Prof. Cav. Gustavo
Monte Prof. Dott. Pietro
Naccari Prof. Dott. Andrea
Palmieri Prof. Comm. Luigi
Pianta Carlo
Pinto Prof. Carlo
Ponci Prof. Luigi
Riatti Prof. Vincenzo
Riccò Prof. Annibale
Rosenbusch Ing. Comm. Edoardo
Rossetti Prof. Cav. Francesco
Sabine Ing. Roberto
Santoni Giovanni
Secchi Prof. Cav. Angelo
Semmola Prof. Cav. Eugenio
Serpieri Prof. Cav. Alessandro
Sommatis di Mombello Cav. Giulio
Ternant Ing. A. L.
Ubicini Comm. Emilio
Viale Cav. Clemente
Volpicelli Prof. Cav. Paolo

Vol. II. — Num. 1. — Gennaio 1878

IN FIRENZE

COI TIPI DI M. CELLINI E C.

alla Galileiana

—

1878

La Direzione in Roma è stata trasferita in via Campo Marzio, 84, 3.° p.°

Fig. 26 Title page of the 1878 annual volume of *L'Elettricista* (compiling the monthly issues), edited by Lamberto Cappanera. The page lists the journal's contributors, including Alessandro Serpieri alongside other prominent Italian and international scientists. Source: (Anonymous [L'Elettricista] 1878c), Author's private collection (scan by the author)

IL TELEFONO.

Carissimo sig. Cappanera.

Mentre da tutte le parti, nel nuovo e nel vecchio mondo, si scrivono elogi del Telefono, permettete che io muova qualche dubbio sulla sua reale perfezione, come strumento sonoro destinato a farsi l'eco fedele della parola.

È egli il telefono un istrumento così perfetto, come apparisce a chi l'usa, a chi ne ascolta le maravigliose trasmissioni? Siffatta questione io feci subito a me stesso, appena l'ebbi provato: e, cosa curiosa! io mi mossi a dubitare della singolare e sorprendente maestria dell'apparecchio, non già perchè lo scoprissi qualche volta in difetto, ma invece appunto perchè lo trovai sempre fornito di una esattezza e fedeltà superiori ad ogni aspettazione. Costui, io diceva fra me stesso, è troppo bravo, è troppo preciso nel copiare e riprodurre ogni minimo elemento della parola: è impossibile che si animi di tante correnti distinte quante sono le vibrazioni tutte che concorrono a formare la parola: non vorrei che si facesse bello di qualche abilità non sua e gli elogi non fossero tutti da darsi alla prontezza e fedeltà dell'induzione magnetica.

Con questi dubbi nella mente io venni a sospettare che gran parte del merito dell'apparecchio fosse dovuta all'abilità dell'ascoltante. Forse l'ascoltante non è al tutto passivo nel ricevere il dispaccio: c'è bisogno che concorra col suo giudizio, colla potenza delle sue abitudini, colla virtù della mente a dare precisa e giusta forma ai suoni telefonici: egli dovrà leggerli, interpretarli, come si legge una scrittura, che abbia, sì, molti caratteri ben scolpiti, ma confusi con altri o dubbi, o appena visibili, o a

Fig. 27 First page of Alessandro Serpieri's letter to Lamberto Cappanera on the telephone (8 February 1878), published in *L'Elettricista*. Source: (Serpieri 1878a, 95), Author's private collection (scan by the author)

To test this thesis empirically, Serpieri designed a series of linguistic experiments under controlled conditions intended to reduce the listener's interpretative contribution. He transmitted "*a language unknown to the listener*" and words "*novel and devoid of meaning*", such as Italian words read in reverse. The results unequivocally demonstrated the instability of telephonic listening in the absence of semantic familiarity. Indeed, in the reception of inverted Italian words, Serpieri documented "*the maximum uncertainty in identifying the value of numerous syllables*", with frequent letter exchanges between acoustically similar or phonologically contiguous phonemes.[50] Significantly, such errors exhibited a statistical regularity, including the confusion between "l" and "r", "e" and "a", or "f" and "s", which Serpieri documented with precision (Fig. 28, top). Similarly, when German words were transmitted to subjects with no knowledge of the language, a faithful phonetic transcription was never achieved; conversely, "*different subjects perceived, or at least believed they perceived, the transmitted sounds differently*" (Serpieri 1878a, 96), demonstrating the "*considerable*" subjective component in the interpretation of telephonic speech (Fig. 28, bottom). Such experiments constitute a remarkably early and methodical inquiry into linguistic perception through the telephone, grounded in controlled phonetic testing and sustained reflection on the listener's interpretative activity.

The difficulties encountered contrasted markedly with the fluidity of conversations in Italian or with the transmission of musical passages, which Serpieri evaluated as possessing "*extraordinary perfection*".

Based on these observations, Serpieri formulated three operational conclusions that qualified the uncritical enthusiasm for the telephone: firstly, the apparatus, in its then-current technical configuration, could not "*be converted into a writing apparatus*", highlighting an intrinsic technological limitation; secondly, the telephone operator must possess active linguistic and cognitive skills, unable merely to record sounds mechanically, but required to comprehend and interpret them through their own intelligence; this made it impossible to manage languages unknown to them; thirdly, even within their own language, margins of semantic ambiguity persisted, particularly in the transcription of proper names, whose correct interpretation could not be deduced from context.

Serpieri also added a theoretical consideration of broader scope: telephonic communication emerged as a reciprocal and dynamic process between technology and the human mind, wherein the machine functioned as an imperfect mediator and the listener's perception assumed a decisive role in completing the message. This critical analysis formed part of a broader reflection that, while appreciating Bell's invention, explored its functional, cognitive, and epistemological limitations, making an original contribution to the contemporary scientific debate. Serpieri's originality lay in his displacement of analytical attention from the machine to the mind of the listener, raising a problem that can be compared, retrospectively, with themes later developed within the cognitive sciences—without implying that Serpieri possessed those twentieth-century conceptual frameworks. A succinct summary of his thought is found in the letter's conclusion: "*the telephone is not in itself a perfect instrument, and much of the performance attributed to the apparatus truly belongs to the listener—to the mind's faculty that gathers, judges, composes, interprets, corrects, and completes the sounds heard*" (Serpieri 1878a, 97). This remark foregrounds the listener as an active component in the communicative circuit—an intuition that can be placed in heuristic dialogue with later twentieth-century discussions of information, feedback, and mediated communication, without implying influence or direct genealogy (Shannon 1948a, 1948b; Wiener 1961; Licklider 1960; Mills 2011, 78–80).

5.4.2 Sound mechanics and technical experimentation

At the meeting held on 21 March 1878 at the *Royal Lombard Institute of Sciences and Letters* in Milan, the Milanese engineer Rinaldo Ferrini presented, on behalf of Alessandro Serpieri, a corresponding member of the Institute, a paper entitled "*On Experiments with Bell's Telephone*".[51] This communication, sent from Urbino on 11 March 1878, marked a significant methodological shift in Serpieri's approach to the telephone: whereas the previous article had centred on the epistemological and interpretative dimensions of sound, Serpieri now concentrated on an experimental analysis of the device, investigating its physical functioning, including the conversion of sound into electrical effects and the underlying electromagnetic phenomena (Serpieri 1878b). For these experiments, he employed a set of Bell telephones purchased from the Loescher firm in Turin (Fig. 29), which he believed to be

[50] The observed phonetic errors (such as the confusion between plosive and fricative consonants or between contiguous vowels) reflected patterns typical of Italian phonology. Serpieri's experimental methodology—based on intersubjective comparison, manipulation of semantic significance, and reception variability—is notable for its anticipation of future studies on categorical perception of language. It revealed how listeners tend to resolve ambiguous signals by drawing upon their established cognitive and linguistic frameworks.

[51] The descriptive account of the meeting specifies that, at the conclusion of Ferrini's reading, the Institute's secretary Camillo Hajech presented "*some of his own particular observations on the same subject*" (Anonymous 1878b, 180).

e spesso inteso per *a* e viceversa
tr per *cr, dr, pr, fr* »
n per *m* »
s per *f* »
et per *eb* — *el* per *en*
d per *t* e viceversa
ic per *ip*
dra, tra per *gra*
ti per *chi*
at (finale) per *ac*
i per *u* e viceversa
l per *r* »
o per *e* »
v per *b* »

ich	era da uno	inteso	per *if* e da altri per *ir*.
habe	»	»	ora per *fade*, ora per *ade*.
wichtiges	»	»	per *vistiges* o per *irtiges*.
gerecht	»	»	per *geracht*.
geschlafen	»	»	per *teslafen* o per *geflaghen*.

Fig. 28 Above: main phonetic alterations observed by Serpieri in the reception of Italian words read in reverse via telephone, including frequent substitutions between phonetically similar sounds (e.g. e/a, tr/cr, n/m). Below: examples of German words misheard by Italian listeners, illustrating perceptual instability in the absence of linguistic familiarity. Source: (Serpieri 1878a, 96–97), Author's private collection (scan by the author)

of German manufacture, a detail that he explicitly noted.[52] The paper consisted of a series of seven experimental protocols comprising a systematic investigation of the telephone's electro-acoustic properties.

[52] Serpieri's supposition proved correct. Ermanno Loescher (1831–1892) began his publishing activity in Turin in 1861 as a supplier of books to the *Royal House*, the *Academy of Sciences*, and other Turinese scientific institutes. In addition to books, he occasionally supplied teaching aids to schools and technical institutes, but operated primarily as a retailer of products from foreign firms, particularly those of German origin.

Fig. 29 Set of Bell telephones purchased by Serpieri, now preserved at *PLUMST*. In the centre, the physics textbook by Luigi Palmieri is open to the section on Bell's apparatus (Palmieri 1883, 352–353). The four black-lacquered instruments on stands are most likely those acquired from the Loescher firm in Turin and used in early 1878 for experiments along the Pesaro–Macerata Feltria telegraph line. Source: *PLUMST Collection*, University of Urbino Carlo Bo (photo by the author)

Fig. 30 Detail from the official map *Telegrafi italiani*. *Carta delle linee e degli uffici dello Stato* (Rome, January 1878), showing the telegraph lines used by Serpieri in his 1878 telephone experiments: Pesaro–Urbino–Macerata Feltria (118 km), Urbino–Macerata Feltria (56 km), and Urbino–Sant'Angelo in Vado (29 km). Red place-names added by the author for clarity. Sources: Courtesy of *TIM Historical Archive*, Turin; (Antinori 1963, Tav. I, p. 16)

The investigation began with experiments conducted along three telegraph lines in central Italy, followed by laboratory trials conducted "in-house" (at a distance of 100 m) to examine more thoroughly the "*theoretical principles of this remarkable apparatus*". The three telegraph lines, of varying length, were as follows: Urbino–Sant'Angelo in Vado (29 km); Urbino–Macerata Feltria (56 km, via Sant'Angelo in Vado); and the Pesaro–Macerata Feltria line (118 km, via Urbino) (Fig. 30). Each station was configured with an earth connection and was equipped with two Bell telephones: one held constantly to the ear as the receiver, and the other placed at the mouth as the transmitter. The three sets of experiments yielded satisfactory results only in conditions of complete silence.

Under such conditions, Serpieri verified not only clear voice transmission through exchanges of questions and answers, but also the perfect intelligibility of numerical sequences, vocal melodies, and instrumental performances, noting with interest that the identification of musical pieces performed on flute, cornet, clarinet, bassoon, bombardon, and trombone—both individually and in ensemble—proved substantially accurate by virtue of the device's capacity to preserve timbral characteristics. Only the clarino produced occasional perceptual ambiguities, as it was sometimes confused with the violin or trumpet.

This acoustic phenomenology contradicted contemporary theoretical predictions concerning progressive signal attenuation over extended distances, raising a crucial question: how to explain the telephone's efficacy under conditions where magnetic induction seemed to lack the energy necessary to sustain signal transmission? Serpieri, confronted with the phenomenon's complexity, identified experimental anomalies that challenged classical electromagnetic theory: why did manual pressure of the diaphragm against the magnet's pole generate no detectable current as registered on his "*most delicate*" galvanometer, whereas the induced currents, described as "*much weaker*", generated by the diaphragm's sonic vibrations enabled unaltered voice transmission across circuits exceeding 100 km? Furthermore, why did the current from the telegraph battery (70 elements) at the Urbino office weaken appreciably—by 4°–6°—for each additional 20–30 km section, while the telephone's induced current, which at the telegraph office's compass produced no measurable fraction of a degree, maintained "*substantially invariant*" sound intensity even when the line length was doubled or tripled? As he observed, citing Pietro Blaserna, "*this surprising phenomenon of the telephone could not have been imagined* a priori" (Serpieri 1878b, 195).

In analysing the system's electrical behaviour in terms of the principles of the induction coil, Serpieri recognised that total resistance comprised, as in the case of a battery, the coil's internal resistance and that of the external circuit. According to classical theory, founded upon Faraday's law and the principles of electrical resistance, the intensity of the induced current should have decreased in proportion to the increase in the circuit's overall resistance, particularly when "*two or three additional telephones*" were included in series, thereby doubling or tripling the external resistance. However, under the described experimental conditions, sound intensity remained "*substantially invariant*", except for "*minor differences deriving from the varying quality of the apparatus*". Particularly significant was the experiment in which, during transmission, the line was suddenly "*opened*" at Urbino and then closed at Pesaro, extending the circuit by approximately 60 km: not only did the voices not weaken, but they "*seemed to become clearer*" (Serpieri 1878b, 196). Confronted with these paradoxical results, Serpieri advanced a bold hypothesis: that "*some still unknown molecular action accompanied the induced currents in the communication wire*". This intuition led him to re-evaluate the "*electro-tonic state*" hypothesised by Faraday, questioning whether such a phenomenon possessed "*a reality and importance greater than is usually thought*". This conjecture stimulated a new series of experiments, aimed at verifying whether sound transmission could occur even in the absence of the metallic diaphragm, hitherto considered an indispensable component for magnetic field modulation. Serpieri took inspiration from a communication by the Scottish physicist Peter Guthrie Tait (1831–1901), presented to the *Royal Society* of Edinburgh,[53] which reported that Mr Blyth had obtained phonic effects, though reduced, by substituting the iron diaphragm with sheets of copper, wood, paper, or elastic rubber, in both transmitting and receiving telephones. However, Blyth had never obtained any sound in a telephone entirely devoid of a diaphragm (Anonymous [L'Elettricista] 1878a, 127–128; Serpieri 1878b, 196). Significantly, Francesco Rossetti, in the same months, conducted analogous experiments,[54] likewise stimulated by the same communication from Tait regarding Blyth's results. Serpieri proceeded methodically. He began by verifying these results and replaced the iron diaphragm of the transmitting telephone with a glass plate. The results were unequivocal: strong sounds emitted against the glass were heard "*perfectly*" at the other station using an ordinary telephone. Reversing the roles—utilising the telephone with the glass plate as receiver—one could clearly distinguish "*the tone and vowel of the emitted cry*". When he interposed two glass plates with the iron sheet "*compressed between them*", the sounds were found to be "*slightly more intense*". For Serpieri, the glass plate experiment unequivocally demonstrated that the vibrations of the glass could not directly modify the magnet's state of magnetisation through "*movements of approach and withdrawal*". The phenomenon must "*depend upon other laws*" (Serpieri 1878b, 196). These results led him to hypothesise that acoustic vibration acted directly upon the magnet, favouring "*a better magnetic alignment of its atoms, which, agitated and oscillating, more readily obeyed polar forces*". According to this interpretation, the two distant magnets vibrated and resonated "*in unison*", achieving perfect acoustic-magnetic reciprocity.

---

[53] Serpieri erroneously cites the Royal Society of London.

[54] In his communication of 27 February 1878 to the *Royal Venetian Institute of Sciences, Letters and Arts*, Rossetti reported having obtained telephonic sounds initially using non-ferrous metallic sheets (copper or other metals), subsequently cardboard, insulating elastic materials, and even configurations completely lacking any diaphragm whatsoever (Rossetti 1878d, 662). In this way, he diverged—like Serpieri—from Blyth's original conclusions, according to which sound transmission would prove impossible in the complete absence of a diaphragm. This experimental orientation, aimed at investigating phonic transduction mechanisms beyond the conventional ferrous diaphragm, was thus shared by several Italian researchers, each operating independently.

This interpretation was supported by earlier research on the relationship between magnetism and mechanical deformation. Serpieri cited the studies of Gustav Heinrich Wiedemann (1826–1899), pioneer of magnetostriction; the research of Charles Nicolas Alexandre De Haldat (1770–1852); the works of Guillaume Wertheim (1815–1861) and William Robert Grove (1811–1896); and the studies of Auguste Arthur De la Rive (1801–1873) on magneto-mechanical phenomena. These investigations provided Serpieri with a conceptual framework for interpreting the telephone as a system exhibiting "*perfect reciprocity*": not only did magnetic variation generate sound, but in turn sound induced magnetic variations (Serpieri 1878b, 197). To test this hypothesis and refute Blyth's assertion concerning the impossibility of transmission without a diaphragm, Serpieri conducted a series of extreme experiments: he had "*prolonged cries of the vowel "o" uttered against the completely uncovered pole of the magnet*". Under these experimental conditions, the receiving telephone (equipped with a standard metallic sheet) perceived "*the emitted cries*", albeit with characteristic phonemic alterations: the "o" was transformed into an "i" or the French "œu". In a parallel arrangement, using a telephone "*completely devoid of its armature*" as a receiver, Serpieri heard "*the cries emitted from the other telephone fitted with its standard diaphragm*" (Serpieri 1878b, 197). The decisive experiment consisted of substituting the human voice with a wooden mallet, which he used to strike the diaphragm-free magnet directly: the receiving telephone, positioned 100 m away, registered "*corresponding sharp taps, devoid of secondary resonances*". This result confirmed the existence of the "*habitual correspondence and harmony of mechanical, magnetic, electrical, and acoustic work*". Serpieri observed with acuity that, even when galvanometers, "*though extremely sensitive, remained silent*", the telephone revealed magnetic and electrical movements otherwise undetectable: "*It is therefore a true stroke of fortune that where the galvanometer is silent, the air speaks*" (Serpieri 1878b, 198). However, Serpieri did not deny the functional superiority of the metallic diaphragm. In the concluding section, he specified that "*in admitting the sonic action of the magnets, I do not exclude vibrations due to the elasticity of the iron sheet, the true and principal vocal organ of the telephone*". The receiving diaphragm operated through three distinct mechanisms: (1) mechanical transmission through contact with the wooden frame, "*as occurs with the glass plate*"; (2) internal magnetic variations within the sheet itself, "*which must operate in the sheet as in the permanent magnet*"; (3) the "*variable intermittent attractions*" that, exploiting the sheet's elasticity, caused it to move "*actually backwards and forwards with an oscillatory movement of exceedingly small and imperceptible amplitude*". This triple operational mechanism explained the "*fidelity and excellence of this metallic tympanum*", whose actions were found to be "*perfectly synchronised*" with those of the magnet (Serpieri 1878b, 198). To further confirm the functional complexity of the diaphragm, Serpieri experimented with "*common tin discs*" and "*thick iron plates*", ranging up to "*massive bars* 3.5 cm in *thickness*", obtaining in each case "*distinct perception of cries*". These experimental investigations demonstrated that "*internal molecular action plays a significant role in the telephone's operation, and its secret cannot be reduced to the mere oscillatory movement of the diaphragm in its entirety*" (Serpieri 1878b, 198–199). In the final section, Serpieri revisited the cognitive limitations of the device, reiterating the transmission trials previously outlined in his earlier communication: Italian words "*read backwards*", "*words and phrases from foreign languages unknown to the listener*". In this renewed experimental series, he again found a high degree of instability in auditory reception, with systematic errors in phonetic decoding and the impossibility of identifying proper nouns. The results corroborated the hypotheses formulated in February: "*it is therefore evident that the telephone is not in itself a perfect instrument*", and that only "*the mental activity of the listening subject*" enables its apparent communicative efficacy (Serpieri 1878b, 199). Serpieri thus outlined the dual and interactive nature of telephonic audition: neither purely mechanical, nor exclusively cognitive, but the result of a dynamic synergy between mind and matter, between the physics of vibrations and processes of comprehension.

6 Conclusions

The three case studies—two situated in the Papal States (1851 and 1854–55) and one in the Kingdom of Italy (1877–78)—trace Serpieri's experimental practice across the political process of Italian unification and, more broadly, clarify the profile of nineteenth-century physical science in provincial settings. Taken together, they delineate a coherent picture of what I term an "*epistemology of the province*": a configuration in which geographical marginality did not entail intellectual passivity, but rather enabled forms of scientific research and experimental practice that were locally grounded and sustained by supra-local circuits of communication and validation. In this context, a "*minor*" centre could absorb stimuli from leading European journals and scientific institutions while also posing original questions, devising new procedures, and constructing or modifying instruments and experimental devices in response to locally specific constraints and resources. In these processes, alongside the periodical press, epistolary exchanges were equally significant—not as a mere biographical accessory, but as operational and reputational infrastructures that extended the discussion of results, their verifiability, and their credibility beyond the locality. A first cross-cutting feature of Serpieri's practice is the combination of strong local embeddedness with a steady orientation beyond the locality. The Panthéon phase of Foucault's experiment, most widely publicised in its canonical form on 31 March 1851, turned the pendulum into an event of broad public and journalistic visibility.

Serpieri's intervention, however, cannot be explained solely by that later publicity. The Urbino replication of 30 March 1851 presupposed an earlier circulation of information, linked above all to the 3 February demonstration at the Paris Observatory, and thus points not simply to the echo of a media event, but to a more discreet and technically significant circulation of news—and to the ability of a provincial man of science to recognise promptly the epistemic and experimental import of a report before the Panthéon demonstration had acquired its fullest public resonance.

Similarly, in the case of duplex telegraphy (1854–55), Serpieri did not merely absorb the French and Austrian debates on Gintl and the first European trials, but intervened with original mathematical analyses of derived currents, refuted Ciampi's objections, and clarified the system's operating principles. In the telephone episode (1877–78), he turned a commercial device newly arrived in Italy into an instrument of perceptual-cognitive inquiry, conducting controlled linguistic experiments that, in retrospect, can be set in dialogue with later discussions of technologically mediated communication—without implying any direct genealogy. Even if the specific channel through which Serpieri received the relevant information cannot always be identified with certainty, the chronology nonetheless shows how a provincial context could intercept scientifically consequential news within relatively short timeframes and convert it into experimental initiative. The episodes also highlight cooperation between different epistemic registers and Serpieri's active role not only as a receiver but as a producer of knowledge, through publications in *La Corrispondenza Scientifica in Roma*, the *Annali di Scienze Matematiche e Fisiche* (Tortolini), *Il Nuovo Cimento*, *L'Elettricista*, the *Rivista Scientifico-Industriale*, and the *Rendiconti del Reale Istituto Lombardo*—periodicals that themselves constituted a polycentric infrastructure of scientific communication. In this sense, the experiments illuminate not only a centre–periphery dynamic, but the workings of a relay network—periodicals, epistolary exchanges, and institutional mediations—through which knowledge circulated along polycentric, not exclusively hierarchical, trajectories, and in which Serpieri functioned as an active node. Secondly, the three cases bring into view an adaptive methodology that turns constraints into operational resources. The scarcity of means—typical of many "*minor*" institutions—should not be read only as a limitation: it could foster an experimental economy attentive to the choice of materials, the organisation of spaces, and the redesign of apparatuses and procedures.

In the pendulum case, the use of a seven-metre length of annealed iron wire and a marble sphere—materials likely available locally or readily obtainable—still allowed an effective demonstration in a room of the *Collegio dei Nobili*, without the need for monumental structures. In duplex telegraphy, the construction of experimental circuits with extremely sensitive galvanometers, horseshoe magnets fitted with self-wound coils (e.g. 27 turns per pole), and the ingenious use of a movable armature to generate transient currents of equal intensity, displayed technical skill and the capacity to obtain significant results with simple, essential, yet carefully designed apparatus. In the telephone case, the strategic use of existing telegraph lines—Urbino–Sant'Angelo in Vado (29 km), Urbino–Macerata Feltria (56 km), and Pesaro–Macerata Feltria (118 km)—as an experimental infrastructure avoided costly dedicated installations and enabled tests over real operational distances. Serpieri never appears as a mere recipient of novelty. Rather, his practice consists in active appropriations: adapting, stabilising, comparing, and at times correcting or reformulating a device or hypothesis in the light of local conditions and specific aims. It is here that the "*province*" reveals its productive potential: not as a site of isolated invention, but as a laboratory for experimental variations and controlled modifications of apparatuses, procedures, and operating conditions—capable of generating knowledge through the material and procedural translation of external stimuli. This adaptive methodology can be read not simply as "*making a virtue of necessity*", but as a legitimate epistemic practice. It implicitly challenges the hierarchies embedded in Blaserna's diagnosis, which contrasted an Italian "*culture of eloquence*" with German laboratories oriented towards practice.

A third element concerns Serpieri's capacity to operate across different epistemic registers and to make them work together. In the pendulum case, experimental observation and theoretical reflection sustained one another. By opening a dialogue with Mossotti—a mathematician of European standing—Serpieri turned a careful local observation (the constant orientation of the bob) into a discussable and publishable problem, prompting Mossotti to formalise it and to make it public in a letter published in Italy that contained—for the first time in Italy—a correct analytical solution to the Foucault pendulum. In duplex telegraphy, Serpieri coupled systematic experiments with a rigorous analysis of circuit conditions and derived currents, displaying not only experimental skill but also rhetorical and argumentative capacity in scientific controversy. His detailed reply to Zantedeschi's criticisms (grounded in a claim of chronological priority) and his theoretical-mathematical refutation of Ciampi's objections (based on the formulas in Moigno's *Traité de télégraphie*) show how effectively he could move between experiment, theory, and public dispute, clarifying the compatibility of the phenomenon with the laws of electrical circuits and providing a theoretical–experimental validation for a technology that was then contested in Italy. In the telephone episode, finally, he developed an analysis on two complementary levels. On the one hand, he tested the device under different conditions (including transmission over long telegraph lines, configurations with rheostats simulating distances beyond 100 km, and "*radical*" trials on the role of vibrating elements—telephones without diaphragms, with glass plates, and with diaphragms of different materials). On the other hand, he carried out controlled observations on the perception and interpretation of sounds through linguistic tests (Italian words read backwards; German words spoken to listeners who did not know the language), ultimately shifting attention from the apparatus in isolation to the communicative circuit and its operating conditions, in which the listener constitutes an active component of instrumental performance. This insight—according to which "*much of the efficacy attributed to the telephone apparatus belongs in reality to the listener*"—shifts the analysis from apparatus to communicative circuit and, in 1878, articulates with unusual explicitness a problem of perception under technological mediation. It should therefore be regarded not merely as an echo of twentieth-century categories but as an autonomous theoretical contribution—formulated in its own vocabulary and grounded in controlled experimental practice.

The article's periodisation also helps to clarify the relationship between political discontinuity and continuity in practice. Significantly, of the three case studies, the duplex episode (1854–55) unfolded entirely within the Papal States, whereas the telephone (1877–78) belongs to the Kingdom of Italy and the pendulum (1851) predates Unification by a decade. Serpieri's experimental practice thus displays methodological continuity across a change of political regime, a point that reinforces the argument that the public diagnoses of 1868 regarding the condition of the physical sciences in Italy (Blaserna; Matteucci), influential though they were in discursive and reforming terms, did not coincide with discontinuities in actual practice. Unification introduced a new normative and administrative centralisation that fuelled diagnoses of deficiency and projects of reform. Yet experimental activity often remained polycentric and continued to depend on local infrastructures (physics cabinets, observatories, telegraph lines) and on channels of recognition and circulation not fully regulated from above.

The network of periodicals and editorial institutions evoked in the case studies likewise constituted a polycentric infrastructure that both preceded and outlived Unification, attesting to forms of coordination and validation that operated across state boundaries and, later, across the Kingdom's administrative reforms.

From this perspective, 1868—with Blaserna's and Matteucci's interventions—functions above all as a discursive node: it makes explicit a rhetoric of "*lack*" and of the need for modernisation, without coinciding with a causal watershed capable, on its own, of accounting for effective transformations. The cases point instead to continuities and graded adaptations and invite a distinction between public diagnoses, institutional conditions, and concrete practices.

Finally, the temporal dimension appears as an epistemic resource that is specific to the province. Serpieri's activity cannot be reduced to isolated episodes: it unfolded through iterative returns, successive updates, and rereadings as technologies and debates changed. Within the perimeter considered here (1851–1878), this "*duration*" takes the form of an ability to revisit different problems and devices with a recognisable experimental habitus—from mechanical-astronomical phenomena (the pendulum, 1851) to electrotechnical questions (duplex telegraphy, 1855; telephone, 1878)—and to maintain operational continuity thanks to local infrastructures and stable editorial networks. This experimental *longue durée* was facilitated by Urbino's institutional continuity—a "*minor*" yet stable university seat—and by the material practices of cabinets and observatories, within which teaching, the use and maintenance of instruments, and scientific investigation coexisted. Urbino's physics cabinet thus functioned as a "*material memory*", accumulating instruments, skills, and practices over decades, enabling Serpieri to build his research trajectories on pre-existing foundations and to sustain a continuous editorial presence. This point also connects, implicitly, with Blaserna's theme of a "*lack of schools*" in relation to Volta, Nobili, Melloni, and Amici. If Serpieri did not found a "*school*" in the German sense—direct pupils who systematically continued his research—his activity nonetheless exemplifies an alternative form of continuity: not through personal descent, but through consolidated practices, accumulated instruments, stable editorial networks, and a scientific reputation progressively built and recognised at a national level. Taken together, these features describe provincial physical science not as a derivative margin of metropolitan science, but as a materially grounded scientific environment, capable of producing knowledge under specific constraints and of circulating it, through circuits of validation, within wider arenas.

At the historiographical level, an "*epistemology of the province*" thus proposes moving beyond a strict centre–periphery dichotomy and adopting more explicitly polycentric and infrastructural models, attentive to mediators, material supports, and practices of recognition. In this key, Serpieri is not merely an exemplary or interesting local case: he embodies an alternative mode of scientific production—territorially grounded, internationally open, methodologically adaptive, and capable of operating across different epistemic registers—that invites a recalibration of how "*centres*" and "*peripheries*" are assessed in nineteenth-century Italy. His case suggests that the production of "*original knowledge*" could emerge even in "*minor*" settings when institutional continuity, technical competence, an experimental culture, and access—direct or mediated—to networks of communication and legitimation were in place. Analysis of concrete practices shows that centre–periphery hierarchies did not always coincide with the conditions under which results were produced and circulated. Geographical marginality, far from constituting an insurmountable obstacle, could translate into methodological originality and into the capacity to formulate non-obvious questions and solutions, turning provincial constraints into distinctive epistemic opportunities.

Two limitations, however, should be made explicit. First, although it is possible to reconstruct chronologies compatible with a relatively rapid reception of scientific news, it is not always possible to identify with certainty the specific channels of circulation—periodicals, epistolary exchanges, institutional mediations—through which Serpieri came into contact with each event or device. Second, the analysis proposed here—centred on three episodes with a high documentary density—inevitably privileges what is traceable in printed sources and in the available correspondence, leaving more ordinary and less visible practices in the background.

These limitations, in turn, suggest further avenues for research: a systematic survey of inventories and acquisition registers of physics cabinets, local libraries, and subscription networks to periodicals; the investigation of epistolary corpora as infrastructures of work, verification, and reputation; the study of practices of maintenance, repair, and instrumental redesign—especially the scientist–mechanician partnership, capable not only of preserving and restoring apparatus but also of modifying it or building it *ex novo* on request and often to the experimenter's design—as indicators of "*material memory*" and experimental capacity; and, finally, a controlled comparison with other Italian provincial cases, in order to assess the extent to which an "*epistemology of the province*" captures a generalisable model rather than an exceptional individual profile.

Funding Open access funding provided by Università degli Studi di Urbino Carlo Bo within the CRUI-CARE Agreement.

Declarations

Conflict of interest The author declares no conflict of interest and no relevant financial or non-financial interests to disclose.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Accademia del Cimento. 1841. *Saggi di naturali esperienze fatte nell'Accademia del Cimento sotto la protezione del Ser.mo Principe Leopoldo di Toscana e descritte dal Segretario di essa Accademia*. Firenze: dai Torchi della Tipografia Galileiana.

Aczel, Amir D. 2005. Léon Foucault: his life, times and achievements. In: *The Pendulum: Scientific, Historical, Philosophical and Educational Perspectives*, eds. Michael R. Matthews, Colin F. Gauld, and Arthur Stinner, 171–183. Dordrecht: Springer.

Ancarani, Vittorio. 1989. Università e ricerca nell'Italia post-unitaria. Saggio introduttivo. In *La scienza accademica nell'Italia post-unitaria. Discipline scientifiche e ricerca universitaria*, ed. Vittorio Ancarani, 1–36. Milano: FrancoAngeli.

Anonymous. 1851a. *Il Diavoletto. Giornale diabolico, politico, umoristico, comico, critico e pittorico* 4(66): 264.

Anonymous. 1851b. Comunicazione del 3 Febbraio presso l'Accademia delle Scienze di Parigi sulle belle esperienze svolte da M. Foucault. *La Civiltà Cattolica* 5: 140.

Anonymous. 1851c. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, Tome 32 (Janvier-Juin). Paris: Bachelier, imprimeur-libraire.

Anonymous. 1851d. Moto del pendolo applicato alla rotazione della terra. *Lo Statuto*, April 23, Year 3(68): 2.

Anonymous. 1855a. Sul passaggio simultaneo di due correnti elettriche dirette in senso contrario sullo stesso filo, e della sua applicazione alle comunicazioni telegrafiche. Esperienze e considerazioni dei sigg. Masson, De La Provostaye, Desains, Zantedeschi, Serpieri e Gaugain. *Il Nuovo Cimento* 1: 132–136.

Anonymous. 1855b. Descrizione dell'apparecchio e del metodo con cui si ottiene la corrispondenza simultanea fra due uffici telegrafici riuniti da un solo filo metallico e da uno strato di terra. Invenzione del Dott. G. Gintl Direttore dei telegrafi austriaci, e degli ingegneri meccanici prussiani Halske e Siemens. *Il Nuovo Cimento* 1: 235–241.

Anonymous. 1856. Telegrafia elettrica. *Giornale dell'Ingegnere-Architetto ed Agronomo* 3: 50.

Anonymous. 1876. *International Exhibition. 1876 Official Catalogue, Part I, Department I – Mining and Metallurgy; Department II – Manufactures; Department III – Education and Science*. Third and Revised Edition. Philadelphia: Riverside Press, Cambridge, Mass.

Anonymous. 1877a. Il telegrafo parlante. Il telefono elettrico del signor Reuss. *Bullettino Telegrafico del Regno d'Italia*: 69–72.

Anonymous. 1877b. Il Telelettroscopio. *La Civiltà Cattolica*, Serie 10, 3(652): 464–465.

Anonymous. 1877c. Il telefono a Milano. *Monitore delle strade Ferrate e degli interessi materiali* 10(32): 870.

Anonymous. 1877d. An Account of Duplex Telegraphy. *Nature. A Weekly Illustrated Journal of Science* 15: 180–184.

Anonymous. 1878a. Adunanza del 16 Dicembre 1877. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti* (dal Novembre 1877 all'Ottobre 1878), Serie 1, 4: 218.

Anonymous. 1878b. Adunanza del 21 marzo 1878. *Rendiconti del Reale Istituto Lombardo di Scienze e Lettere*, Serie 2, 11(4–5): 180.

Anonymous [Corriere della Sera]. 1877a. Il Telefono a Milano. *Corriere della Sera*, November 30 – December 1, 2(330).

Anonymous [Corriere della Sera]. 1877b. Il telefono. *Corriere della Sera*, December 5–6, 2(336).
Anonymous [Corriere della Sera]. 1877c. Il telefono. *Corriere della Sera*, December 7–8, 2(337).
Anonymous [Corriere della Sera]. 1877d. Nuove esperienze col telefono. *Corriere della Sera*, December 15–16, 2(345).
Anonymous [Corriere della Sera]. 1877e. Il telefono a palazzo Marino. *Corriere della Sera*, December 24–25, 2(354).
Anonymous [Corriere della Sera]. 1877f. Nuovi esperimenti col telefono. *Corriere della Sera*, December 27–28, 2(356).
Anonymous [Corriere della Sera]. 1878. Il telefono. *Corriere della Sera*, January 2–3, 3(3).
Anonymous [L'Elettricista]. 1877a. Telefono. *L'Elettricista. Rivista Mensuale* 1(2): 54–55.
Anonymous [L'Elettricista]. 1877b. Telefono. *L'Elettricista. Rivista Mensuale* 1(4): 135.
Anonymous [L'Elettricista]. 1877c. Il Telefono. *L'Elettricista. Rivista Mensuale* 1(5): 166.
Anonymous [L'Elettricista]. 1877d. Telefono. *L'Elettricista. Rivista Mensuale* 1(6): 192.
Anonymous [L'Elettricista]. 1877e. Il telefono articolante di Bell. *L'Elettricista. Rivista Mensuale* 1(8): 258–260.
Anonymous [L'Elettricista]. 1877f. Intorno ai telefoni del Gray, del Bell e dell'Edison. *L'Elettricista. Rivista Mensuale* 1(9): 289–291.
Anonymous [L'Elettricista]. 1877g. Il Telefono. *L'Elettricista. Rivista Mensuale* 1(10): 311–312.
Anonymous [L'Elettricista]. 1877h. Lettura del sig. W. H. Preece sul telefono al Congresso della Società Britannica per il Progresso delle Scienze in Plymouth. *L'Elettricista. Rivista Mensuale* 1(10): 312–314.
Anonymous [L'Elettricista]. 1877i. Lettura del Prof. Graham Bell. *L'Elettricista. Rivista Mensuale* 1(10): 314–315.
Anonymous [L'Elettricista]. 1877j. Applicazioni del telefono alle miniere. *L'Elettricista. Rivista Mensuale* 1(10): 315–316.
Anonymous [L'Elettricista]. 1877k. Il Telefono. Sunto di una conferenza tenuta dal prof. Graham Bell presso la Società degl'ingegneri telegrafici di Londra. *L'Elettricista. Rivista Mensuale* 1(12): 378–380.
Anonymous [L'Elettricista]. 1877l. Il Telefono nel N. 35 del Journal Telegraphique. *L'Elettricista. Rivista Mensuale* 1(12): 380–383.
Anonymous [L'Elettricista]. 1877m. Il Telefono dal Telegraphic Journal. *L'Elettricista. Rivista Mensuale* 1(12): 383–384.
Anonymous [L'Elettricista]. 1877n. Sopra una modificazione del Telefono di Bell, a membrane multiple. Nota del sig. Trouvé. *L'Elettricista. Rivista Mensuale* 1(12): 384.
Anonymous [L'Elettricista]. 1878a. Telefono senza diaframma di ferro. *L'Elettricista* 2(2): 127–128.
Anonymous [L'Elettricista]. 1878b. Telefono di Leppin e Masche con breve descrizione. *L'Elettricista. Rivista di Scienze Fisiche e loro applicazioni* 2: 23–24.
Anonymous [L'Elettricista]. 1878c. *L'Elettricista. Rivista di scienze fisiche e loro applicazioni dedicata particolarmente all'Elettricità*, Vol. 2 (complete). Firenze: coi Tipi di M. Cellini e C.
Anonymous [L'Elettricista]. 1892. Necrologio di Marco Maroni. *L'Elettricista. Rivista mensile di Elettrotecnica* 1(4): 96.
Anonymous [L'Illustrazione Italiana]. 1877a. Il Telegrafo parlante. *L'Illustrazione Italiana* 4(19): 300, 302.
Anonymous [L'Illustrazione Italiana]. 1877b. Il Telefono del Signor Gray. *L'Illustrazione Italiana* 4(55): 121–122.
Anonymous [L'Illustrazione Italiana]. 1877c. Ancora del Telefono. *L'Illustrazione Italiana* 4(38): 202.
Anonymous [L'Illustrazione Italiana]. 1878. Un esperimento col telefono. *L'Illustrazione Italiana* 5(2): 24, 27.
Antinori, Albino. 1963. *Le telecomunicazioni italiane 1861–1961.* Roma: Edizioni dell'Ateneo.
Antinori, Vincenzo. 1851a. Letter to the editor. In appendix to "Moto del pendolo applicato alla rotazione della terra." *Lo Statuto*, April 23, Year 3(68): 2.
Antinori, Vincenzo. 1851b. Anciennes observations faites par les Membres de l'Académie del Cimento sur la marche du pendule (Lettre de M Antinori, directeur du Musée de Physique et d'Histoire naturelle de Florence, à M. Arago). *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences* 32: 635–636.
Baudrimont, Alexandre-Édouard. 1851. Projet d'un appareil destiné à rendre sensible aux yeux le mouvement rotatoire de la terre. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences* 32: 307–308.
Bellavitis, Giusto. 1855. Adunanza del giorno 26 Febbraio 1855. *Atti delle Adunanze dell'I. R. Istituto Veneto di Scienze, Lettere ed Arti. Dal Novembre 1854 all'Ottobre 1855*. Venezia: Presso la Segreteria dell'Istituto nel Palazzo Ducale.
Belli, Giuseppe. 1855. Sulla possibilità di contrarie correnti elettriche simultanee in un medesimo filo conduttore. *Il Nuovo Cimento* 2: 401–447.
Belli, Giuseppe. 1857. Sulla possibilità di contrarie correnti elettriche simultanee in uno stesso filo conduttore: memoria seconda. *Il Nuovo Cimento* 6: 81–123.
Besso, Beniamino. 1875. *Le Grandi Invenzioni Antiche e Moderne nell'Industria, nelle Scienze e nelle Arti. Parte terza*, sesta edizione. Milano: Fratelli Treves.
Blaserna, Pietro. 1868. Sullo stato attuale delle scienze fisiche in Italia e su alcune macchine di fisica. In *L'Italia alla Esposizione Universale di Parigi nel 1867. Rassegna critica descrittiva illustrata*, 70–74. Firenze: Tipografia dei Successori Le Monnier.
Blaserna, Pietro. 1878. Il Telefono. *La Nuova Antologia* 37: 687–696.
Boillot, Alexis. 1888. Expériences sur le pendule non oscillant. *Comptes Rendus des Séances de l'Académie des Sciences* 106: 1664–1665.
Cantoni, Giovanni. 1867. *Sommario di un corso di lezioni su la gravità.* Pavia: Tipografia in Ditta Eredi Bizzoni.
Cardarelli, Fedele. 1877. Sul Telefono articolante di Bell (London, January 22, 1877). *L'Elettricista. Rivista Mensuale* 1(2): 55–56.

Carletti, Christian. 2014. Keeping Abreast with the Technology of Science: The Economic Life of the Physics Laboratory at the University of Padua, 1847–1857. *History of Technology, Special Issue: Italian Technology from the Renaissance to the Twentieth Century* 35: 191–209.

Chelini, Domenico. 1851a. Sulla spiegazione dell'esperienza del sig. Foucault intorno al pendolo. Nota. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 243–246.

Chelini, Domenico. 1851b. Addizione alla nota sull'oscillazione del pendolo: nuova dimostrazione geometrica del principio dinamico de' moti relativi. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 311–317.

Ciampi, Felice. 1855. Altri esperimenti sulla trasmissione simultanea di correnti elettriche opposte nel medesimo filo comunicati al direttore della Corrispondenza Scientifica di Roma dal P. F. Ciampi prof di fisico-chimica al Collegio Romano. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(47): 393–395.

Ciccolini, Lodovico. 1851. Sulla deviazione del pendolo. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 409–413, 543–546.

Coe, Lewis. 1995. *The Telephone and Its Several Inventors: A History*. Jefferson, NC: McFarland & Company, Inc., Publishers.

Colombo, Giuseppe. 1877a. Il Telefono. *Il Politecnico – Giornale dell'ingegnere architetto civile ed industriale* 6(5–6): 377.

Colombo, Giuseppe. 1877b. Il Telefono (text reproduced from the newspaper "La Perseveranza" of December 13, 1877). *Il Politecnico – Giornale dell'ingegnere architetto civile ed industriale* 12(11–12): 685–688.

Colombo, Giuseppe. 1934a. Esperienze di telefonia. Lettera al quotidiano "La Perseveranza" del 4 dicembre 1877. In *Giuseppe Colombo. Scritti e discorsi scientifici ordinati da Federico Giordano*, Vol. 1, articolo no. 68, 474–475. Milano: Hoepli.

Colombo, Giuseppe. 1934b. Il Telefono. Lettera al quotidiano "La Perseveranza" del 13 dicembre 1877. In *Giuseppe Colombo. Scritti e discorsi scientifici ordinati da Federico Giordano*, Vol. 1, articolo no. 69, 476–482. Milano: Hoepli.

Dal Pozzo di Mombello, Enrico. 1868. *Sull'insegnamento della fisica in Italia. Osservazioni*. Foligno: Stab. Tip. e Lit. di P. Sgariglia.

Della Casa, Lorenzo. 1855. Sulle correnti elettriche simultaneamente dirette in versi contrarii. *Memorie dell'Accademia delle Scienze dell'Istituto di Bologna* 6: 367–379.

Ferraris, Galileo. 1878a. Di una dimostrazione del principio di Helmholtz sulla tempera dei suoni ricavata da alcuni esperimenti fatti col telefono. Nota presentata alla Reale Accademia delle Scienze di Torino nell'Adunanza del 27 gennaio 1878. *Atti dell'Accademia delle Scienze di Torino* 13: 287–298.

Ferraris, Galileo. 1878b. Sul telefono di Graham Bell. Conferenza fatta alla Società degli Ingegneri e degli Industriali di Torino. *Atti della Società degli Ingegneri e degli Industriali di Torino* 11: 53–78.

Ferrini, Rinaldo, and Pietro Pogliaghi. 1882. *La Luminosità Elettrica dei Gas e la Materia Radiante*. Milano: Fratelli Dumolard.

Garibaldi, Pietro Maria. 1878. Resoconto stenografico della conferenza sul telefono tenuta dal Prof. Cav. P. M. Garibaldi innanzi alla Società di Letture e Conversazioni Scientifiche la sera del 20 Febbraio 1878. *Giornale della Società di Letture e Conversazioni Scientifiche di Genova* 4: 162–180.

Gariel, Charles-Marie. 1878. *Recueil des travaux scientifiques de Léon Foucault, publié par Mme veuve Foucault sa mère, mis en ordre par C.-M. Gariel, et précédé d'une notice sur les oeuvres de L. Foucault, par J. Bertrand*. Vol. 1, 378–382. Paris: Gauthier-Villars.

Giovannozzi, Giovanni. 1887. *Della vita e degli scritti di Alessandro Serpieri delle Scuole Pie*. Firenze: Tipografia Calasanziana.

Giuliani, Giuseppe. 1996. *Il Nuovo Cimento. Novant'anni di fisica in Italia 1855–1944. Percorsi della Fisica*. Pavia: La Goliardica Pavese.

Grove, William Robert. 1846. *On the Correlation of Physical Forces: Being the Substance of a Course of Lectures delivered in the London Institution, in the year 1843*. London: Printed by Order of the Managers of the London Institution.

Hagen, Johann Georg. 1911. *La rotation de la Terre, ses preuves mécaniques anciennes et nouvelles. Introduction, sect. II, Esquisse historique*. Vol. 1. Roma: Specola Astronomica Vaticana.

James, Frank Arthur James Lancelot. 2002. Davy, Faraday and Italian Science, in *Atti del IX Convegno Nazionale di Storia e Fondamenti della Chimica* (Modena, 25–27 ottobre 2001), Roma: Accademia Nazionale delle Scienze detta dei XL, 149–158.

Lacaita, Carlo G. 1996. Un organizzatore della cultura scientifica e tecnica italiana nell'età del Risorgimento: Gio. Alessandro Majocchi e gli «Annali di fisica, chimica e matematiche». In *Ricerche di storia in onore di Franco Della Peruta*, vol. II: *Economia e società*, eds. M. L. Betri and D. Bigazzi, 198–218. Milano: FrancoAngeli.

Lacaita, Carlo G. 2001. Programmi di rinnovamento in ambito tecnico-scientifico prima dell'Unità. *Archivio Storico Siciliano* (Serie IV, Vol. XXVII): 9–21.

Lacaita, Carlo G. 2016. Cultura tecnico-scientifica e "risorgimento economico". In *Istituto Lombardo – Accademia di Scienze e Lettere – Incontri di Studio* 56: 9–28. Milano: Istituto Lombardo.

Licklider, J. C. R. 1960. *Man-computer symbiosis. IRE Transactions on Human Factors in Electronics* HFE-1(1): 4–11. https://doi.org/10.1109/THFE2.1960.4503259

Luvini, Giovanni. 1878. Conferenza sul telefono nella Società degl'ingegneri di Torino. *L'Elettricista* 2(2): 98–102.

Magrini, Luigi. 1855. Notizie storiche, considerazioni ed esperimenti sul quesito: possono in uno stesso filo coesistere due correnti contrarie, e trasmettersi simultaneamente due dispacci elettrici in senso opposto? *Giornale dell'I. R. Istituto Lombardo di Scienze, Lettere ed Arti e Biblioteca Italiana* 7: 3–18.

Mantovani, Roberto, and Flavio Vetrano. 1991. Inventario del carteggio scientifico inviato allo scolopio Alessandro Serpieri. *Nuncius* 4(1): 135–166.

Mantovani, Roberto. 1996. The Collection of Scientific Instruments at Urbino University: Catalographic Cards. In *The old "Gabinetto di Fisica" of the Urbino University: its History, its Museum/Il Gabinetto di Fisica dell'Università di Urbino: la sua Storia, il suo Museo* (bilingual edition), edited by Flavio Vetrano, 89–259. Roma: Istituto Poligrafico e Zecca dello Stato.

Mantovani, Roberto. 1998. La strumentazione scientifica di Padre Alessandro Serpieri. In *Alessandro Serpieri scienziato riminese. Atti del Convegno tenuto a Rimini il 22–23 marzo 1996*, 63–76. Rimini: Raffaelli e Luisè editori.

Mantovani, Roberto. 2025. Alessandro Serpieri and his seismographs: innovations in late nineteenth-century Italian seismology. *Eur. Phys. J. H* 50, 20. https://doi.org/10.1140/epjh/s13129-025-00106-w

Matteucci, Carlo. 1868. Review. Sullo stato attuale delle Scienze fisiche in Italia e su alcune macchine di Fisica, per Pietro Blaserna. *Nuova Antologia di Scienze, Lettere ed Arti* 7(2): 421–424.

Melloni, Macedonio. 1851. Sopra una memoria offerta in dono alla Reale Accademia delle Scienze di Napoli. Osservazioni del Cav. Macedonio Melloni. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 547–554.

Melloni, Macedonio. 1854. Sull'eguaglianza di velocita che le correnti elettriche di varia tensione assumono nello stesso conduttore metallico. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 5: 319–325.

Mills, Mara. 2011. On Disability and Cybernetics: Helen Keller, Norbert Wiener, and the Hearing Glove. *differences* 22(2–3): 74–111. https://doi.org/10.1215/10407391-1428852

Moigno, François-Napoléon-Marie (Abbé). 1852. *Traité de télégraphie électrique: comprenant son histoire, sa théorie, ses appareils, sa pratique, son avenir, sa législation; précédé d'un exposé de la télégraphie en général et de la télégraphie ancienne de jour et de nuit*. 2e éd. Paris: A. Franck, Libraire-Editeur.

Moroni, Gaetano. 1857. *Dizionario di Erudizione Storico-Ecclesiastico*. Vol. 86. Venezia: Tipografia Emiliana.

Mossotti, Ottaviano Fabrizio. 1851a. Letter to P. Serpieri, Pisa, April 14, 1851. Archivio Provinciale delle Scuole Pie Toscane in Florence, MS, Regesto Religioso N. 470 [Religious Register no. 470].

Mossotti, Ottaviano Fabrizio. 1851b. Soluzione analitica del problema delle oscillazioni del pendolo avuto riguardo alla rotazione della terra del Sig. Prof. F. Mossotti. Squarcio di lettera al P. Serpieri. Pisa, April 18, 1851. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 232–236.

Nobile, Antonio. 1855. *Elogio storico di Macedonio Melloni recitato nella reale Accademia delle Scienze di Napoli nella tornata del 1 dicembre 1854*. Napoli: Stabilimento Tipografico di G. Nobile.

Palmieri, Luigi. 1883. *Nuove lezioni di fisica sperimentale e di fisica terrestre dettate dal Prof. Luigi Palmieri*. Napoli: Giovanni Jovene Librajo-editore.

Pancaldi, Giuliano, ed. 1983. *I congressi degli scienziati italiani nell'età del Positivismo*. Bologna: CLUEB.

Pianta, Carlo. 1878. Il Telefono a Milano (Milano, 10 Dicembre 1877). *L'Elettricista. Rivista Mensile* 2: 19–23.

Piazzoli, Emilio. 1880. La materia radiante e la teoria di Crookes. *Rivista Scientifico-industriale* 12: 141–155.

Powell, Baden. 1851. On the recent experiment showing the Rotation of the Earth by means of the Pendulum, May 9, 1851. *The London, Edinburgh, and Dublin Philosophical Magazine* 1: 561–564.

Reeves, Barbara. 1980. *Italian Physicists and Their Institutions, 1861–1911*. Ph.D. thesis (History of Science), Harvard University, Cambridge, MA.

Reeves, Barbara J. 1989. Le tradizioni di ricerca della fisica italiana nel tardo diciannovesimo secolo. In *La scienza accademica nell'Italia post-unitaria. Discipline scientifiche e ricerca universitaria*, ed. Vittorio Ancarani, 53–95. Milano: FrancoAngeli.

Regno d'Italia. 1862. *Regio Decreto 14 settembre 1862, n. 842: Approvazione del Regolamento universitario e di quelli delle Facoltà di giurisprudenza, di medicina e chirurgia, di scienze fisiche, matematiche e naturali, e di filosofia e lettere.* In *Raccolta ufficiale delle leggi e dei decreti del Regno d'Italia*, vol. 4, 2227–2251. Torino: Stamperia Reale.

Renzetti, Luigi. 1929. Le vicende storiche della Università di Urbino. In *Annuario della Università degli Studi di Urbino*, Anno Accademico 1928–29, 3–10. Urbino: Tipografia Melchiorre Arduini.

Rigge, William F. 1913. Experimental proofs of the Earth's rotation. *Popular Astronomy. A review of astronomy and allied sciences* 21(5): 208–216, 267–276.

Ròiti, Antonio. 1880–1883. *Elementi di Fisica. Libro di testo per i Licei*. Vol. 1–4. Firenze: Successori Le Monnier.

Rossetti, Francesco. 1878a. Sul Telefono di Graham Bell. Comunicazione effettuata nell'Adunanza del 16 Dicembre 1877 presso il Reale Istituto Veneto di Scienze, Lettere ed Arti di Venezia. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti* (dal Novembre 1877 all'Ottobre 1878), Serie 1, 4: 291–297.

Rossetti, Francesco. 1878b. Intorno ad alcune esperienze telefoniche. Comunicazione nella Adunanza del 10 Febbraio 1878. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti* (dal Novembre 1877 all'Ottobre 1878), Serie 5, 4: 351–353.

Rossetti, Francesco. 1878c. Relazione su alcune esperienze telefoniche. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti* (dal Novembre 1877 all'Ottobre 1878), Serie 1, 4: 567–577; *L'Elettricista* 2: 156–165.

Rossetti, Francesco. 1878d. Sui telefoni senza lamine. Comunicazione del 27 febbraio 1878. *Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti* (dal Novembre 1877 all'Ottobre 1878), Serie 1, 5: 661–665.

Secchi, Angelo. 1851. Sulle oscillazioni del pendolo avuto riguardo alla rotazione della terra. Lettera di A. Secchi al Compilatore. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 238–242.

Secchi, Angelo. 1864. *L'Unità delle Forze Fisiche. Saggio di Filosofia Naturale*. Roma: Tipografia Forense.

Serpieri, Alessandro. 1850. *Sull'Osservatorio Meteorologico del Collegio dei Nobili in Urbino. Al Sig. Conte Domenico Paoli di Pesaro. Relazione di Alessandro Serpieri delle Scuole Pie, Urbino, 30 Maggio 1850*, 3–8. Urbino.

Serpieri, Alessandro. 1851. Nota di A. Serpieri delle S. P. [This note refers to the preceding letter by Mossotti, "Soluzione analitica del problema delle oscillazioni del pendolo avuto riguardo alla rotazione della terra"]. *Annali di Scienze Matematiche e Fisiche, compiled by Barnaba Tortolini* 2: 237.

Serpieri, Alessandro. 1855a. Esperimenti sulla trasmissione simultanea di correnti elettriche opposte nel medesimo filo. Nota di A. Serpieri d. S. P. comunicata al direttore della Corrispondenza Scientifica di Roma. Urbino, 13 genn. 1855. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(45): 373–375.

Serpieri, Alessandro. 1855b. Sul fenomeno della trasmissione simultanea di correnti elettriche opposte in un medesimo filo. Seconda comunicazione del P. Alessandro Serpieri d. S. P. prof. di fisica e matematiche nella Università di Urbino. Urbino, 24 febraro 1855. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(48): 397–398.

Serpieri, Alessandro. 1855c. Risposta del prof. Serpieri al prof Zantedeschi. Lettera al Sig. Direttore del 12 marzo 1855. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(49): 411.

Serpieri, Alessandro. 1855d. Sulla trasmissione simultanea di correnti elettriche opposte in un medesimo filo. Terza comunicazione del P. Alessandro Serpieri d. S. P. professore di fisica nella Università di Urbino. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(50): 413–415.

Serpieri, Alessandro. 1855e. Descrizione del Telegrafo di Gintl col quale si effettua la corrispondenza simultanea fra due stazioni congiunte da un solo filo. *La Enciclopedia contemporanea formante un repertorio universale di fatti e notizie importanti in istoria, scienze, lettere, ed arti, commercio, e industria, e bibliografia italiana e straniera* 1: 244–249.

Serpieri, Alessandro. 1855f. Sul metodo Gintl per ottenere la corrispondenza simultanea fra due uffizi telegrafici riuniti da un filo metallico e da uno strato di terra: Lettera del Padre A. Serpieri ai Compilatori. *Il Nuovo Cimento* 1: 372–374.

Serpieri, Alessandro. 1868a. *La forza considerata nelle sue principali trasformazioni: discorso letto per l'incominciamento dell'anno scolastico 1867–68 nella Libera università di Urbino*. Urbino: Tipi della Cappella, per Savino Rocchetti.

Serpieri, Alessandro. 1868b. Leggi teoriche dell'efflusso dei gas dedotte dai nuovi principj termo-dinamici. Lettera del P. A. Serpieri al Prof. Giovanni Cantoni. Urbino, 1 May 1868. *Rendiconti del Reale Istituto Lombardo di Scienze e Lettere*, Serie 2, 1 (part one): 605–618.

Serpieri, Alessandro. 1869. *La forza considerata nelle sue principali trasformazioni. Seconda Edizione con aggiunte e note*. Urbino: Tipografia del Metauro.

Serpieri, Alessandro. 1878a. Il Telefono. Lettera a Lamberto Cappanera datata Urbino, 8 febbraio 1878. *L'Elettricista. Rivista di Scienze Fisiche e loro Applicazioni* 2(2): 95–97.

Serpieri, Alessandro. 1878b. Alcune esperienze sul telefono. Lettera del S. C. P. A. Serpieri al Prof. R. Ferrini. Urbino, 11 marzo 1878. *Rendiconti del Reale Istituto Lombardo di Scienze e Lettere*, Serie 2, 11(4–5): 194–199.

Serpieri, Alessandro. 1880a. Intorno agli esperimenti del Crookes sulla materia allo stato radiante: lettere del Prof. P. Alessandro Serpieri al direttore della Rivista Scientifico-Industriale di Firenze (dated May 2 and May 9, 1880). *Rivista Scientifico-Industriale* 12: 213–216.

Serpieri, Alessandro. 1880b. Nuove osservazioni e note sugli apparecchi di Crookes: lettera del Prof. P. Alessandro Serpieri al direttore della Rivista Scientifico-Industriale di Firenze (dated July 13, 1880). *Rivista Scientifico-Industriale* 12: 300–302.

Serpieri, Alessandro. 1882. *Il potenziale elettrico nell'insegnamento elementare della elettrostatica. La moderna teoria dei fenomeni elettrici trattata in modo elementare per i licei e gli istituti tecnici italiani*. Milano: Ulrico Hoepli.

Serpieri, Alessandro. 1884. *Das elektrische Potential oder Grundzüge der Elektrostatik. Die neuere Theorie der elektrischen Erscheinungen in elementarer Darstellung* (Translated by Dr. R. von Reichenbach). Wien: A. Hartleben's Verlag.

Serpieri, Alessandro. 1885a. *Le misure assolute meccaniche elettrostatiche ed elettromagnetiche con applicazioni a vari problemi. Trattato elementare*. Milano: Ulrico Hoepli.

Serpieri, Alessandro. 1885b. *Die mechanischen, elektrostatischen und elektromagnetischen absoluten Maasse mit Anwendung auf mehrfache Aufgaben* (Translated by Dr. R. von Reichenbach). Wien: A. Hartleben's Verlag.

Serpieri, Alessandro. 1886. *Traité élémentaire des mesures absolues, mécaniques, électrostatiques et électromagnetiques, avec applications à de nombreux problèmes; traduit et annoté par Paul Marcillac*. Paris: Gautier-Villars.

Shannon, Claude E. 1948a. A Mathematical Theory of Communication. *Bell System Technical Journal* 27(3): 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Shannon, Claude E. 1948b. A Mathematical Theory of Communication. *Bell System Technical Journa*l 27(4): 623–656. https://doi.org/10.1002/j.1538-7305.1948.tb00917.x

Shulman, Seth. 2008. *The Telephone Gambit: Chasing Alexander Graham Bell's Secret*. New York: W. W. Norton.

Targioni Tozzetti, Giovanni. 1780. *Notizie degli aggrandimenti delle scienze fisiche accaduti in Toscana nel corso di anni LX del secolo XVII*, Tome 2, Part 2. Firenze: Giuseppe Bouchard Libraio.

Vescovali, Angelo. 1851. Costruzione geometrica per determinare la deviazione angolare del piano d'oscillazione di un pendolo a qualunque latitudine. Nota. *Annali di Scienze Matematiche e Fisiche compilati da Barnaba Tortolini* 2: 301–305.

Wiener, Norbert. 1961. *Cybernetics: Or Control and Communication in the Animal and the Machine*. 2nd ed. Cambridge, MA: The MIT Press.

Zantedeschi, Francesco. 1855a. *Memoria sul simultaneo passaggio delle correnti elettriche opposte ai circuiti metallici chiusi ed isolati dalla terra, e delle loro differenze coi circuiti misti delle linee aereo-telluriche, in relazione alla telegrafia elettrica*, 3–17. Venezia: Tip. Antonelli.

Zantedeschi, Francesco. 1855b. Estratto di una sua memoria sul simultaneo passaggio delle correnti elettriche opposte ai circuiti metallici chiusi ed isolati dalla terra e delle loro differenze coi circuiti misti delle linee aereo-telluriche, in relazione alla telegrafia elettrica. *Atti delle Adunanze dell'Imp. Reg. Istituto Veneto di Scienze, Lettere ed Arti* (Anno Accademico 1854–1855), Puntata 3: 111–125.

Zantedeschi, Francesco. 1855c. Delle correnti elettriche simultanee che passano in direzioni opposte sul medesimo filo. Esperienze di Fr. Zantedeschi. *Annali delle opere pubbliche e dell'Architettura* 5: 140–142.

Zantedeschi, Francesco. 1855d. *Telegrafo a correnti dirette successive e derivate contemporanee per la doppia simultanea corrispondenza sopra un solo filo comunicante colla terra*, 1–2. Padova: Co' Tipi di Angelo Sicca.

Zantedeschi, Francesco. 1855e. Delle correnti elettriche simultanee che passano in direzioni opposte sul medesimo filo. Esperienze del prof. Cav. Francesco Zantedeschi comunicate alla Corrispondenza Scientifica di Roma. Padova, 27 Ottobre 1854. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(41): 238–239.

Zantedeschi, Francesco. 1855f. Risposta del prof. Zantedeschi al prof. Serpieri sulla Nota riguardante la trasmissione simultanea di correnti elettriche opposte sul medesimo filo. Lettera al Sig. Direttore del 27 febbraio 1855. *La Corrispondenza Scientifica in Roma. Bullettino Universale* 3(49): 411.