HISTORY OF WIRELESS

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Preface

The motivation to write about the History of Wireless comes from Auguste Comte (1798–1857), a French philosopher who is termed the father of positivism and modern sociology [*Les Maximes d'Auguste Comte* (Auguste Comte's Mottos), http://www.membres.lycos.fr/clotilde/]:
On ne connaît pas complètement une science tant qu'on n'en sait pas l'histoire.
(One does not know completely a science as long as one does not know its history.)
Aucune science ne peut être dignement comprise sans son histoire essentielle (et aucune véritable histoire n'est possible que d'après l'histoire générale).
(No science can be really understood without its essential history (and no true history is possible if not from general history.)
L'histoire de la science, c'est la science même.
(The history of science is the science itself.)

and from Marcus T. Cicero (106–43 BC), Roman statesman, orator, and philosopher:

To be ignorant of what occurred before you were born is to remain always a child. For what is the worth of human life, unless it is woven into the life of our ancestors by the records of history?
The causes of events are ever more interesting than the events themselves. History is the witness that testifies to the passing of time; it illuminates reality, vitalizes memory, provides guidance in daily life, and brings us tidings of antiquity.

and enforced by Niccolò Machiavelli (1469–1527), from Florence, Italy:

Whoever wishes to foresee the future must consult the past; for human events ever resemble those of preceding times. This arises from the fact that they are produced by men who ever have been, and ever shall be, animated by the same passions, and thus they necessarily have the same results.

and further elucidated by William Cuthbert Faulkner (1897–1962), the American Nobel Laureate writer:

You must always know the past, for there is no real Was, there is only Is.

and the rationale given by David Hume (1711–1776), the Scottish philosopher and historian:

Mankind is so much the same, in all times and places, that history inform us of nothing new or strange in this particular. Its chief use is only to discover the constant and universal principles of human nature.

and ending in Aristotle (384–322 BC), the Greek philosopher:

If you would understand anything, observe its beginning and its development.

However one has to be careful in writing history, as the British historian Arnold Joseph Toynbee (1989–1975), reminds us that:

"History" is a Greek word which means, literally, just "investigation".

In addition, the French humanist François-Marie Arouet de Voltaire (1694–1778), points out the duties of the historian:

A historian has many duties. Allow me to remind you of two which are important. The first is not to slander; the second is not to bore.

and further reinforced by Pope Leo XIII, born Vicenzo Gioacchino Raffaele Pecci in Italy (1810–1903):

The first law of history is to dread uttering a falsehood; the next is not to fear stating the truth; lastly, the historian's writings should be open to no suspicion of partiality or animosity.

However, in writing about history one has to follow the definition of the American lawyer Noah Webster (1758–1843), in his 1828 dictionary, that states:

History is a narrative of events in the order in which they happened with their causes and effects. A narrative (story) is very different from an annal (a summary listing of dates, events, and definition). Narratives (stories) should be used for teaching history if the student is to gain any understanding. Annals are best used for summary review by one who has already learned the stories as Annals relate simply the facts and events of each year, in direct chronological order, without any observations of the annalist.

For a person to appreciate history, there must be told a story that relates the heart-felt beliefs that led those people to the actions they chose. Without such an understanding of their heart, there is no understanding of the history. To know history is to know what people did and why, that is to know their heart. Cold names without warm understanding of why they did the things they did is no more use to a child than learning the alphabet and not learning to form words. It takes stories from the time to be able to understand the time you are studying. It takes stories leading up to the time, as well as stories of that time.

Therefore to fulfill the requirements of the definition of history according to Webster, we have followed in this book, the two paths as suggested. **The first two chapters provide the annals of wireless, whereas the remaining chapters are narratives of history.**

History is reflected on by the French writer François-René de Chateaubriand (1768–1848), as:

History is not a work of philosophy, it is a painting; it is necessary to combine narration with the representation of the subject, that is, it is necessary simultaneously to design and to paint; it is necessary to give to men the language and the sentiments of their times, not to regard the past in the light of our own opinion.

and history follows the path described by the German philosopher, social scientist, historian, and revolutionary Karl Heinrich Marx (1818–1883):

Men make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under circumstances directly found, given and transmitted from the past.

ending in the words of the American president Abraham Lincoln (1809–1865):

History is not history unless it is the truth.

and those of the Scottish writer Hugh Amory Blair (1718–1800):

As the primary end of History is to record truth, impartiality, fidelity and accuracy are the fundamental qualities of a Historian.

However, it is important to remember that as the American poet and writer Robert Penn Warren (1905–1989), suggests:

History cannot give us a program for the future, but it can give us a fuller understanding of ourselves, and of our common humanity, so that we can better face the future.

and the French historian Numa-Denis Fustel de Coulanges (1830–1889), notes what history is not:

History is not the accumulation of events of every kind which happened in the past. It is the science of human societies.

However, we sincerely hope that in presenting the history of wireless we have paid proper attention to it so that the following quotes do not come true, particularly in the words of the Spanish philosopher, poet, literary and cultural critic, Jorge Augustín Nicolás Ruiz de Santayana y Borrás (known in the United States, where he lived for many years, as George Santayana) (1863–1952):

History is always written wrong, and so always needs to be rewritten.

and enforced by the American jurist Oliver Wendell Holmes, Jr. (1841–1935):

History has to be rewritten because history is the selection of those threads of causes or antecedents that we are interested in.

Finally, we must be failing in our responsibilities if we do not follow the British historian Lord John Emerich Edward Dolberg-Acton (1834–1902):

History, to be above evasion or dispute, must stand on documents, not on opinions.

However, one must remember, as the Jacques Maritain Center points out, what history can and cannot do:

But the truth of history is factual, not rational truth; it can therefore be substantiated only through signs — after the fashion in which any individual and existential datum is to be checked; and though in many respects it can be known not only in a conjectural manner but with certainty, it is neither knowable by way of demonstration properly speaking, nor communicable in a perfectly cogent manner, because, in the last analysis, the very truth of the historical work involves the whole truth which the historian as a man happens to possess; it presupposes true human wisdom in him; it is "a dependent variable of the truth of the philosophy which the historian has brought into play." Such a position implies no subjectivism. There is truth in history. And each one of the components of the historian's intellectual disposition has its own specific truth.

A final remark is that conjecture or hypothesis inevitably plays a great part in the philosophy of history. This knowledge is neither an absolute knowledge in the sense of Hegel nor a scientific knowledge in the sense of mathematics. But the fact that conjecture and hypothesis play a part in a discipline is not incompatible with the scientific character of this discipline. In biology or in psychology we have a considerable amount of conjecture, and nevertheless they are sciences.

Mr. Ferenc M. Szasz (professor of history at the University of New Mexico) collected the above list of quotations about history over the course of his career. The *History Teacher* first published his list in the 1970s. The current list includes scores of new quotations he has come across in the intervening decades. We have also added a few. Readers are welcome to add to the list.

Next comes the definition or meaning of the word “wireless”. We follow here the explanation given by J. D. Kraus and R. J. Marhefka in their book on *Antennas for All Applications*, which states:

After Heinrich Hertz first demonstrated radiation from antennas, it was called wireless. And wireless it was until broadcasting began around 1920 and the word radio was introduced. Now wireless is back to describe the many systems that operate without wires as distinguished from radio, which to most people implies AM or FM.

And, finally we provide the roadmap of the book. In Chapter 1 we present a chronology of the developments in magnetism, electricity, and light till the time of Maxwell, who is generally regarded as the greatest physicist of the nineteenth century. The name of Maxwell is synonymous with electromagnetics and electromagnetic waves. Hence we make an attempt to describe who Maxwell was and what he actually did. It is also imperative to point out what was/is his theory as related to wireless. Chapter 2 provides the chronology of the development of wireless up to recent times. The evolution of Continental and British Electromagnetics in the nineteenth century ending in Maxwell is described in Chapter 3. Chapter 4 deals with the genesis of Maxwell's equations. In Chapter 5 it is outlined how the followers of Maxwell redeveloped Maxwell's theory and made it understandable to a broader audience through the experimental verification of Maxwell's results by Hertz. It is interesting to note that the four equations that we use today were not originally developed by Maxwell but by Hertz, who wrote them in the scalar form, followed by Heaviside, who in turn wrote them in vector form. Chapter 6 describes the work of Heaviside and his contributions. The relevant scientific accomplishments in wireless before Marconi is presented in Chapter 7 in detail. Chapter 8 discusses the achievements of Tesla, who holds the first patent for radio in the United States. In Chapter 9 the early experiment of Bose on millimeter waves is described. In fact, many of the artifacts like horn antennas and circular waveguides that he performed experiments with are still in current use. The contributions of Fleming in the development of wireless are presented next in Chapter 10. The many contributions of German scientists to wireless, including the achievements of Hertz, are described in Chapter 11, followed in Chapter 12 by the development of wireless telegraphy and telephony, including the pioneering attempts to achieve transatlantic wireless communications. Chapter 13 presents the evolution of wireless telegraphy in South Africa at the turn of the twentieth century. The development of antennas in Japan is described in Chapter 14, including both the past and the present. The historical background and development of Soviet quasi optics at near-mm and sub-mm wavelengths are illustrated in Chapter 15. Since waveguides are necessary for the circuits that generate, detect and process the waves, it is important to discuss the evolution of electromagnetic waveguides, as done in Chapter 16, from hollow metallic waveguides to microwave integrated circuits. Incidentally, that chapter is the only one that describes the important progress in electromagnetic waves made during and around the World War II period. Finally, in Chapter 17 a history of phased array antennas, and their relations to previous scanning array technology, is provided.

It is important to note that due to the large volume of literature existing on Marconi's work and because his fundamental contributions to the development of wireless communications are widely known and referred to, we explicitly choose to concentrate our attention on most specific and less known aspects and people who also made invaluable contribution to the development of wireless.

Every attempt has been made to guarantee the accuracy of the material in the book. We would, however, appreciate readers bringing to our attention any errors that may have appeared in the final version. Errors and any comments may be e-mailed to tksarkar@syr.edu, regarding all the contributors.

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1

INTRODUCTION

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1.1 PROLOGUE

This chapter provides an overview of the origin and the developments of magnetism, electricity, and light theories. The chronology is traced up to the time of Maxwell who was the first to link all three together in a formal way even though many conjectured about their interrelations before him. First, an overview of magnetism is provided, followed by that of electricity, and then that of light. The material presented in this chapter is collected from the various references given at the end of the chapter. In addition, the various scientific works done by Maxwell and his legacy are described. Finally, an overview of the theory of electromagnetic waves first developed by Maxwell and how it was subsequently modified by Hertz and Heaviside and later on by Larmor is presented. This is a unique theory in physics where the basic fundamental equations did not change, while their physical interpretations underwent at least two major modifications.

1.2 DEVELOPMENT OF MAGNETISM

The development of magnetism is traced through the last 5000 years.

2637 BC:

- Emperor Huang-ti of China used the compass in a battle to find the direction along which he should pursue his enemies.

1110 BC:

- Taheon-Koung, the Chinese minister of state, gave his crew a compass to sail from Cochin, China, to Tonquin.

1068 BC:

- Chinese vessels routinely navigated the Indian Ocean by compass.

1022 BC:

- Some Chinese chariots had a floating magnetic needle, the motion of which was communicated to the figure of a spirit whose outstretched hands always indicated the south.

1000 BC:

- Homer of Greece wrote that loadstones were used by the Greeks to direct navigation at the time of the siege of Troy.

950 BC:

- King Solomon (970–928 BC) of Israel knew how to use the compass.

900 BC:

- Magnes, a Greek shepherd, walked across a field of black stones which pulled the iron nails out of his sandals and the iron tip from his shepherd's staff, as suggested by the Italian natural philosopher Giambattista della Porta (1540–1615). The same story had also been told by Gaius Plinius Secundus, better known as Pliny the Elder (23–79AD). This region became known as *Magnesia* in Asia Minor. Probably, the word magnet evolved from this and the iron oxide ore was named as magnetite. Pliny in *Naturalis Historia* also wrote of a hill near the river Indus that was made entirely of a stone that attracted iron.

600 BC:

- First recorded information by Greek philosophers, particularly by Thales of Miletus (624–546 BC), about the magnetic properties of natural ferric oxide (Fe_3O_4) stones. It was also known to the Indians. For example Susruta, a physician in the sixth century BC in India, used them for surgical purposes.

121 AD:

- The Chinese dictionary *Choue Wen* contained an explicit recorded reference of the magnet.

1186:

- Alexander Neckam (1157–1217), a monk and man of science of St. Albans, England, described the working of a compass in the western literature for the first time and he did not refer to it as something new, indicating that it had been in use for some time.

1254:

- Roger Bacon, a philosopher also called Friar Bacon and surnamed Doctor Mirabilis (1214–1294), a Franciscan monk of Ilchester, England, dealt with the magnet and its properties in *Opus Minus*.

1269:

- Petrus Peregrinus or Pierre de Maricourt, a Crusader from Picardy, France, who was a mathematician, aligned needles with lines of longitude pointing between two pole positions of the stone and established the concept of two poles of the magnet. He wrote it in *Epistola de Magnete*.

1400:

- Jean de Jaudun of France wrote about magnets and the problem of action-at-a-distance.

1492:

- Christopher Columbus (1451–1506), from Italy (navigating under the Spanish flag) was the first to determine astronomically the position of a line of no magnetic variation. He observed the compass changes direction as the longitude changes.

1497:

- Portuguese navigator Vasco da Gama (1469–1524) used the compass for his trip to the Indies. He said that he found pilots in the Indian Ocean who made ready use of the compass.

1530:

- Spanish cartographer Alonzo de Santa Cruz produced the first map of magnetic variations from the true north.

1544:

- German technician and physicist Georg Hartmann (1489–1564) also discovered the magnetic dip of the compass.

1558:

- Giambattista della Porta (1540–1615), an Italian natural philosopher, performed experiments with the magnet for the purpose of communicating intelligence at a distance.

1576:

- Robert Norman, a manufacturer of compass needles at Wapping, England, rediscovered the dip or inclination to the Earth of the magnetic needle in London and was the first to measure them.

1590:

- Giulio Moderati Caesare, an Italian surgeon, observed the conversion of iron into a magnet by geographical position alone.

1600:

- Sir William Gilbert (1544–1603), court physician to Queen Elizabeth I, discovered that the Earth was a giant magnet and explained how compasses worked. He gave the first rational explanation to the mysterious ability of the compass needle to point north-south.

1644:

- René Descartes (1595–1650), the French physicist, physiologist, mathematician, and philosopher, in the *Principia Philosophiae*, theorized that the magnetic poles were on the central axis of a spinning vortex of fluids surrounding each magnet. The fluid entered by one pole and leaves through the other.

1687:

- English scientist and mathematician Sir Isaac Newton (1642–1727) estimated an inverse cubed law for the two poles of a magnet. He also published *Principia* that year whose costs and proofreading of the material were carried out by the English astronomer and mathematician Edmund Halley (1656–1742).

1699:

- Halley performed the first magnetic survey showing the variation of the compass.

1716:

- Halley proposed that the magnetic effluvia moving along the magnetic field of the Earth results in the aurora.

1730:

- English scientist Servigton Savery produced the first compound magnet by binding together a number of artificial magnets with a common pole piece at each end.

1740:

- Gowen Knight produced the first artificial magnets for sale to scientific investigators and terrestrial navigators.

1742:

- Thomas Le Seur and Francis Jacquier, of France, in a note to the edition of Newton's *Principia* that they published, showed that the force between two magnets was inversely proportional to the cube of the distance.

1750:

- English scientist John Mitchell (1724–1793) published the first book on making steel magnets. He also discovered that the two poles of a magnet were equal in strength and that the force between individual poles followed an inverse square law.

1759:

- German physicist Franz Maria Ulrich Theodor Hoch Aepinus (1724–1802) published *An Attempt at a Theory of Electricity and Magnetism*, the first book applying mathematical techniques to the subject.

1778:

- Sebald Justin Brugmans (1763–1819), a Dutch professor of natural history, demonstrated the diamagnetic properties of bismuth and antimony. A diamagnetic substance is one that has a permeability of less than one. A bar or a needle of such a substance, when free to move, will tend to be at right angles to the lines of force in a magnetic field.

1785:

- French physicist Charles-Augustin de Coulomb (1736–1806) independently verified Mitchell's law of force for magnets and extended the theory to the law of attraction of opposite electricity. He was the proponent of a two fluid theory proposed in 1759 by the English physicist Robert Symmer based on the ideas of the French physicist Charles François de Cisternay du Fay (1698–1739).

1820:

- French physicists Jean-Baptiste Biot (1774–1862) and Felix Savart (1792–1841) showed that the magnetic force exerted on a magnetic pole by a wire falls off as $1/r$ and is oriented perpendicular to the wire similar to what the Danish physicist Hans Christian Ørsted (1777–1851) had predicted. The English mathematician Edmund Taylor Whittaker (1873–1956) says that "This result was soon further analyzed, to obtain $d\mathbf{B} \propto (I d\mathbf{s} \times \mathbf{r})/r^3$, where $\mathbf{B}$ stands for the magnetic flux vector, I for the current, $\mathbf{r}$ for the position vector, and ds for the elemental length of current."

1821:

- British scientist Michael Faraday (1791–1867) discovered that a conductor carrying a current would rotate around a magnetic pole and that a magnetized needle would rotate about a wire carrying a current.

- Self-educated British physicist William Sturgeon (1783–1850) made the first electromagnet.
- Physicist Prof. Joseph Henry (1797–1878) of Albany Academy, New York, made an electromagnet with superimposed layers of insulated wires.
- German physicists Johann Solomon Christoph Schweigger (1779–1857) and Johann Christian Poggendorf (1796–1877) constructed independently the first galvanometers.

1824:

- French mathematician Siméon–Denis Poisson (1781–1840) invented the concept of the magnetic scalar potential and of surface and volume pole densities described by the formula

$$\boldsymbol{F} = -\int \boldsymbol{M} \bullet \frac{\boldsymbol{r}-\boldsymbol{r}'}{|\boldsymbol{r}-\boldsymbol{r}'|^3} dV' = \int \frac{\nabla' \bullet \boldsymbol{M}}{|\boldsymbol{r}-\boldsymbol{r}'|} dV' - \int \frac{\boldsymbol{M} \bullet \boldsymbol{n}'}{|\boldsymbol{r}-\boldsymbol{r}'|} dS' .$$

  where $\boldsymbol{F}$ is the electric vector potential, $\boldsymbol{M}$ is the magnetic current, $\boldsymbol{r}$ and $\boldsymbol{r}'$ are the field and the source coordinates, respectively, $\boldsymbol{n}'$ is the direction of the outward normal to the surface, dS' and dV' are the elemental surface and volume elements, respectively. He also provided the formula for the magnetic field inside a spherical cavity within magnetized material.
- French physicist Dominique François Jean Arago (1786–1853) demonstrated that a copper disk can be made to rotate by revolving a magnet near it.

1825:

- French mathematician and physicist André-Marie Ampère (1775–1836) published his collected results on magnetism. His expression for the magnetic field produced by a small segment of current was different from that which followed naturally from the Biot-Savart law by an additive term which integrated to zero around a closed circuit. In his memoir one found the result known as *Stoke's theorem* written as $\oint \boldsymbol{B} \bullet d\boldsymbol{s} = \mu_0 I$, where μ_0 is the permeability of vacuum. James Clerk Maxwell described this work as *one of the most brilliant achievements in science*.
- Italian physicist Leopoldo Nobili (1784–1835), invented a static needle pair, which produced a galvanometer independent of the magnetic field of the Earth.

1831:

- Henry discovered that a change in magnetism can make currents flow, but he failed to publish this. In 1832 he described self-inductance as the basic property of an inductor. In recognition of his work, inductance is measured in henries. He improved upon Sturgeon's electromagnet, substantially increasing the electromagnetic force. He also developed the principle of self-induction.

1832:

- Karl Friedrich Gauss (1777–1855), the mathematician, astronomer, and physicist from Germany, independently stated Green's theorem (named after the British mathematician George Green, 1793–1841) without proof. He also reformulated Coulomb's law without proof. He formulated separate electrostatic and electrodynamic laws including Gauss's law. All of it remained unpublished till 1867.

1838:

- Wilhelm Eduard Weber (1804–1891), a physicist from Germany, together with Gauss applied potential theory to the magnetism of Earth.

1850:

- Irish-Scottish physicist William Thomson (Lord Kelvin, 1824–1907) invented the idea of magnetic permeability and susceptibility, along with the separate concepts of ***B***, ***M*** and ***H***, where ***H*** stands for the magnetic field intensity.

1853:

- William Thomson used Poisson's magnetic theory to derive the correct formula for magnetic energy: $U = 0.5 \int \mu H^2 \, dV$. He also gave the formula $U = 0.5LI^2$, where U is the magnetic energy, μ is the permeability, and L is the self induction parameter.

1864:

- James Clerk Maxwell (1831–1879), the physicist and mathematician from Scotland, published a mechanical model of the electromagnetic field. Magnetic fields corresponded to rotating vortices with idle wheels between them and electric fields corresponded to elastic displacements, hence displacement currents. The equation for ***H*** now became $\nabla \times \boldsymbol{H} = 4\pi \boldsymbol{J}_{tot}$, where $\boldsymbol{J}_{tot}$ is the total current, conduction plus displacement, and is conserved, i.e., $\nabla \bullet \boldsymbol{J}_{tot} = 0$. They were all available in scalar form in his paper *On Physical Lines of Force*. This addition completed Maxwell's equations and it now became easy for him to derive the wave equation exactly, and to note that the speed of wave propagation was close to the measured speed of light. Maxwell wrote:

  > *We can scarcely avoid the inference that light is the transverse undulations of the same medium which is the cause of electric and magnetic phenomena. Thomson, on the other hand, says of the displacement current, (it is a) curious and ingenious, but not wholly tenable hypothesis.*

  Maxwell read a memoir before the Royal Society in which the mechanical model was stripped away and just the equations remained. He also discussed the vector and scalar potentials, using the Coulomb gauge. He attributed physical significance to both of these potentials. He wanted to present the predictions of his theory on the subjects of reflection and refraction of electromagnetic waves, but the requirements of his