Foreword

The electronic science is quite young. Apart from early investigations on electric conduction phenomena in rarefied gases, we must wait until the early twenties to have a comprehensive explanation by the atomic theory of the so called thermoionic emission and of the conduction in vacuum. The term ‘electronics’ derives from the conduction by electrons between electrodes inside vacuum tubes. The same term was improperly extended to circuits which used solid state devices to replace vacuum tubes, but semiconductor circuits should be better referred to as solid-state electrotechnics. We must remember that the mobility of electrons in conductors has been estimated in about one millimeter per second. Signals could not propagate through solid-state circuits by moving electrons. For the said reason, dating the beginning of electronic science around 1910 somewhere after the invention of the diode by John Ambrose Fleming and of the ‘Audion’ triode by Lee De Forest, we have to deal with about sixty years of developments. At the very beginning we observe a limited, occasional and even sometimes empirical use of vacuum tubes and in many cases electro-mechanical solutions were still preferred, mainly due to the gross inadequacy of vacuum technologies and to the lack of experience in the new science by designers. In the twenties and in the thirties we assist to the development of radios which enters into the everyday life of people and in some specialized fields, as in simple communication and navigation sets. The frequency spectrum in those years did not exceed few megahertz and anything above some 20 MHz was considered as UHF, Ultra High Frequency, worth of publication on specialized press.

The most impressive momentum in electronics occurred immediately before and during WWII, pushed by military. The most noticeable results could be seen in the developments of radar, navigation and communication equipment. Useful frequency spectrum broadened to about 30 GHz. Electronic devices took the control of every activity in military operations. At the end of the war and for the next couple of decades the fallout of military efforts involved all the fields, from instrumentation to computers and peripherals, from microwave communication links to air traffic control, leading to the deep changes in habits and lifestyle of people. The microwave oven was a byproduct of radar industry. The same transistor, the elementary active building block of solid-state electronics, was a byproduct of developmental balanced mixers for radar receivers. At the same time modern computers are an evolution of early code cracking machines, as ‘Colossus’.

Well in the sixties and even with the precautions due to the evolution in components and in circuits, generations of top electronic designers and engineers grew referring to the twenty eight volumes condensing experiences gained during the war at the M.I.T. Radiation Laboratory.

In the fifties we assist to the continuous improvement of components and circuits with subsequent increase of complexity, performances and reliability and with some trends toward the miniaturization. Vacuum tubes still were the only possible choice in critical and high-power applications. Subminiature and high-performance tubes were still preferred in the late fifties with few exceptions in the most complex equipment, where power saving was a premium, as in digital computer mainframes. Solid-state devices were attractive for many aspects, as miniaturization, readiness to operate, power saving. Unfortunately point-contact and later diffused junction transistors were still largely unreliable, subject to irreversible damages by vibrations, voltage spikes and overheating, and then viewed with suspicion.

From the sixties we assist to the gradual growth of semiconductors that replace vacuum tubes wherever possible. Tubes continue to be used in high-power applications and in some niche markets, as in the case of cathode ray television and computer displays. In many equipment engineering still resembles the rules of the vacuum tube golden ages, with aluminum chassis hosting the various printed circuit subassemblies, all designed for ease of service and interconnected by a complex harness. But ease of service gradually lost its importance due to the increase in reliability derived from large scale integration and resulting part count reduction. Assembling techniques moved to single printed circuit boards populated of surface mounted devices to be discarded at the end of their life.

With use of microcontrollers and of programmable logic the same architectural design evolved toward an amorphous block diagram with an equally amorphous appearance. A keyboards, some menus and a display replaced knobs, switches, lamps and panel meters. All the sets had the same look, all were more or less easily useable, all could do more and more, well beyond actual needs, but none of them could be appreciated and loved as happened in the past for a simple vacuum tube radio with its polished mahogany cabinet, its smell of overheated varnish and its warm sound.

The evolution of electronics in the years can be appreciated looking at remarkable applications, as radio, radar, television, telecommunications, computers and at all the related instrumentation. Unfortunately many electronic sets were bulky and heavy. A collection of such sets would have required prohibitive space. A simpler and more accurate way to appreciate the progress of this science in the years is to give a closer look to the basic components, the vacuum tubes. The following table summarizes some of the relevant steps related to the collection both in applications and in the vacuum tube developments.

Year(s)	
1900 - 1910	In 1904 Ambrose Fleming, adviser of Marconi Wireless Company, used for the first time a bulb similar to the Edison ‘Electrical Indicator’ as ‘Oscillation Valve’, later known as diode, to detect radio frequency waves. In 1907 Lee De Forest, after having experimented some electrode arrangements capable of amplifying, disclosed its grid type Audion, the first triode amplifier. Both diodes and triodes remains laboratory oddness and radio continues to use electro-mechanic solutions. This 1910 Marconi catalog shows how magnetic and carborundum detectors were widely preferred.
1915	Robert Goddard, later known for his work on the rockets, patents a double anode oscillator tube which would originate Collins-Amperex C100A around 1936.
1915 - 1918	The Great War pushed the diffusion of vacuum tubes mainly for telephone and short range communications. Power limits for transmitting tubes gradually increased up to some 250 W. In long range communications, spark gaps were still the sole reliable source, while vacuum tube amplifiers helped to increase the sensitivity of receivers.
1920	In England Captain Stanley Mullard founded Mullard Radio Valves, beginning to manufacture high power tubes for British Admiralty with silica envelope. Albert Hull at General Electric investigated the behavior of cylindrical diodes operating in a magnetic field, originating the magnetron.
1921	J.B. Johnson improved the Brown cathode ray tube using a hot cathode. This can be considered the forerunner of any CRT later used in radar, television, instrumentation and computer displays. Modern atomic theories by Rutherford, Bohr et al definitely stated that the conduction in vacuum tubes is caused by elementary particles referred to as electrons. The term ‘electronics’ began to be used referring to circuits based on vacuum tubes and to the same tubes.
1923	Housekeeper perfected a glass to copper seal process, making it possible the design of high power tubes with external anode in contact with cooling fluids.
About 1923	Introduction of high-efficiency, oxide-coated emitters in vacuum tubes. The most known dull-emitter tubes were made by Philips with the Miniwatt trademark.
1924 - 1925	Introduction of unipotential cathode (indirect heated cathode) vacuum tubes for use with AC mains, as the Kellog type 20 and 401.
About 1927	Introduction of the early screen grid amplifiers for high-frequency improved gain
1935	Oscar Heil and his wife Agnessa Arsenjeva devised the first velocity modulated UHF oscillator. Known as Heil tube, it was the forerunner of klystron. RCA introduced all-glass ‘acorn’ tubes, designed to operate in the UHF region. Early experimental microwave links use split-anode magnetrons.
1936-1937	Bell Telephone introduced doorknob style power tubes, capable of operation in the UHF region. Doorknobs were used in the transmitter of early air intercept radar prototypes made in Great Britain by the Bowen group. Similar tubes were used in 1939 in the prototypes of the American CXAS naval radar. Special silica tubes are designed for radar transmitters.
1939 1939	Russell and Sigurd Varian at Stanford University build the early klystron tube which used the ‘Rhumbatron’ resonators devised by W. W. Hansen. In Palo Alto, California, Bill Hewlett and Dave Packard, graduated at Stanford under Frederick Therman, founded Hewlett-Packard to manufacture audio generators. In England STC introduced the early disc sealed planar triodes, useful as signal

	amplifiers in VHF and UHF regions. In the meanwhile GEC introduced some external anode triodes capable of generating high-power pulses up to 300 MHz. First network of Chain Home early warning radar system was completed.
1940	GEC build samples of E-1189 multicavity magnetron operating at 9.8 cm and developed at the Birmingham University. In August a sample was brought to America by the Tizard Mission, giving rise to a very close cooperation between the two countries in the development of radar sets for every application. E-1189 was produced as NT98 and originated several American productions, as 706A, 2J22 or Canadian REL 3C and 3D. The Tizard mission also established the basis for the development of other innovative systems, as the air traffic control based upon ground radar stations and IFF transponders, or even accurate navigation systems as Loran, Shoran and DME. Waiting for production of S-Band airborne radar sets, America starts to equip its aircraft with British VHF AI radar sets and copies of the same. By December samples of American made copies of E-1189 magnetron were delivered by Bell Labs. and presumably by Raytheon. R.W. Sutton designed the very early S-band klystron oscillator, known as 'Sutton tube'. Samples were delivered complete of resonator as 10E/501.
1941	By February an S-Band radar prototype starts to operate from the roof of M.I.T. Radiation Laboratory. By the end of March the early British S-Band 271 naval radar starts to operate on HMS Orchis. In July James Sayers devised the magnetron strapping technique to prevent oscillations in modes different from the pi one. The way was then opened to design and build magnetrons of unlimited power. By the same month a prototype of X-Band magnetron was operating at M.I.T., followed shortly later by the first production batch of the type 2J21. At the same time early production batches of 723A X-band klystron and of 724A T/R switch were launched.
1942 to 1945	Both America and Great Britain continued the development of ground, naval and airborne radar sets for every military needs. EMI builds the only pulse power klystron of the war, the CV150. New components are introduced for X-band radar transmitters. They include 725A and 2J51A in America and CV208 and CV209 in England, In parallel we see the development of ECM system to intercept and jam hostile emissions. In America this activity is coordinated by the Radio Research Laboratory of the Harvard University, leading to the development of split-anode magnetrons as 5J29, 5J30, 5J32, 5J33 and ZP-599. See also DV27 and DV57. Small radar-like systems enter even in the fuzes of anti-aircraft ammunition and of artillery shells to make them detonate to the proper distance from the targets. Vacuum tubes and other components used in fuzes are designed to withstand accelerations exceeding 20.000 G. Communication systems become more and more complex, ranging from VLF up to microwaves depending upon the needs. Teletype and facsimile sets are in use in American forces. America introduces revolutionary designs in communication equipment, with the use by Collins of solutions as Autotune and PTO beating with crystal controlled oscillators to obtain accuracy and ease of tuning. Even instrumentation evolves to maintain the new systems directly in theaters of operation. Radar installations were all equipped with synchroscope, spectrum analyzer, power meter and other equipment hard to find even in advanced laboratories. Instruments had to be rugged and readily usable in field and their accuracy easily verifiable, often against a self-contained calibrator.

1946	After the end of WWII Howard Vollum and Melvin Murdock founded the Tektronix, building a new generation of oscilloscopes characterized for their time-base sync and sweep features. In the same year the decision of dismantling the MIT Radiation Lab. is taken. People who had contributed to the most advanced innovations during the war are guaranteed one more year of salary to summarize their relevant experiences. Thus is born the MIT Radiation Laboratory Series, a 28-volume encyclopedia covering all the issues on microwaves, radar and navigation systems developed at the date. The Radiation Lab. Series will be the primary reference, a true bible, for each electronic engineer well in the sixties. Rudolf Kompfner at the Clarendon Laboratory developed the TWT amplifier, later improved with Pierce at Bell.
1947	Most of the military contracts continue and delivered sets are directly sold on the surplus market, but conversion back to commercial products is encouraged. Radar and navigation systems, as ILS, DME, Loran and VHF omni-range, are approved by PICAO for use worldwide by civil aircraft. Collins introduces the 75A1, the first commercial receiver with crystal controlled first conversion and variable frequency PTO in the second conversion. This scheme is likely to become a classic in the Collins line, as in the 51J and in the marvelous R-390. It will be copied by any manufacturer of high-end receivers. In December at Bell Laboratories Walter Brattain, John Bardeen and their colleague William Shockley demonstrate the first transistor amplifier. Transistor will be a laboratory oddness until the mid fifties, when more reliable diffused-junction types are available in volume at attractive prices.

From the late forties to the mid fifties we see a trend to miniaturization of vacuum tubes and of associated components together with an increase of their reliability and a parallel increase of circuital complexity. High performance analog computers give the solutions to new problems arising by high-speed jet propelled aircraft and their intercept by missiles, but vacuum-tube digital computers and related peripherals, as digital mass memories, start growing in complexity and performances.

A high-speed printer may require over than 1.000 tubes to store the characters to print, but it is fully operating in 1951. In 1955 we find an optical character reader operating at 3.600 words per minute. Small and lightweight computers control the flight of military aircraft. Digital techniques enter in the instrumentation and we find 10 MHz digital frequency meters since 1952.

Vacuum tubes evolve accordingly with increased performances and reliability required in the new applications. Industry had gained considerable experience during the war in hastily designing tubes capable to operate in extreme environments and now they have the time to refine materials and technologies for every major application. So we find high-rel tubes developed for computer applications, with low cathode interface resistance and long operational life. For very special applications, as the repeaters of the submarine cables Avana - Key West and TAT-1 transatlantic system, we also see very special tubes, the Bell Telephone 175HQ and the 455A, with observed MTBF of several centuries.

From the mid fifties we assist to a parallel growth of vacuum tubes and of semiconductors, with solid state devices progressively occupying new application areas. Vacuum tubes evolve with the introduction of new ceramic materials in their bodies and new multi-layer materials for electrodes. Semiconductors start to diversify and new devices are added, including zener and tunnel diodes, varactors, unijunction transistors, silicon controlled rectifiers or silicon controlled switches.

The collection is mainly focused on the evolution of electronics around WWII and later, up to the sixties, in two leading countries, Great Britain and America. This because of the relevance of these countries in developing most of the known technologies, equipment and components and even because of the relative ease in finding every kind of related technical papers and documentation.

The evolution is also monitored by observing some communication and navigation sets and even some samples of high-end instrumentation, oscilloscopes and signal generators, as well as AC bridges. A special section is dedicated to DC measurements, including the today banned voltage standards based upon Weston reference cells. Another section is dedicated to monitoring the evolution of music reproduction through FM radio sets. Radio evolution was related to the parallel development of music sources, vinyl records, tape recorders and Hi-Fi equipment.

Nevertheless the more complete vision of the evolution is given by the collection of electron tubes, covering a wide variety of special types developed for almost any kind of application, thanks to the human ingenuity and the continuous research efforts.

FR-114/U digital frequency meter using trochotron decade counters. Click on image for more information.