Some History of Residential Wiring Practices in the U.S.

David A. Dini P.E.
Underwriters Laboratories Inc.

Abstract:

On December 31, 1879, Thomas Edison exhibited his newly invented electric lighting in a few houses along a residential neighborhood in Menlo Park, New Jersey. That New Year's Eve night proved to be not only historical in terms of its significance to American ingenuity and invention, but it also signified the beginnings of residential electrification in the United States. Although originally available to only the wealthiest of families, by the turn of the century electricity in the home was becoming a reality for more and more people. This paper traces the history of some residential wiring practices from the early days of electricity into the 21st century. Wire and cable systems, overcurrent protection, raceways and boxes, wire splices and terminations, wiring devices, grounding, polarity and special protection devices are presented from the historical perspective of time, necessity, and technology. The influence of Code[1] requirements and common trade practices are also presented.

Wire and Cable Systems:

In 1892 Thomas Edison was awarded a patent for what he called "electric conductor." Edison described the object of his invention as effectively insulating wire so that it will be waterproof and fireproof. His electric conductor consisted of three parts (see Fig. 1); a) the conducting wire, b) a cotton braid separator over the wire, and c) an outer covering of rubber compound. Edison obviously knew that if his electric lamp was ever going to become a household item, the house itself had to be "wired" to accommodate the use these lamps, as well as countless other appliances that were soon to be envisioned. Edison also knew the dangers of electricity and fire, and in his patent he states, "… also fire-proof, so that if by accident the wire becomes red-hot the insulating-covering will not be set on fire and burned, …" Here are some of the more typical residential wiring systems.

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[1] "Code" or "NEC" refers to the National Electrical Code®, published by the National Fire Protection Association, Quincy, Ma.

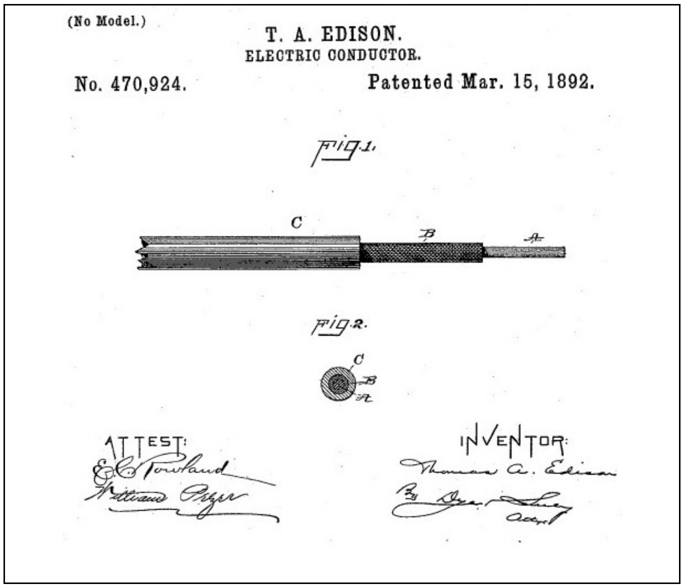


Fig. 1 – Edison’s Electric Conductor

Knob-and-Tube

The very earliest residential wiring systems were an open wiring system often referred to as “knob-and-tube.” The individual conductors were run spaced apart at least 2-1/2 inches (if exposed), but as the wires passed through walls and floors, they could be susceptible to dampness and abrasion, which could eventually lead to leakage currents and arcing fires. For protection in these places, “insulating tubes” were used. These tubes were made of porcelain, with a flange on one end and set on an angle to prevent the tube from sliding through the hole. To support the individual conductors in other places, a wide variety of insulators, including porcelain knobs and cleats were used (see Fig. 2). These were nailed to the wood structure, and would have a leather washer under the nail head to prevent the porcelain from being cracked when it was hammered in place. Although knobs had two grooves, they could not be used to support two wires of opposite polarity. However, cleats could be used when wires were run in parallel. In addition to keeping the wires spaced apart, these knobs and cleats also helped keep the conductors away from wood and other damp surfaces, as well as providing a degree of strain relief. Where free ends of wire attached to boxes, fixtures, and other devices, a special water resistant cotton braid tubing known as “loom” was used to cover the wire. Knob-and-tube wiring systems began being phased out in the 1930’s, probably because of the then growing popularity of non-metallic and armored cable systems for residential buildings. Knob-and-tube wiring has not been permitted by the NEC for new installations since the mid-1970’s, however, is still described in the 2005 NEC in Art. 394 for existing installations and by special permission.

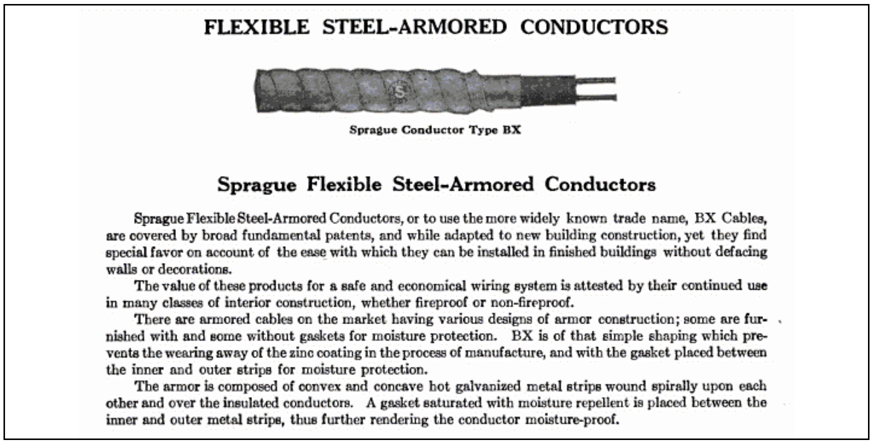
Fig. 2 – Old Knob, Tube, and Cleat

Open wiring systems like knob-and-tube, because they are in open air, can dissipate heat very well, however, in some cases improper or failed splices and joints can “glow” red-hot (as Edison pointed out) and go unnoticed for quite some time. During the energy crisis of the 1970’s, it became popular to blow loose-fill cellulose insulation into the attics and walls of older houses. This became a problem for older homes with knob-and-tube wire splices with glowing connections or overheated conductors that could easily ignite this insulation and cause a fire.

Armored Cable

Armored cable (AC) was first listed in 1899 for the Sprague Electric Co. of New York, and was originally called “Greenfield Flexible Steel-Armored Conductors,” after one of its inventors, Harry Greenfield (see Fig. 3). There were originally two experimental versions of this product, one called “AX” and the other “BX,” with the “X” standing for “experimental.” The “BX” version became the one that eventually got produced, and hence the name “BX” stuck, which also became the registered trade name of armored cable for General Electric, who later acquired Sprague Electric.

Armored Cable, or BX, first appeared in the 1903 NEC, but didn’t start becoming popular until around 1930, and is still a popular wiring method today. AC cable is described in Art. 320 of the NEC. The armor of AC cable systems is tested for grounding and can provide a suitable equipment grounding path. AC cable made after 1959 requires an aluminum bonding strip under the armor to help improve the conductivity of this path. Although originally produced with steel armor, in the late 1980’s lightweight aluminum armored AC cable first became listed.



FLEXIBLE STEEL-ARMORED CONDUCTORS

Sprague Conductor Type BX

Sprague Flexible Steel-Armored Conductors

Sprague Flexible Steel-Armored Conductors, or to use the more widely known trade name, BX Cables, are covered by broad fundamental patents, and while adapted to new building construction, yet they find special favor on account of the ease with which they can be installed in finished buildings without defacing walls or decorations.

The value of these products for a safe and economical wiring system is attested by their continued use in many classes of interior construction, whether fireproof or non-fireproof.

There are armored cables on the market having various designs of armor construction; some are furnished with and some without gaskets for moisture protection. BX is of that simple shaping which prevents the wearing away of the zinc coating in the process of manufacture, and with the gasket placed between the inner and outer strips for moisture protection.

The armor is composed of convex and concave hot galvanized metal strips wound spirally upon each other and over the insulated conductors. A gasket saturated with moisture repellent is placed between the inner and outer metal strips, thus further rendering the conductor moisture-proof.

Fig. 3 – Early Catalog Description of Armored Cable

Nonmetallic Cable

Although nonmetallic-sheathed cable, or NM for short, was first listed and described in the NEC in 1926, it was actually invented a few years earlier by General Cable at their Rome Wire Division in Rome, NY, and marketed under the trade name “Romex®.” Today many installers still refer generically to NM cable as Romex. Early NM cable had their individual conductors jacket wrapped in a cotton braid that was impregnated with either a varnish or tar-like substance for moisture protection.

Around 1950, synthetic spun rayon was being permitted to replace the cotton thread in the jacket braid. Then in the early 1960’s, thermoplastic began replacing the braided jacket altogether, and by about 1970, most all NM cable had a PVC outer jacket, even though a braid was still permitted until 1984. Also in 1984, NM-B cable was developed and required to have 90°C rated individual conductors, and a 75°C outer jacket (see Fig. 4).

Until the early 1960’s, most NM cable for residential use did not have a grounding conductor. However, changes in the 1962 Code that mandated equipment grounding for all branch circuits popularized the use of NM cable with ground. Earlier versions of NM cable with ground permitted the grounding conductor to be No. 16 AWG for 14 and 12 gauge copper NM, and No. 14 AWG ground for 10 gauge copper NM. In 1969, new requirements no longer permitted an undersized grounding conductor for 14, 12 and 10 gauge NM cable.

Fig. 4 – Older Cloth Braid and Newer NM-B Jacketed Cable

Individual Conductors:

Beginning in Edison’s time, the original residential wiring systems used conductor insulation made of gum-rubber. This “rubber” insulation was actually a mixture of ingredients including vulcanizing agents containing sulfur for curing. These various additives, especially sulfur, had a very corrosive effect on the copper conductor, so the copper had to be tinned. Rubber was also very soft when first vulcanized, so a cotton braid or wrap was added as an outer covering for mechanical protection. When rubber insulated conductors were suitable for outdoor use they had to incorporate three of these braids or wraps that were saturated with a weatherproofing compound.

During the 1950’s, the wire industry began transitioning residential wire insulation from rubber to the newly developed thermoplastics (PVC). PVC had advantages in that it did not suffer from the brittleness and cracking with age that was typical of the older rubber insulation. It also did not have sulfur additives that could damage the conductor, so the copper did not have to be tin-coated. Another advantage of PVC is that there were more options with color pigmentations, and the color tended to hold its pigmentation better than rubber, which often had a painted wrap that discolored with time. In the mid-1980’s, 90°C rated wire began replacing the 60°C and 75°C wire typical of the earlier installations (see Fig. 5).

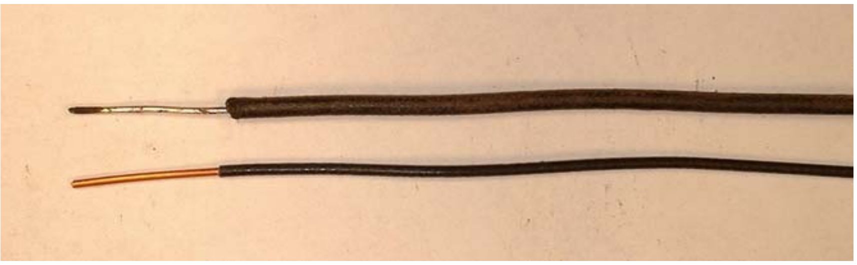


Fig. 5 – Older Tinned Rubber Wire (top) and Newer 90°C Wire (bottom)

Homes built before 1965 were unlikely to have aluminum conductor branch circuit wiring, however, from the mid-1960's through the 1970's, aluminum wire became very popular because of the sudden escalating cost of copper. Aluminum wire before 1972 is generally referred to as "old technology" aluminum because of its higher iron content. After 1972, the newer technology wire improved upon the alloy and its propensity for high resistance connections. However, as the price of copper began to retreat in the mid-1970's, and with homeowner concerns over the bad publicity surrounding aluminum wire, aluminum is rarely used for residential branch circuit wiring today.

In the U.S., the standard method of denoting the wire diameter of non-ferrous materials, like copper and aluminum, is the American Wire Gauge, or "AWG" for short. The first attempt to adopt this geometrical system was in 1855 by Messrs. Brown and Sharpe. They established 39 steps progressing from No. 0000 to No. 36, with increasing gauge numbers giving smaller diameter wires. This predecessor to the AWG system was originally known as the B&S gauge. Wire is made by drawing it through a series of increasingly smaller dies or "draw-plates" to create its final size. It is believed that wire gauge numbers were originally based on the number of dies that the wire was drawn through. For example, No. 1 was the original rod, and if it was drawn through 12 dies it became 12-gauge wire. If two more dies were added, it became 14-gauge wire, etc. Thus, the larger the gauge number, the larger number of dies it was drawn through, and the smaller the wire.

Overcurrent Protection:

The earliest form of overcurrent protection was referred to as a "fusible cut-out." The fusible cut-out consisted of a block or box of porcelain arranged so that a piece of easily fusible material, called the "fuse," would form part of the electrical circuit. When the current in the circuit became too great, the fuse would melt and "cut-out" the load to that circuit. By 1900, the term fusible cut-out was becoming known as a fuse-block or fuseholder.

To make the replacement of the fusible material easier, the safety plug was developed in the 1890's to be easily replaced by simply screwing a new fuse into the fuseholder once it had blown. Because of the popularity of the Edison-base screw shell, all plug fuses soon standardized on this thread arrangement. However, because of the high cost of the early plug fuses, the fuse link was often renewable and could be replaced when the fuse opened, allowing the actual plug base to be reused (see Fig. 6). One drawback of the early plug fuses was that they were opaque, and it was difficult to tell which fuse had blown. In 1921, the clear window plug fuse was developed by Bussmann, and that allowed one to easily see which fuse had opened. As the cost of making plug fuses came down, they became a disposable item, and soon there was no longer a need for those with renewable links.

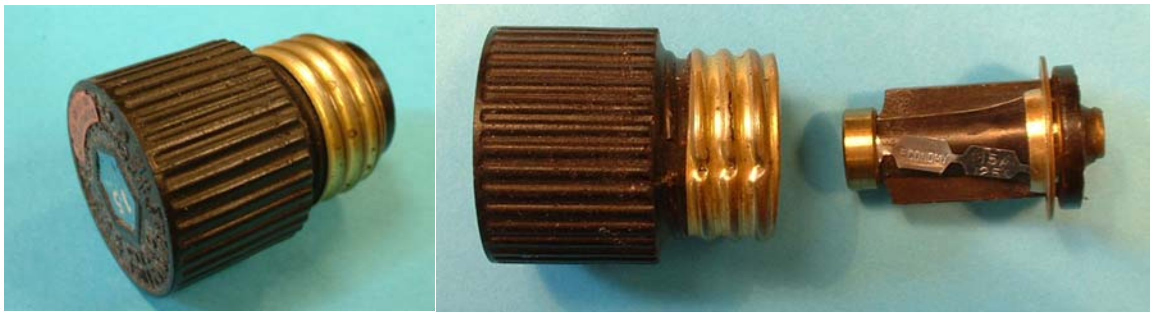


Fig. 6 – Old Renewable Edison-Base Plug Fuse

Plug fuses were interchangeable with fuses of different current ratings up to 30 Amps, and that could be a problem when fuses of a higher current rating were inappropriately placed in a circuit rated for smaller ampacity. However, plug fuses rated 15 A or less had to be identified by a hexagonal cap or other prominent top part to distinguish them from fuses of higher ampere ratings (see Fig. 7). This requirement can still be found in Sec. 240.50 of the NEC. The Edison base design also made it easy to use a penny to bridge a plug fuse, and that could be very dangerous.

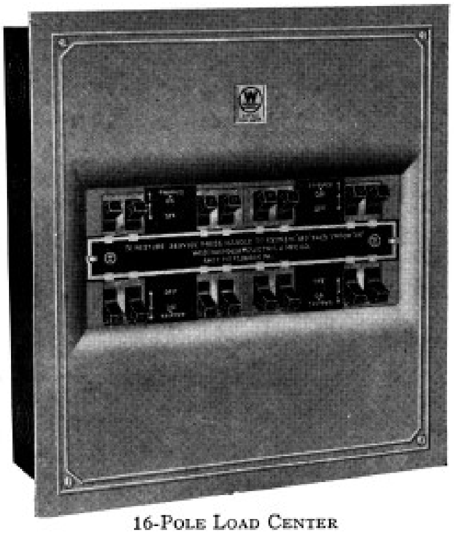
Fig. 7 – 15 Amp Plug Fuses with Hexagonal Caps

The 1940 NEC contained a new requirement effective Nov. 1, 1941 which stated that for new installations, plug fuseholders must only accept a "Type S" tamper resistant plug fuse. In addition to not being usable in a standard Edison-base fuseholder, the new Type S fuse had to be designed such that fuses rated 16 – 30 A could not be used in a fuseholder intended for fuses rated 0 – 15 A. The product requirements for Type S fuses eventually incorporated three non-interchangeable current ranges, 0 – 15, 16 – 20, and 21 – 30 A. The tamper-resistant plug fuse was also of a design that would not allow a penny to bridge the fuse when installed (see Fig. 8). According to NFPA's Electrical Committee Report of 1940, the "S" in Type S came in recognition of a Mr. Fred Squires of IAEI, who's diligence and persistence finally convinced the Committee to require the use of these tamper-resistant fuses.

Fig. 8 – Type S Plug Fuse and Insert

The earliest main switches were of a blade type typically rated 30, 60 or 100 A. When a cut-out or fuse opened, power to all or most of the house was lost. It soon became popular to add several circuits or “branch circuits,” each protected by an individual fuse. Often times these additional fuses were located in a separate box called the “fuse cabinet.” By the 1930’s, the fusible pull-out switch was becoming a popular form of service equipment for new housing. This switch incorporated two main cartridge fuses in a single base that could be pulled out for fuse replacement, or inverted and reinserted in an “off” position when used as a disconnect. A second fusible pull-out switch was often incorporated and marked “range.” This fused circuit was typically used to provide power for the growing use of residential electric range cooking. This range circuit could either be in series or parallel with the main fuses. The lighting and appliance branch circuits were fed through plug fuses and fuseholders that were integral to the box.

In the 1930’s, Westinghouse introduced the then very modern “No-Fuze Load Center.” Instead of fuses, this new load center used residential circuit breakers for the main and branch circuit overcurrent protection (see Fig. 9). Literature at that time touted the no-fuze (sic) load center as a great convenience because fuses were seldom on hand when they were needed the most. Also they claimed that circuit breakers could carry temporary overloads without tripping, whereas a 15 A fuse would blow almost instantly at 25 A. This led to the development of the time-delay plug fuse at about that same time. Even though in the 1930’s a no-fuze load center typically cost less than $10, that was a considerable amount during the depression, and all but the very expensive houses at the time were still being built with fuses for overcurrent protection. It wasn’t until the early 1950’s, and the post-war housing boom that other manufacturers, such as Square D, began developing low cost residential circuit breakers and load centers, and by 1960 the circuit breaker had almost completely replaced fuses as the choice for overcurrent protection in new construction housing.



16-Pole Load Center

Fig. 9 – No-Fuze Load Center

Conduit, Raceways and Boxes:

The earliest residential wire raceway was called “moulding” (sic). It consisted of two pieces of wood, a backing and a capping. The backing had two or more individual grooves, one for each wire, and a capping to cover over the grooves. The grooves separated the wires ½ inch, and provided mechanical protection (see Fig. 10). Moulding should not have been used in concealed places or damp locations, but was required to have two coats of waterproof paint or impregnated with moisture repellant. By the mid-1910’s wood moulding was being phased out as AC cable was becoming available. At about that same time surface metal raceway was being introduced. In some older homes with gas lighting, it was common to replace the gas fixture with an electric lighting fixture, and then use the gas pipe as the conduit for the electrical wires.

Fig. 10 – Wood Moulding

In 1902, flexible metal conduit was invented by Harry Greenfield and Gus Johnson. It was first listed that same year by Sprague Electric under the trade name “Greenfield.”

By the late 1920's, boxes made of Bakelite, an early thermoset plastic material developed by Dr. Leo Baekeland, were in common use, however, boxes made of more modern PVC thermoplastic material were not introduced until the late 1960's. Rigid nonmetallic conduit was introduced in 1962, followed by nonmetallic flexible conduit in 1981, and nonmetallic tubing in 1983.

Wire Splices and Terminations:

Most early wire splices were soldered and taped joints. Solder joints are still permitted in the NEC today (Sec. 110.14), and require the splice to be mechanically secure without solder (twisted), and then soldered. The joint must then be covered with insulation equivalent to the conductors. Early splice joints were twisted, soldered, wrapped with rubber insulating tape, and then covered with friction tape to prevent abrasion (see Fig. 11). Friction tape is a cloth tape impregnated with a sticky tar or pitch substance. Friction tape was not known to be an insulating material, but some old splices can be found improperly wrapped with friction tape alone. Plastic insulating tape, often referred to as vinyl tape, was developed by 3M in the 1940's, and by 1960 was replacing rubber tape and the need for friction tape for most common splices. Black became the standard color for vinyl tape because of its resistance to ultraviolet light, but modern vinyl tapes are also available in a wide variety of colors so they can be used not only for insulation purposes, but also for wire identification.

Fig. 11 – Soldered Splice with Friction Tape (top) over Rubber Tape (bottom)

The origins of the twist-on wire connector are obscure, but references to their use can be found since the early 1920's. Originally called "porcelain connectors," twist-on connectors are often referred to by the industry name "wire-nut®," which has been the trademark of Ideal Industries since 1939. The early twist-on connectors were made of porcelain and similar inorganic materials, and did not contain an inner spring (see Fig. 12). By 1930 plastic Bakelite connectors were beginning to appear, and by the 1940's inner springs were added to better twist and more securely capture the conductors. By the late1960's thermoplastic (nylon, polypropylene, etc.) twist-on connectors were becoming common, and aluminum wire combinations were added to accommodate the increased use of aluminum wire. In the mid-1980's, enhanced requirements were added to the product standard for twist-on connectors for use with aluminum wire, and as a result, these type connectors with aluminum wire combinations were suddenly no longer available. However, in the mid-1990’s, a twist-on connector with copper to aluminum wire combinations was reintroduced, and is still available today.

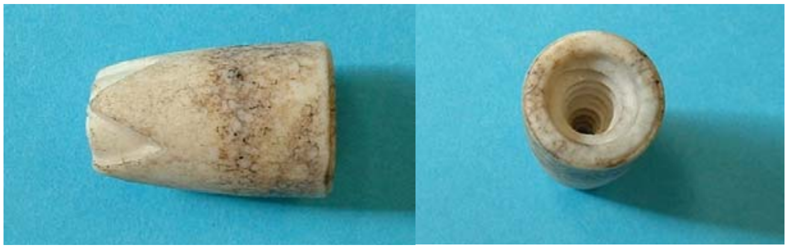


Fig. 12 - Porcelain Twist-On Connector

Most wiring devices have long used wire binding terminals to terminate wires typically formed in a hook shape to prevent disengagement if loosened. In the early 1950’s the back-wired push-in terminal was developed for quick and easy insertion and termination of 14 and 12 AWG size wires. In the mid-1990’s the use of push-in terminals was restricted to 14 AWG size wire only. Since the early 1970’s, wiring device binding terminals for use with aluminum wire have been marked CO/ALR, which stands for “copper/aluminum revised.”

Receptacle Outlets:

Reference to number of receptacle outlets required in family dwellings first appeared in the 1933 NEC. New Article 20, Wiring Installation Design, included Section 2012 for Adequacy Provisions in Residential Occupancies. It stated: “Where sufficient branch-circuits of appropriate capacities according to conditions as to their subsequent use that are likely to obtain are desired, the following is *recommended* (note not required) for all single family dwellings and for all multiple-family dwellings having provisions for cooking in individual apartments, that have a total floor area for a single family of more than 400 square feet … (b) In every kitchen, dining room, breakfast room, living room, parlor, library, den, sun room, recreation room and bed room, where any outlet is installed in such room, a sufficient number of receptacle outlets to be installed to provide that no point on the wall, as measured horizontally on the wall, will be more than 15 feet distant from such outlet.”

In 1935, the 15-foot distance remained as only a recommendation, but a requirement was added to indicate that at least one receptacle outlet must be installed in each room. Two years later, in 1937, the “15 foot” recommendation was changed to “10 feet,” and the recommendation became a requirement. In 1940 the requirement was changed to state that one outlet shall be provided for every 20 linear feet of distance around the room as measured horizontally along the wall at the floor line. And then in 1956, the “20 linear feet” measurement was changed to “12 linear feet.” And finally in 1959, the first use of the current language in Article 210 is found that requires receptacles to be installed so that no point measured horizontally along the floor line in any wall space is more than 6 feet from a receptacle outlet.

The need for more and more receptacle outlets in the dwelling can be directly traced to the increased use in cord- and plug-connected appliances. Some of the earliest cord-connected products, such as electric irons and Christmas tree lights, incorporated an Edison-base plug that screwed into a lampholder, as lampholders were more prevalent than receptacle outlets in the early homes (see Fig. 13). Here is a brief chronology of some electric home appliances and when they first became listed or available:

1905 – electric iron
1905 – Christmas tree lights
1907 – motor-driven phonograph
1909 – vacuum cleaner
1911 – electric toaster
1921 – refrigerator
1924 – blender
1925 – electric mixer
1927 – coffee percolator
1927 – electric saw
1930 – heat lamp
1935 – electric fan
1937 – washing machine
1938 – garbage disposer
1939 – television set
1947 – room air conditioner
1951 – hand-held hair dryer
1956 – electric can opener
1959 – lighted telephone
1967 – microwave oven
1972 – drip-type coffeemaker
1973 – garage door opener
1975 – video game system
1975 – videotape recorder
1978 – personal computer
1982 – CD player
1984 – phone answering machine
1997 – DVD player
1999 – plasma TV
2002 – wireless router

Fig. 13 – Old Christmas Tree Lights
With Edison-Base Plug

Grounding:

Circuit grounding was one of the more hotly contested topics in the early history of electrification. In the early 1890's, the New York Board of Fire Underwriters had condemned the practice of grounding the neutral as a dangerous practice, especially in a 3-wire Edison (120/240 Volt) system. The Edison utility companies, on the other hand, found just cause to ground their supply systems, even as others thought the utilities were doing this to just save copper and money at the cost of an increased fire risk. The great debate continued for over a decade, but in 1903 the Code was revised to recommend that these circuits be grounded, and finally in the 1913 Code a mandatory circuit grounding requirement was included for circuits like the popular residential Edison 3-wire system.

The most common way to ground a residential wiring system has always been to use the building's metal water piping as a grounding electrode. The early Codes permitted water-piping systems of 3-Ohms or less to ground to be used as an electrode, which was usually the case if the metal water pipe extended several feet into the ground. In 1923, the Code first mentioned electrodes of driven rod or pipe. The 1925 Code further referred to these driven electrodes as "artificial" electrodes, and required them to be at least 8 feet long, with minimum diameters of ½ inch for a rod and ¾ inch for pipe. It also noted that if only one of these artificial electrodes had a resistance of greater than 25 Ohms to ground, then two artificial electrodes had to be provided spaced at least six feet apart.

In 1951 the Code was revised to indicate that if there was 10 feet or less of metal water pipe in contact with the earth, or if there was the likelihood of the metal water piping system being disconnected, then the grounding system needed to be supplemented with an additional electrode. Ten years later, in 1971, the Code further strengthened that requirement by stating that a water pipe electrode must always be supplemented with an additional electrode, which in most cases meant adding a rod or pipe electrode to the house's grounding system. In 1999 the Code was again revised to require this water pipe supplemental rod or pipe electrode to have a resistance to ground of 25 Ohms or less, or be augmented by an additional electrode. Also in recognition of the increased use of non-metallic water pipe, the 1993 Code was revised to state that interior water pipe more than 5 feet from the entrance to the building shall not be used as part of the grounding electrode system.

Homes built before the 1960's had most of their original 125 V receptacle outlets of the non-grounding type (2-prong) (see Fig. 14). In 1947, the Code first required grounding type (3-prong) receptacles for the laundry. In 1956 the required use of grounding type receptacles was extended to basements, garages, outdoors and other areas where a person might be standing on ground. Finally, in 1962 the Code was revised to require all branch circuits to include a grounding conductor or ground path to which the grounding contacts of the receptacle must be connected. That effectively discontinued the use of non-grounding type receptacles except for replacement use in existing installations were a grounding means might not exist.

Fig. 14 – Non-Grounding (2-prong) Type Receptacle

The permission for neutral grounding, the practice of using the neutral conductor as an equipment grounding conductor, was first permitted in the 1947 Code for electric ranges. At around that time many electric utilities were promoting the use of residential 240 V cooking for the post WWII housing boom, and many were even offering to install an upgraded service to older homes at no charge. However, there were no NM cables available at the time with conductors of sufficient ampacity to handle these higher amperage branch circuits. There were, though, service entrance cables of sufficient size, but they had a bare neutral conductor. This special Code permission allowed the frames of these large appliances to be grounded through the uninsulated grounded neutral conductor of the Type SE service entrance cable used to supply the branch circuit. The use of neutral grounding was also extended to electric clothes dryers in 1953. However, almost 50 years later, this special permission for neutral grounding was taken away in the 1996 Code for all but existing branch circuit installations.

Polarity:

Polarity is a means of identifying voltages of different potential. In wiring systems, polarity is used to differentiate grounded conductors from ungrounded conductors. Since the early 1920's, the Code has required grounded conductors to be identified by an outer covering that is white or natural gray. Back then, the cotton cloth braid covering the grounded conductor could be bleached, in which case it was white, or more often left unbleached, which in the case of cotton would have its original "natural gray" color. If the cotton was dyed or pigmented with a color, such as black or red, it could only be used as an ungrounded conductor (see Fig. 15). In later years when the cotton braid or wrap was no longer used as a conductor covering, natural gray came to mean the natural color of thermoplastic insulation when no intentional coloring was added. However, finding thermoplastic wire insulation in natural gray was rare. In recognition of this, the 2002 NEC was revised to permit white or gray to identify a grounded conductor, however, a fine print note warns that the color gray may have been used in the past as an ungrounded conductor.


Fig. 15 – Old Conductor of Natural Gray (top) and Black (bottom) Cotton Braid

Polarized light fixtures (luminaires) have been required since the late 1920’s. In this case the shell of the lampholder must be connected to the grounded conductor which will reduce the risk of an electric shock when relamping. The use of polarized receptacle outlets can be traced back to about that same time.

Special Protection Devices:

From the earliest days of Edison’s first electric lighting, the dangers of electricity have been well known. Overcurrent protection for residential circuits has long been required, but protection from electric shock has been a more recent development.

In the early 1880’s a patent was applied for the use of electricity to execute criminals condemned to death. In 1888, New York passed a law allowing for the electrocution of criminals, and in 1890 the first electrocution as a form of capital punishment took place. While public opinion and debate continued back then on the use of electricity for this purpose, accidental electrocutions became even more of a concern with the growing use of electricity in the home. By 1970, accidental electrocutions in the U.S. were exceeding 1100 per year.

The ground-fault circuit-interrutper (GFCI) was developed in the 1960’s based on a concept by Professor Charles Dalziel of the University of California at Berkeley. The GFCI became a success soon after it was developed into a commercial product by a handful of companies, including several circuit breaker manufacturers. The GFCI was first required by the Code in 1968 for underwater swimming pool lighting fixtures. Backyard swimming pools were becoming popular at that time as more and more city dwellers were moving to the more spacious suburbs. In subsequent years the Code was revised to add the required use of GFCIs to other areas of the house, especially locations where people would be standing on earth or cement ground, or near water. By the 1980’s, receptacle type GFCIs were also becoming popular. Just 25 years after the GFCI was first introduced, the number of accidental electrocutions in the U.S. had dropped in half, even though the use of electricity had more than doubled in that same time period.

These are the locations in and around the home when GFCIs were first required:

1968 - Swimming Pool Underwater Lighting
1971 - Receptacles Near Swimming Pools
1973 - Outdoor Receptacles
1975 - Bathroom Receptacles
1978 - Garage Receptacles
1981 - Whirlpools and Tubs
1987 - Receptacles Near Kitchen Sinks
1990 - Receptacles in Unfinished Basements and Crawl Spaces
1993 - Receptacles Near Wet Bar Sinks
1996 - All Kitchen Counter-Top Receptacles
2005 - Receptacles Near Laundry and Utility Sinks

The arc-fault circuit-interrupter (AFCI) was developed in the 1990’s by several circuit breaker manufacturers to enhance the overcurrent protection that was being provided by the residential breaker. AFCIs provide protection from the effects of arc faults by using electronics to recognize current or voltage characteristics unique to arcing, and then function to quickly de-energize the circuit when an arc fault is detected (see Fig. 16). Although first described in the 1999 Code, the AFCI was not required until January 1, 2002, and then only for 15- and 20-Ampere branch circuits supplying bedroom outlets. Proposals tentatively accepted for the 2008 NEC would require AFCIs for all dwelling unit 15- and 20-Ampere branch circuits.

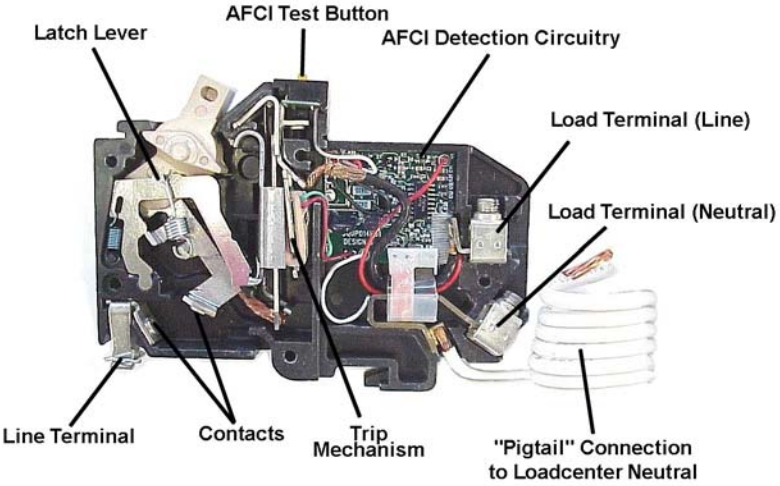


Fig. 16 – Modern AFCI Circuit Breaker
(Courtesy Eaton Corp.)

Epilogue:

The 20th century, often referred to as the “inventive century,” produced many great technological advancements in a relatively short period of time. Take for example aerospace progressing from the Wright brothers’ first flight to man landing on the moon, telecommunications progressing from Alexander Graham

Bell's first phone to the global cellular telephone network, from Marconi's earliest radio to plasma TV, from the slide rule to the laptop computer, the list goes on and on. Yet, the technology that we probably take most for granted, the reliable and safe use of electricity in our home, has for the most part remained relatively unchanged in that same time. Except for that one word, "plastic," much of the history and technology of residential wiring practices has not changed all that much since the days of Edison. Armored and nonmetallic cables, fuses and circuit breakers, wall switches and receptacle outlets have all withstood the test of time. Many people would think nothing of spending the night in an old house wired 90 years ago, but how many of those same people would fly in an airplane built during that same vintage?

As the 21st century gets underway, one wonders how the history of residential wiring practices will write itself one-hundred years from now. What lies beyond GFCIs and AFCIs can only be imagined similar to what those who witnessed Edison's first electric lighting would have thought of these devices. In the words of Thomas Edison, ***"There's a way to do it better … find it."***