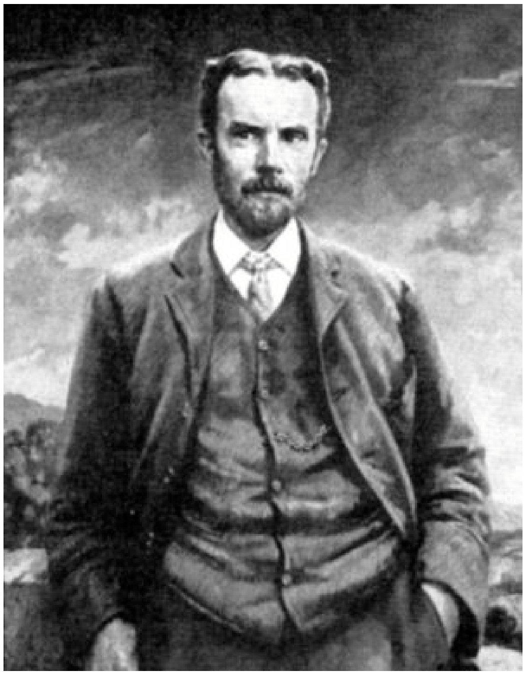
History of coaxial cable

Introduction

Radio amateurs today use coaxial cable to connect the equipment to an antenna. Prior to its invention the common transmission line was an open-wire balanced feeder made from wire and insulating spacers. The history of coaxial cable is an interesting topic.



First recorded patent for coaxial line

The first known patent granted for coaxial transmission line was a British patent in 1880 to Oliver Heaviside, a self taught British electrical engineer. Those astute in history will recognise the name as the one due to the Kennelly-Heaviside layer; we now call the ionosphere, which Heaviside in conjunction with Kennelly discovered the reflecting medium high above Earth. Heaviside was the nephew of the British inventor Sir Charles Wheatstone, the co-inventor of the British telegraph system and known for his invention of the Wheatstone Bridge to measure resistance.

Oliver Heaviside

Heaviside's coaxial cable was a copper tube, which formed the outer of the line. The inner concentric (coaxial) conductor was a copper wire which was supported by insulating discs to keep the central wire a constant distance from the inner of the copper tube. The major dielectric was air, giving low loss to signals travelling along it.

The use of the word "*cable*" as we know it today for coaxial lines implies a flexible type of conductor. In the old days the word cable meant anything that contained wires, such as mains cable, or telephone cable with multiple pairs. Similarly transatlantic cables could be multiple pairs or coaxial lines or a mixture of both types, today we also have fibre optic cable, but the "*conductors*" are strands of glass or plastic to act as a waveguide for a light source.

Heaviside was a prolific experimenter and he coined the names of several items used today. He invented the word impedance, admittance, conductance, permeability, inductance, reactance, reluctance and permittance, which we still use today. (He seemed to like the use of the letters ANCE at the end of the item). He also solved Maxwell's equations and invented differential equations in order to perform this work.

Heaviside's coaxial transmission lines found many uses; not the least was the transatlantic cables used to carry telegraph and later telephone traffic over vast distances. The first transatlantic telegraph cable was a normal wire cable laid in the late 1800s and was a disaster. The inventor was Lord Kelvin, earlier Sir William Thompson. He however did not know about distributed capacitance, inductance and impedance, the signal loading on this cable was so high it limited the signalling speed to about 5wpm. Unfortunately the cable failed about 2 weeks after it was laid and was never re-established. It was a financial disaster for the sponsors.

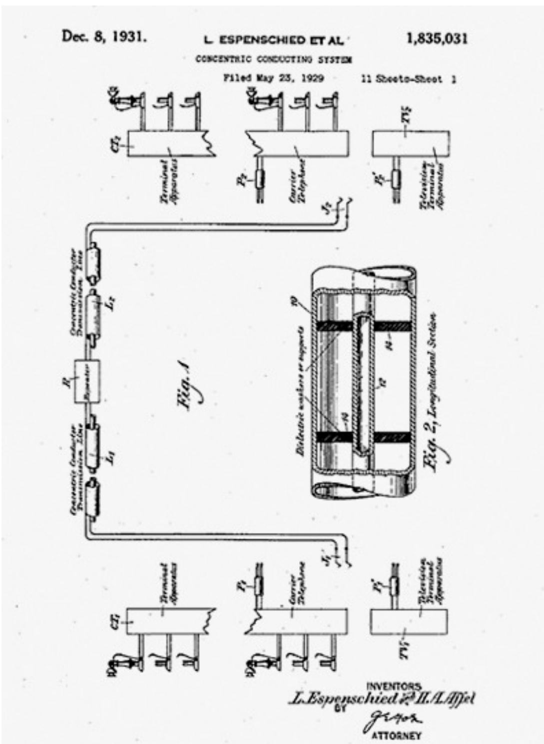
A German patent in 1884 was granted to Ernst Werner von Siemens for a concentric coaxial transmission line similar to Heaviside's design, but little detail is known about this patent or whether the cable was ever put into service.

US patent for coaxial cable

The next known patent for coaxial cable was granted to two American engineers. This patent granted in 1931 was almost the same as Heaviside's original design but had a subtle difference. It was semi-flexible and could be coiled more easily. The patent diagram clearly shows a similar construction to Heaviside's design with an outer copper jacket and inner wire supported by insulating discs.

U.S. Patent No. 1,835,031 for a "*concentric conducting system*" was awarded to Lloyd Espenschied of Kew Gardens, New York, and Herman A. Affel of Ridgewood, New Jersey, and assigned to the American Telephone & Telegraph Co (today AT&T). This although similar to Heaviside's patent allowed more bending to occur and the cable could be coiled on a large diameter drum for laying at sea. They also showed the use of repeater stations along the line to boost the signal level.

Lloyd Espenschied in 1904 became an amateur radio operator and later a telegraph operator with a maritime station. He also later determined experimentally the optimum impedance to use for high power, high voltage and minimum attenuation at 10GHz in the 1940s, these being 30-ohm, 60-ohm and 77-ohm respectively. Significantly the Germans standardised on 60-ohm before the war.



The next significant use of coaxial cables occurred in 1936.

The first experimental carrier telephone system was laid between London and Birmingham with a cable made by Standard Telephones and Cables (STC) which consisted of 4-coaxial cables carrying up to 4-channels per coax. The cable was sheathed in lead as per the normal telephone cables to protect the inner conductors. This revolutionised telephony as many separate telephone channels could be carried on a single cable. The system used SSB suppressed carrier transmissions spaced 15kHz apart.

US patent diagram for coaxial line, which clearly shows the outer tube, inner tube and insulating discs as used by Heaviside.

The second significant event in 1936 was the televising of the Berlin Summer Olympic Games. The transmission was carried by a coaxial cable between Berlin and Leipzig where the main German television transmitter was located. The cable used was very similar to the British Post Office type and laid in sections about 50km in length with repeater stations to boost the signal level, no doubt gleaned from the US patent paper.

Lloyd Espenschied and Herman A. Affel with a section of their original coaxial cable taken on the 20 anniversary of the patent.

The 1936 Berlin Summer Olympics was a massive propaganda event for Hitler where the entire German team were only members of the Aryan race. Hitler wanted to demonstrate to the world their superior race and its technological advances. Hitler however was greatly displeased when an American-African athlete, Jesse Owens, claimed 4 gold medals in the field events.

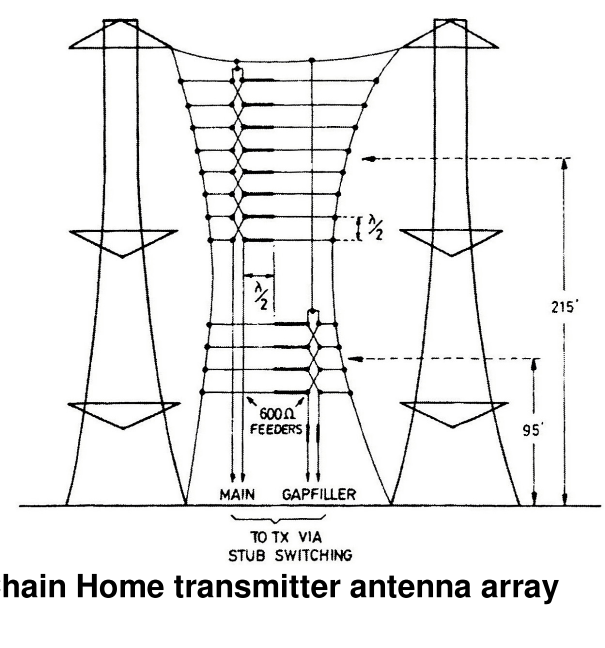
All of these coaxial cables where either rigid or semi-rigid in form. The next significant step was the invention of flexible coaxial cable as we know them today. Prior to this, during the run up to the Second World War, a committee was set up in the USA to ponder on the ideal impedance for coaxial cable. This was still rigid line made from copper tubing.

The impedance battle

As the war in Europe was inevitable the allied scientists and engineers needed to define the common impedance so that coaxial cable could be manufactured in high volume to suit the various users and to introduce some standards. Some factions of this committee favoured 75-ohm cable and they demonstrated that this was the ideal impedance to feed half wave dipole antennas and they also showed that 75-ohms had the lowest attenuation per unit length. This committee had many engineers and scientists and the arguments went back and forth as to which was the ideal impedance to adopt. During all this wrangling a Canadian engineer had little to say but finally spoke. He told the committee he had been studying the US copper water pipe tables and proposed that 52-ohm be the preferred impedance, although this hadn't been tabled previously. He showed that 52-ohm impedance could be made in any required diameter as the standard US water pipe tables had all the necessary size tubes. Hence, no extra tooling was needed and so 52-ohm became the standard for a practical reason.

Chain Home Radar

During the run up to WW2 the British realised that a radio direction finding system (later called RADAR) was necessary and embarked on a design called Chain Home in 1935. The transmitter developed very high peak power and the need was to convey this signal from the transmitter to the base of the transmitting tower with the minimum loss. On the prototype system ordinary GPO telephone poles and insulators were used with 200-pound per mile copper wire as a balanced feeder arrangement, although this worked the danger of damage from enemy bombing led to a later change to a buried feeder system. A scheme was devised using two copper tubes laid in parallel with central wires and insulating discs, similar to the telephone coaxial cables and Heaviside's original patent. This formed a balanced shielded line that connected to the 600-ohm balanced feeder wires that ran up the tower and fed the multiple antenna arrays. In the final installations the STC telephone coaxial cable was utilised to feed the transmitter and receiver antenna arrays.



Chain Home transmitter antenna array

Flexible coaxial lines

The next saga is the invention of what we know today as "*flexible coaxial lines*". Edward (Taffy) Bowen was a Welsh engineer working on the Chain Home radar system but left in late 1936 to take up the challenge of developing airborne radar for the allied night fighters. Bowen had been the transmitter designer for Chain Home but friction within the team and the overall supervisor Watson-Watt led Bowen to ask for a transfer to AI work (airborne intercept).

During this development in 1937 he needed a flexible coaxial transmission line. Bowen originally tried balanced wire feeders but this presented problems, the wing mounted dipole arrays were susceptible to damage, as were the feed lines. Where the lines passed through the aircraft skin arcing occurred at high altitude because of the high peak power required. Next Bowen tried rigid coaxial line but this suffered from fatigue fractures under the high vibration experienced in fighter aircraft.

Bowen had recently learnt of a new insulating material developed by Imperial Chemical Industries (ICI) which was called *polyethylene*. He asked the scientists at ICI whether it was possible to extrude a tubular layer of polyethylene with a constant diameter onto a stranded wire conductor. They replied it was possible and made a short length for Bowen. He then encased this with a sheath of copper braided wire bound on tightly with electrical insulating tape to form a concentric flexible coaxial line. Flexible coax cable was born!

Later in the war the British took to America with the Tizard Mission many secret devices to assist the Americans in making equipment vital to the war effort. Amongst these were the cavity magnetron, Bowen's coaxial cable and others as a bargaining tool in the final "*Lend-Lease*" agreement between Britain and America.

Connectors for this new type of coaxial cable did not exist and Burndept, a British company, came up with a suitable connector that was widely used on allied equipment. We find this connector on the WS-19, C-11, C-13 and many others. The American company Amphenol in the mean time invented the PL-259 connector which at the time was designated the "*UHF connector*" as at that time VHF was regarded to start at 30 MHz and UHF was regarded to start at 100 MHz, the connector was rated up to 300 MHz. Although this connector was not "*constant impedance*" it was used in many 400 MHz radar systems during the war and only later did Paul Neill of Bell Labs invent the "*N-type*", which is named after him, it being a constant impedance connector rated up to at least 11 GHz. The N-type connector, unlike the PL-259, was inherently waterproof and rapidly became the preferred connector. Even the Russians used the N-type towards the end of the war, although they had a different name for it.