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The Beginnings of Air Radio Navigation and Communication

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1. INTRODUCTION. In our present age, radio communication and navigational aids are taken without comment throughout the aviation industry. However, all developments must start somewhere and it is the intention of this paper to look into the earliest days of "wireless" and its gradual application to aviation.

The first step was, as far as I can ascertain, in October 1866 when Mahlon Loomis flew a kite from a mountain top in Virginia, USA. He had fitted a copper mesh to the kite and connected this to a copper wire. Between the wire and earth he connected a galvanometer which, he noted, deflected from static electricity. On flying an identical kite at a similar height some fourteen miles away, if the copper wire were earthed, the deflection on the galvanometer changed. However, if the kite wires were of different length, this effect was not observed. For this, in 1872, he was issued with a US Patent 129971 for "wireless telegraphy" but, as far as we know, apart from a few fading freehand notes, (See Figure 1) no details of his apparatus survive, so it must remain a matter of conjecture what was actually achieved.

The following year (1873) James Clerk Maxwell published his book "Treatise on Electricity and Magnetism" which brought together the known facts concerning light, electricity and magnetism, and postulated that other waves existed that would propagate through space with the velocity of light and would obey the classical laws of optics.

In 1879 Prof D. E. Hughes constructed a primitive spark transmitter and a receiver using a microphonic joint as detector and a telephone earpiece. He demonstrated this to a group of distinguished scientists by receiving signals at distances up to 600 yards, as he walked up and down Great Portland Street in London. However, the observers dismissed the demonstration as an induction effect and he did not proceed further with this work. [18].

Some five years later Prof Onesti demonstrated that if iron filings were placed in a tube of insulating material between copper electrodes, the application of a fairly high voltage could cause them to cohere, or stick together sufficiently to allow current to pass. Rotating the tube de-cohered them. This phenomenon interested a number of workers including Oliver Lodge and Prof Branley, and over the next few years the coherer, as it was called, was developed to the stage of being a practical detector for wireless waves. Further to this, the work of Heinrich Hertz in this period verified the existence and characteristics of the waves predicted by Maxwell some fifteen years previously.

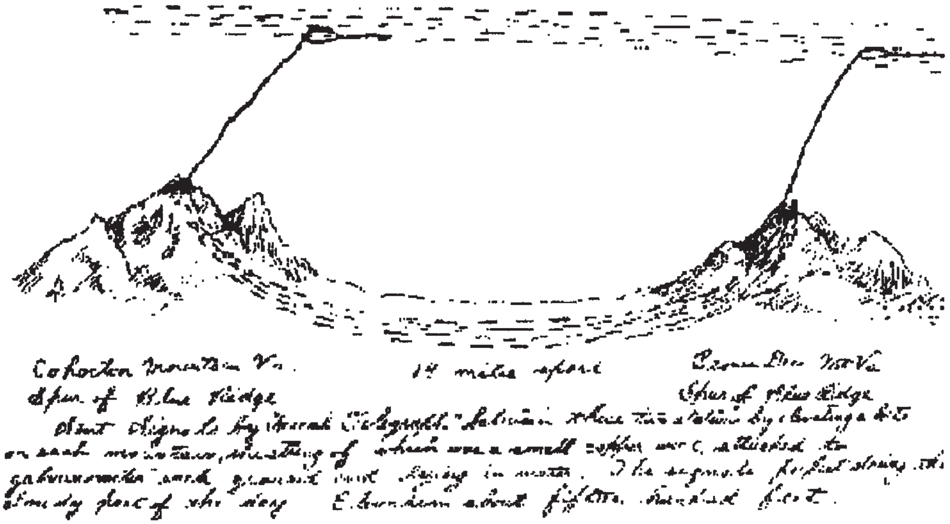

Figure 1. Drawing done by Mahlon Loomis, showing his kites flying a distance of 14 miles apart between mountains. (From Library of Congress Archives).

By the early 1890s workers from several countries were realising the potential of wireless waves as a communications medium. Marconi was possibly the most publicised exponent, but Capt H. B. Jackson was experimenting on behalf of the Royal Navy, Preece for the Post Office, Popoff similarly in Russia, Fessenden, Tesla, Edison and Armstrong in the United States, Branley in France, Hertz, Braun and Slaby in Germany, Poulsen in Denmark and Righi in Italy. In 1889, a group led by Sir William Preece, the Chief Engineer of the Post Office, had demonstrated communication across Lake Coniston in the Lake District, a distance of about one mile, thus predating Marconi by several years. Sir William also organised tests on Salisbury Plain during 1896 that proved that by using vertical wire antennas 37 metres long, communication was possible over some tens of kilometres. This proved invaluable, for wireless communication was used only a few years later during the Boer War in South Africa using antennas supported by hydrogen balloons. This, as far as I can ascertain, was quite successful [17].

By the turn of the century workers were looking rather further than plain communication. Over the previous ten years greater and greater distances had been achieved culminating in Marconi's Trans-Atlantic transmissions in 1901.

Hertz, whilst investigating the characteristics of electromagnetic radiation had demonstrated both refraction and reflection using both plane and circular reflectors. Zenneck carried out work on screening radiation from a vertical aerial in certain directions by the use of vertical wires. From his own accounts, even after moderately promising results, he discontinued his experiments.

It was in 1901 that Fessenden first worked on telephony transmission. Early results were encouraging, but not of sufficient quality for commercial use. However, transmission techniques were improved and the first satisfactory public broadcast was made on Christmas Day 1906. [18].

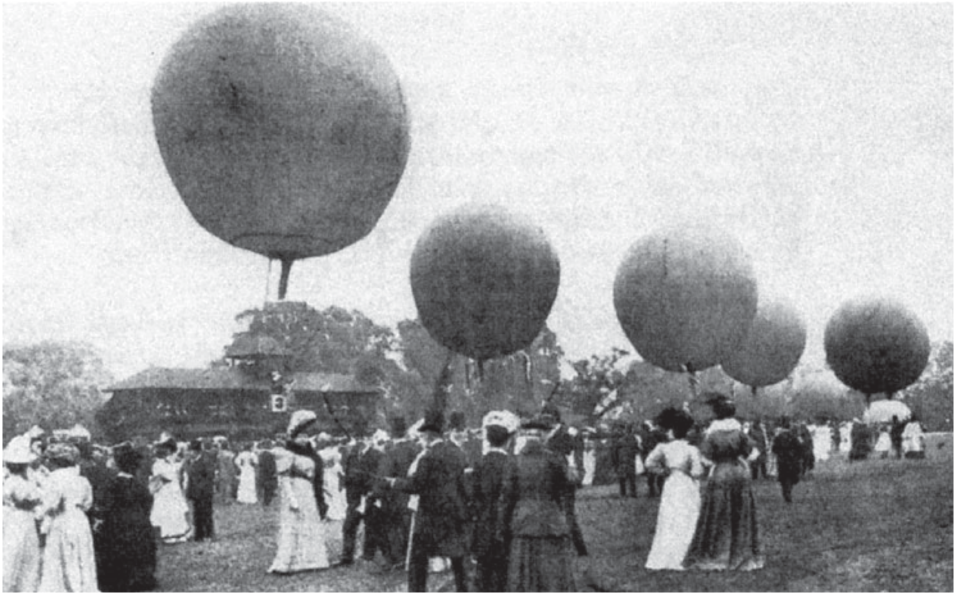

Figure 2. Balloons at an Edwardian flying meeting. It was in a balloon such as these that Col Capper made his first experiments in wireless communication.

2. COMMUNICATION. It is commonly believed that the first air-to-ground wireless transmission was by J.A.D. McCurdy at Sheepshead Bay Racetrack while flying a Curtiss biplane on 10th August 1910, with the experiment repeated by the British actor and aviator Robert Lorraine flying a Bristol Boxkite on Salisbury Plain a month later [3]. These are certainly the first recorded transmissions from heavier-than-air machines, but air/ground communication had taken place several years previously between both balloons and airships and ground [19].

The first wireless company of the Royal Engineers was formed at Farnborough in 1907 under the command of Col. J.E. Capper, with the main intention of investigating airborne wireless for military use. An early report was that in May 1908 the balloon "*Pegasus*", while over Petersfield in Hampshire and piloted by Col. Capper, either received from or communicated with Aldershot some 20 miles distant. Which alternative, I have so far been unable to ascertain as one report said that the balloon was equipped only with receiving equipment and another that good signals were received at Aldershot [12] [20]. (See Figure 2.)

It is interesting that Col. Capper together with the legendary Col. Sam Cody designed the *Nulli Secondus No 1*, the first British semi-dirigible airship, which made its maiden flight the following year. The subsequent British airship "Beta" was fitted with wireless equipment and made two-way communication up to distances of 48 kilometres, although they found it necessary to stop the engines whilst communications were taking place due to the interference caused by the unscreened ignition systems.

The United Kingdom, however, was not the only country interested in ground-to-air communication, for in the autumn of 1908, the German Army balloon "*Gross II*" made successful two-way communication with a ground station. The following year the Belgian balloon "*Condor*" made uninterrupted communication with a station on the Brussels Palais de Justice and also contacted a station at the Eiffel Tower in Paris. During the German Army manoeuvres in which the Gross II was used, the Zeppelin LZ6 was also present but was not equipped with wireless equipment. However, this was remedied the following year and the LZ6 demonstrated communications up to 300 miles, after which all German airships were fitted with wireless equipment [20].

It may be that all these reported communications may have been preceded by Prof Slaby working in Germany, because a paragraph in the New York Times of Oct 9th 1897 reported that while working with the Prussian Balloon Corps he exchanged messages at a distance of 21 kilometres. However from the brief report it is not possible to determine whether the signals were air-to-ground or whether the Balloon Corps was just assisting in raising the aerials [8].

However it is clear that all these events preceded J.A.D. McCurdy's transmissions to Horton on the grandstand of the Sheepshead Bay Racetrack, New York.

3. NAVIGATION.

From 1900 onwards a number of workers had investigated the directional characteristics of inclined wire aerials, but it was Marconi who determined that for an aerial comprising both horizontal and vertical elements, where the horizontal limb is much longer than the vertical, a much enhanced signal was received from stations in the direction opposite to that at which the horizontal limb was pointing. In 1906, he took a further step and patented a system in which a number of these inverted "L" aerials were mounted around a central point and when a signal was received, the aerial receiving the loudest signal indicated the direction from which it was coming. In other words, the first direction finder [13].

By 1907 Telefunken had produced their "*Kompass*", a version of the Marconi Direction Finder, but this time in the transmitting idiom. The aerial system comprised 32 aerials aligned to the points of the magnetic compass plus a central omni-directional aerial. (See Figure 3.) Stations wishing to use the system were issued with a stop watch whose hand rotated in 32 seconds and was calibrated with the points of the compass [13] [21]. In use, the *Kompass* first radiated from the omni-directional aerial. On hearing this, the user would start the watch. The system then radiated one second pulses on pairs of opposite aerials of the ring of aerials in turn. Initially the watch was stopped at the loudest signal but later it was found that a signal minimum was more accurate and from this, the user could determine their bearing from the transmitting facility. In use, Zenneck claimed that with practice an accuracy of 5 to 7 degrees was possible. In all probability this was the prototype of all modern rotating beacons [13].

A further development by Oskar Scheller of the Lorenz Company led to the "*Course Setter*" by which a highly accurate course could be delineated if transmissions were made from two aerials with intersecting radiation patterns. If the aerials were energised alternately such that one radiated dashes and the other dots, or any other interlocking Morse code signals such as A and N or D and U, when on a desired course between the patterns, the receiver would receive equal strength from each aerial and hear a steady tone, whilst if to one side or the other, dots or dashes would predominate. The alignment of the desired course could be varied slightly by varying the relative power fed to the aerials. This, of course became the basis for many

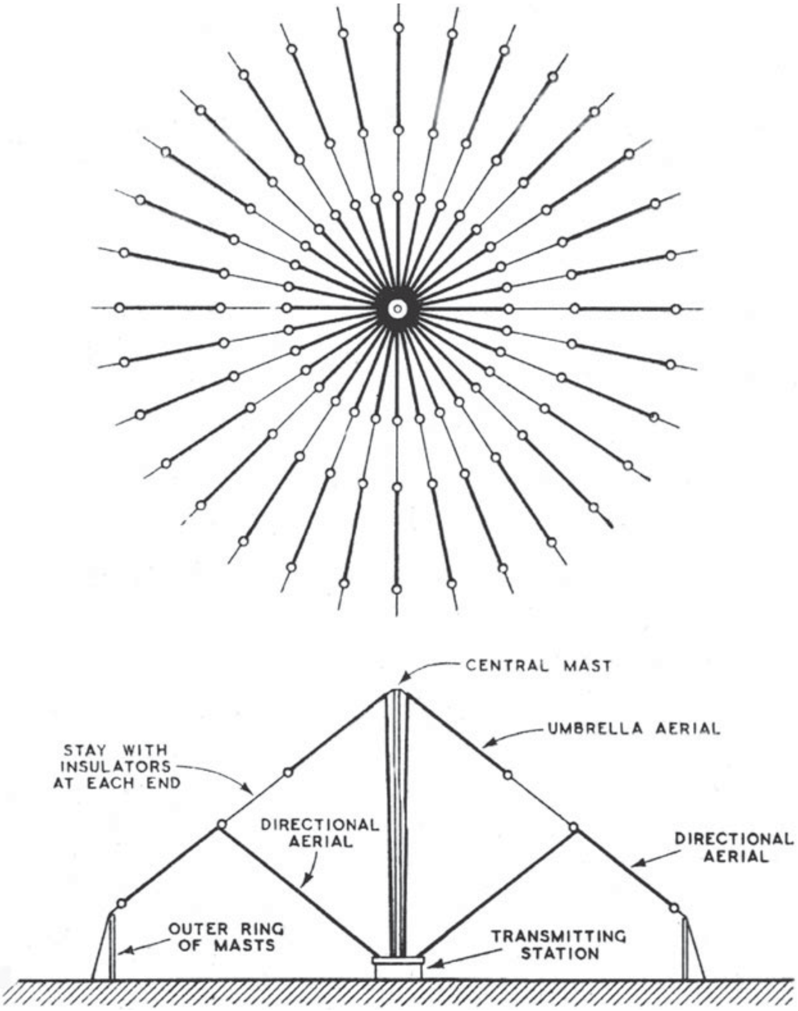

Figure 3. The basic layout of the Telefunken Kompass transmitter. Top: plan view, Bottom: side view.

later systems, including radio range, Lorenz, SBA and (albeit using interlocking tones) ILS. It was also the basis for the bombing aids used by the Luftwaffe in WWII [13].

In that same period Maj. H.J. Round carried out some work on small frame aerials and demonstrated that the addition of an open aerial to the loop could convert the normal figure-of-eight to a heart shaped pattern i.e. a single null (shown in Figure 4 Right). However, due to the insensitivity of the receiving equipment, the work was abandoned. To overcome this insensitivity, E. Bellini and A. Tosi made use of two large loops mounted at right angles. The outputs from the loops were fed to a radio-goniometer thus enabling, by rotating the pick up coil, the effect of rotating a single large loop. This proved very accurate and became the standard direction finding system for many years to come [13]. (See Figure 4.)

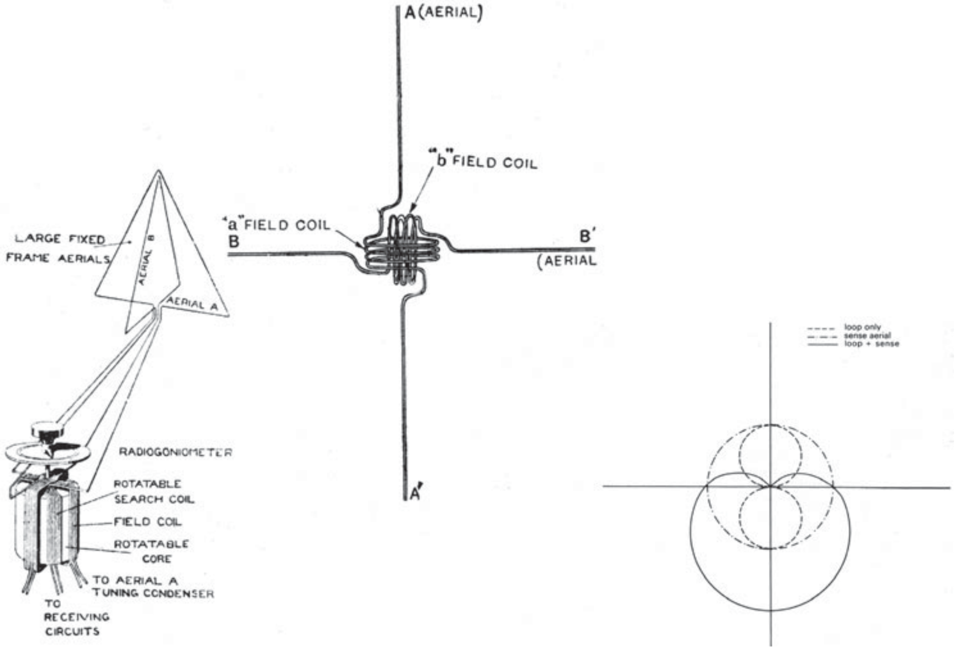

Figure 4. Left and centre. The basic principle of the Bellini Tosi Direction Finder using the radiogoniometer. Right. The horizontal polar diagram for a loop aerial together with the modification to a classical heart shape when combined with an open aerial.

Developments of the Bellini Tosi system were used for transmission and when added to the Scheller Course Setter by the US Signal Corps and the US Army Air Service, became the Radio Range system that remained in use for another fifty years.

In November 1909 Reginald Fessenden was awarded US Patent 941565 "Method for Determining the Position of Vessels". The basis for this was that Fessenden (erroneously) believed that the signal strength of a wireless transmission diminished linearly with distance. Thus by measuring signal strength, the distance from the transmitter could be determined. Compare this with the signal from a second transmitter and a fix could be obtained. Although the premise on which the patent was based was wrong it can, nevertheless, be considered the first suggestion for hyperbolic wireless navigation.

The position therefore was that by 1910 the basic principles of every non-radar, radio navigational aid used in the 20th century was established.

4. TECHNICAL ASPECTS.

To present day readers it may be difficult to imagine the physical problems of a hundred years ago. First let us consider the transmitter. From the very beginning, until thermionic valves of sufficient reliability and power were developed, with one exception, all types of transmitters used a spark to generate the radio frequency power. This could be developed in several ways, but weight considerations decreed that in aircraft, either heavier- or lighter-than-air, an induction coil technique should be used. This was then coupled inductively to the aerial system, which could be either fixed aerial wires from wingtip to tailplane or a wire trailing below the aircraft. Considering the low frequencies then in use, the latter became the more popular. However, the self-inductance and capacitance of the aerial could load the transmitter-tuned circuit and cause a frequency shift. Furthermore, these parameters could vary depending on the aircraft altitude and the weather conditions.

A further difficulty arose for lighter-than-air aircraft, for their lifting medium was the normally highly inflammable hydrogen gas. Even the smallest gas leak coming in contact with the spark could cause ignition with disastrous results. The Zeppelin Company took this danger very seriously and insisted from the very beginning that all equipment where a spark might be generated, such as commutators, circuit breakers, lights, in addition to the transmitter, should be built into gas proof containers maintained at a higher internal air pressure and the wireless room had to be both sound and gas proof [22]. These standards were mandatory from 1910 onwards, among the earliest being the DELAG airships that carried passengers around destinations in Germany from 1910 to the outbreak of WW1 when they were requisitioned for military use. The wireless equipment was used for the convenience of passengers and navigation. (Presumably D/F and Kompass) [22].

The British made little use of rigid airships, their first (RMA9) not delivered until 1916, but their semi-rigid SS class and its successors were all fitted with wireless installations. However, with these types of airship, the gondola was initially an aircraft fuselage without wings, control surfaces etc, suspended well below the main envelope and it may have been considered that this was sufficient insulation from gas ignition problems. About 200 of these airships and their successors were built and proved highly successful for marine patrol. It is claimed that only one merchant ship escorted by an airship was sunk by U boats.

The receivers also had their complement of problems. In the earliest days the most common detector circuit was one of various versions of the coherer. In time various types of the crystal detector were developed and Marconi developed the magnetic detector. For the crystal detector, several types of crystals were used, each with varying characteristics, most using the "cats whisker" method to determine the sensitive spot where a semiconductor action would take place. The exception was the carborundum detector where the crystal was mounted securely between two brass plates. However, it was found that this crystal required a bias voltage for operation. Although not as sensitive as galena and several other types, it was often preferred because of its resistance to vibration, etc. The Marconi magnetic detector did not see use in the airborne environment due to its physical size and weight.

Another problem was the interference caused by the ignition systems on the aircraft engines, but this was later overcome by screening and the bonding of all metal parts of the aircraft.

The spark transmitter together with a carborundum or other crystal detector became the standard aircraft installation in larger lighter or heavier-than-air aircraft until valves (tubes) became sufficiently robust and reliable to be introduced into the operational environment about 1917.

5. OPERATIONS IN WWI.

In the early part of the war, heavier-than-air aircraft were only considered suitable for reconnaissance and artillery spotting. In the former role it was sufficient to fit a camera pointing downwards on the side of

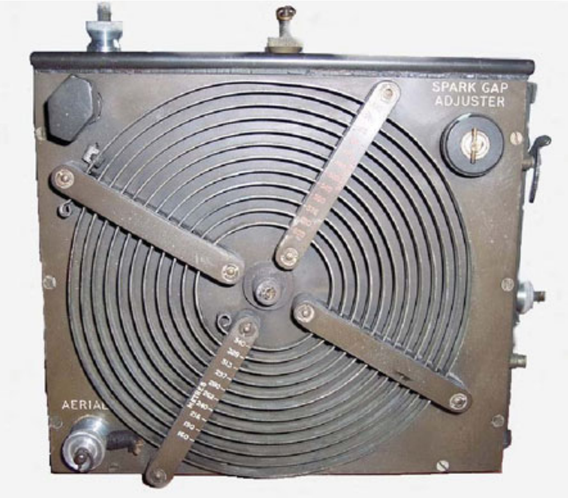

Figure 5. The Sterling transmitter that was used extensively by the British in WWI. (Courtesy of RAF Signals Museum, Henlow)

the aircraft. However, for artillery spotting, each aircraft would be allocated to a gun battery. In the air the aircraft observer would observe the muzzle flash, estimate the flight time of the shell and note the fall of shot compared with the intended target using a "Clock" system. He would then return to base, land and relay the information to the gunners by telephone before taking off for the next artillery round [3]. This technique was obviously very inefficient and the suggestion was made to equip the aircraft with radio. For British aircraft this was the Sterling transmitter. (See Figure 5.) Unfortunately, due to weight (75 lbs) and space restrictions, it was considered impossible to carry both a transmitter and an observer. The pilot therefore flew solo operating a Morse key as and when he had the opportunity. It was considered too much of an imposition to expect him to operate a receiver as well.

With wireless fitted, the technique was for the aircraft to take off and make a test transmission that the operator at the gun battery would attempt to receive. If successful, this would be indicated to the aircraft by laying out strips of linen in the form of a pre-arranged code. By now the aircraft would be heading for the target area, noting the muzzle flash and estimating when the shot would fall. On noting the fall of shot the aircraft would transmit details of its position and return to overhead the gun battery to receive acknowledgement of reception of the data or not by the laying out of linen strips. If successful, the aircraft would then head towards the target to note the next fall of shot. The aircraft sorties could easily last for several hours flying these figure-of-eight tracks [3].

As described, this sounds a simple system, but it was complicated by the fact that more than one battery might be shooting at the target. Furthermore the selectivity of the receivers was poor and there may have been several dozen spotting aircraft within receiver range. The receiving operator had therefore to rely on recognising the individual characteristics of the aircraft transmission and the pilot's "fist" whilst the pilot had to be certain that he was observing the fall of shot of the battery for which he was spotting. A further complication was the action of enemy aircraft that were attempting to disrupt the operation by shooting down the observing aircraft. In the early years of the war, this technique was used by all the combatants on the Western Front, the only differences being the ground codes used and whether these were exhibited using linen strips or light signals.

Lighter-than-air aircraft all used wireless in a far more sophisticated manner. The British semi-rigid airships were deployed mainly for coastal patrol and used wireless communication to call for surface assistance when shadowing enemy vessels. They also reported their position regularly as patrols frequently lasted many hours. When necessary for navigation, they also had the availability of bearings from Admiralty D/F stations.

Even more sophisticated was the use of wireless by the German Naval airships on bombing raids over the United Kingdom. Their frequently used technique was for the airships to depart from their bases in the early evening and then heave-to over the North Sea until they could approach the British coastline in total darkness. On crossing the coast at some easily identifiable point, a course could be set for their target. That, at least was the theory, but it was fraught with difficulty. Whilst hove-to over the North Sea, they had little idea of the strength or direction of the wind with consequent errors in their dead reckoning position. Furthermore, if, as frequently occurred, they were between cloud layers, they had no view of the sea for drift measurements and no view of the horizon or stars for astronomical navigation. It is not surprising therefore, that they often experienced great difficulty in making accurate landfalls.

However, the airships had two alternative means of determining their position. First, was the use of transmissions from two or more Telefunken "*Kompass*" stations and, secondly obtaining bearings from one or more of the extremely accurate direction finding stations such as those at List, Borkum and Nordholz. The accuracy of the latter systems was such that Von Buttlar Brandenfels, who was a Zeppelin Commander throughout the war, claimed that wireless navigation was far superior to astronomical [14]. Unfortunately, there were disadvantages too, for the British Admiralty also had a number of highly accurate D/F stations which received and tracked the Zeppelins throughout their flights over the United Kingdom.

6. THE INTRODUCTION OF THE VALVE (TUBE).

It may be considered that the history of the valve (tube, in America) started with Thomas Edison in 1880 who, while attempting to stop the blacking inside the bulb of electric lamps, discovered that if an additional electrode were placed inside the bulb, a small current would flow if the additional electrode were positively charged compared with the filament. Furthermore the current increased rapidly with increasing voltage. For this he obtained the US Patent No 307031.

From this early beginning, the British physicist John Ambrose Fleming showed that this device could be used as a rectifier and detector of radio waves and patented this in November 1904. In February 1907, De Forest filed a patent (879532) for an improved device which included an additional electrode, which later became known as the grid, to form the triode valve. This had the advantage that it could be used as an amplifier. However, it was not until about 1916 that valves were considered sufficiently reliable to be considered for commercial equipment. Even then the failure rate was high.

Maj. H.J. Round of the Marconi Company was designing both equipment and the valves. These, however, were "soft" valves, or in other words contained a gas at low pressure. Unfortunately, they were difficult to manufacture and unsuitable for mass production. It was therefore not until the high vacuum French "*TM*" valve became available in 1916, that production of valve sets became possible. These valves were also made by a number of British manufacturers under the nomenclature of "*R*" valve.

By the end of 1917, transmit and receive equipment for all modes of transmission, specially designed for the RFC were being installed in aircraft. At the time of the armistice on Nov 11th 1918, between 400 and 500 aircraft were so equipped. Progress on air-to-ground R/T was also being made by AT&T in the United States and by the time that they entered the war some aircraft were being equipped [24].

Within the United Kingdom the HMA9 and HMA23 airships were both fitted with valve transmitters, the latter transmitter using two de Forest Oscillion valves rated at 250 watts. It is interesting that the receiver was quoted as only suitable for receiving spark transmissions although it was intended to replace it by one that would receive both spark and valve transmissions at a later date. This indicates that a crystal detector circuit must have been used although there was also facility to utilise a three-valve amplifier. One can only presume that the reason for this limitation was that a spark transmission comprised of a series of sparks at 500–1000 per second which sounded like a "buzz" in the receiver headphones. On the other hand, the valve transmission was a pure unmodulated carrier wave which could not be resolved in a simple receiver without an internal oscillator to hetrodyne the signal and produce a beat waveform in the audible range [23].

Although the valve had also been developed in Germany they had not made the progress of the Allies, as a document dated June 1918 and addressed to the XI Army Corps staff indicates, for it requested that every effort be made to capture allied wireless equipment in the hope that it might save considerable time and finance in developing their own equipment [3]. However, insufficient progress had been made to replace the older spark equipment before the armistice. It is interesting that the Germans were in a similar position regarding aircraft compasses, for there was a directive in force that the compass, if undamaged, should be removed from crashed British aircraft for use in German aircraft.

7. CONCLUSION.

By 1918 the practicality of wireless communication had been proved. With the development of the hard vacuum valve, Radio Telephony transmission was practical for equipment at all power levels and the principles remained unchanged until superseded in commercial service by Single Sideband Suppressed Carrier transmission some forty years later. Even so the Amplitude Modulation mode continues in use on the Medium Frequency and High Frequency broadcast bands to the present day.

The combination of the Scheller "*Course Setter*" with the *Bellini Tosi* direction finder led to the Radio Range which served the aviation community until the mid-1950s. This same principle using interlocking signals gave the first VHF approach aids, Lorenz and SBA, the Luftwaffe WWII bombing aids, Knickebein, X-gerat and Y-gerat, whilst by changing to interlocking tones became ILS. The principles of the Telefunken *Kompass* are today enshrined within the VHF Omni Range (VOR), TACAN and several forms of direction finders. Fessenden's 1909 patent "Method of determining the position of vessels" can be considered the basis of subsequent hyperbolic navigation systems including GEE, Decca, Loran and even, in three dimensions, GPS. It can therefore be argued that the basic principles of all non-radar navigation systems in use throughout the 20th century had been developed before the first equipment had been installed in a heavier-than-air aircraft.

The only systems not mentioned in this paper are those associated with radar. However, Christian Hulsmeyer patented a system, known as the Telemobiloscope in 1906 which could detect a ship up to a distance 3000 metres, although a ranging technique had not been developed. This, arguably, could have been the first step towards radar. It was, however, designed for use with ships and did not find its way into the airborne environment. It has therefore not been discussed within this paper.

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