LISTENING TO GRIMETON

A radio station, its listeners and its history

The World Heritage of Grimeton
Arne Sikö

CONTENTS

PREFACE

This booklet has been made possible thanks to resources granted by the Radio Historical Society of Western Sweden. Its purpose is to provide our listeners with information, relevant to this specialized group, and to better get to know them. To that end, an inquiry form was mailed to listeners who had previously sent reports of their listening to the station.

Now, this comprehensive and interesting material can be presented. Besides questions concerning such things as age and equipment, our respondents were asked what they would like to read in a booklet like this. The result was: everything - as could have been anticipated from the outset. Some emphasis has, however, been put on things not readily found in English. We hope that the result presented here can be of use, not only among listeners, but also to anyone interested in the Grimeton World Heritage.

In some names the vowels å, ä and ö appear. They can be long or short and are pronounced approximately like the English vowel sounds in “hot”, “best” and in “sir”, respectively.

The project was initiated by Kjell Markström, who also played a crucial role for the World Heritage appointment. Other indispensable contributions have been made by the staff at the radio station and members of the Alexander Association*, among them Lars Kålland, SM6NM, who has gathered and managed the listeners´ reports over the years. Many others, too, have generously shared their material, experience and time. Many thanks to all of you!

May 2013
The author

*) Also named “Grimeton Veteranradios Vänner”, meaning “the Grimeton Veteran Radio Friends”, or just Alexander.

Title-page image by courtesy of Per Hellgren.

Part one

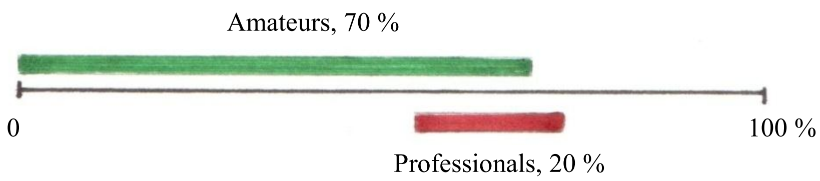
Who listens to Grimeton?

Listening where it happens… (Photo by John Strandberg.) From Alexander Day open house in 2012. Visitors are offered ear-protectors due to the loud noise when the machine is on. The life-buoys in the very rear are part of the Titanic centenary memorial exhibition.

The radio station, SAQ, has a lot of very dedicated listeners, many of whom send in reception reports after our transmissions. In fact, they start coming in on the Internet already before the machine has stopped running. The reports, always esteemed and interesting, are taken care of by the Alexander Association and by now they amount to a considerable number, carefully organized for the future.

Studying these voices from all over the world with their many nice comments is always a pleasure and it is obvious that great efforts are made with such things as preparations and experimentation. This is what has made us send out the inquiries, also with an invitation to submit ideas and proposals on any topic.

We were happy to receive as many answers as 157, making some statistics relevant. It came as no surprise that about three fourths of the participants are radio amateurs and one fifth radio/electronics professionals, most of them amateurs too, as can be seen below.



A lot of good reasons for listening were found among the answers, many giving more than one. They could be divided into the following categories:

Interested in old technics	71 comments
Generally interested in radio	35
Wave propagation at VLF	27
A challenge	25
Experiments with receivers and antennas	20
Exercising telegraphy	5
Just fun to listen	3

Some typical comments:

“A thrill to listen to the beat signals from the old station.”
“Nice to hear the old lady on air.”
“It is always a great adventure.”
“ I love radio!”
“Hearing SAQ is like hearing the sound of the last dinosaur.”
“It´s romantic.”
“… the obvious enthusiasm of the staff and operators adds to the magic.”

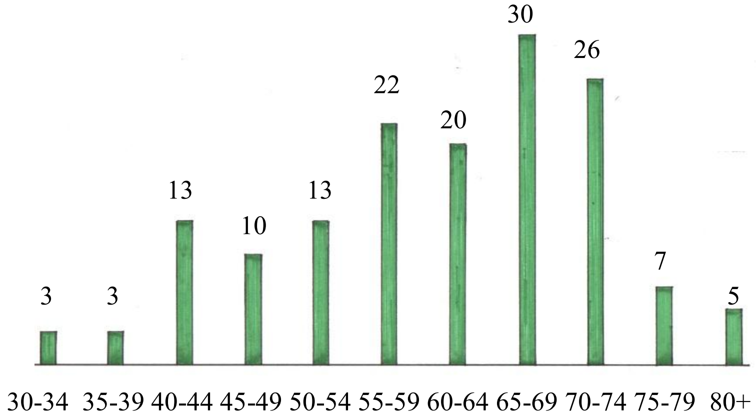
Certainly, it is most encouraging to read comments like these!

Country	Number of answers		
Austria	3	Luxembourg	1
Belgium	4	Netherlands	17
Croatia	1	Poland	3
Czech Republic	5	Portugal	1
Denmark	3	Romania	1
Finland	7	Russia	1
France	9	Slovenia	2
Germany	49	Spain	2
Great Britain	16	Sweden	9
Ireland	1	Switzerland	4
Italy	10	Ukraine	2
Japan	2	United States	4

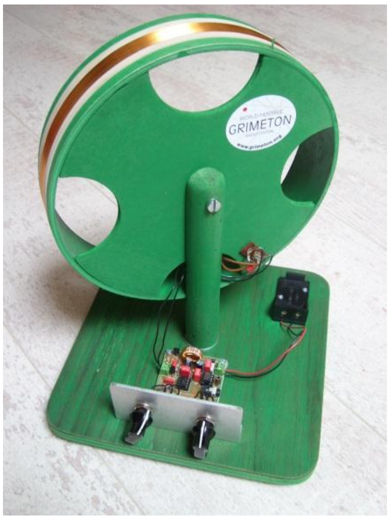
We received answers from 24 countries.

None of the participants was younger than 30 years, but five were older than 80 and the oldest 89. This is not very surprising, considering the mean age of 61 and perhaps with the general impression that the interest in historical things tends to grow with age. Also, the sex distribution differed dramatically from that of society as a whole: there was, in spite of some of the comments above, only one woman.

Listening can obviously grow into a habit. The mean number of attempts, nearly all successful, seems to be something like eight or nine. Not unexpectedly, there is some correlation with age. The greatest number, 25 times, is reported by a listener aged 78.

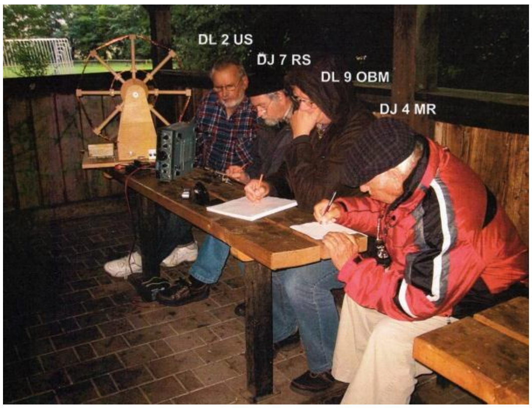


Number of listeners in five years intervals from 30 to 80 and above.



Two receivers, one new and one vintage model. To the left the Grimeton Kit Receiver, which can be bought in the shop at the radio station, here assembled and constructed by Patrick Wargée, Kapellen, Belgium. To the right Bo Samuelsson, Linköping, Sweden. "One of my vintage receivers, R1155, about the same age as me."

Common antennas are long-wire and Mini-Whip active antennas (see below), resonant and non-resonant loop and square antennas, the latter types having the advantage of less sensitivity to disturbances from electric fields since they are sensitive only to the magnetic component of the radiation. By turning them, noise from a localized source can be effectively nulled (though probably at the cost of reduced signal strength of the wanted signal). Among the long-wire antennas we find a few Beverage antennas, one of them as long as 900 metres. Also, amateur band antennas are in frequent use.



Upper left: OH7OL Reino Multanen in Finland, listening with a computer and an antenna made from a degaussing TV coil, tuned to 17.2 kHz.

Upper right: DJ8MP Fritz Lauenstein, Wennigsen in Germany, and grandson.

Lower left: Listening with DJ7RS´s home-made receiver after DL6OBJ. The receiver employs direct mixing with timer circuit 555 as the local oscillator. A feedback circuit provides higher and variable Q of the antenna part. See page 8. (Photo by DJ6GL.)

Lower right: Tomasz Dobrowolski, listening in the forests of Szczecin, Poland.

Students from the School of Technology and Management in Lamego, Portugal, with their teachers, Ricardo Gama and Nuno André. (Photo by Nuno André.) The Douro River flows below the hill.

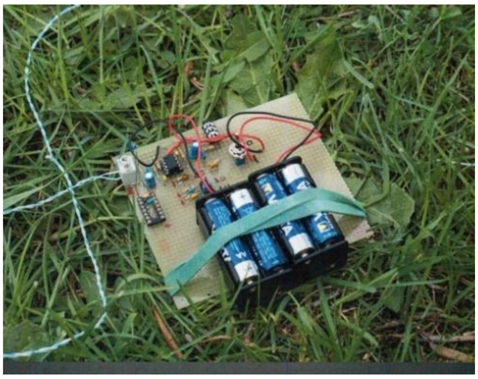
“A set up of my antenna and equipment on Christmas Eve in the dark, on the beach with a sea gale blowing in your face from the ocean is always an interesting and challenging adventure. … But there is nothing like setting up in the dark and sitting freezing in your automobile, waiting and then hearing the initial tune up usually with the Grimeton operator sending VVV´s then followed by a Christmas Message to the world.” Brech Smith, Delaware, USA.

More antennas. A Marconi antenna by Giancarlo Vadruccio, Italy, made up of a 30 metre long irrigation sprinkler. A PC was used as receiver. To the right a Various Liquids Filled antenna with a PC, Partially Crystallized receiver, designed by Lubomir Bobalik, Czechia.

The variety of reception equipment can be broken up into the following categories, the first three making up the majority:

- All-band receivers, covering the VLF band
- SDR, Software Defined Receivers
- Receivers for higher frequencies, combined with a converter
- Direct mixing receivers
- Receivers for measurement purposes

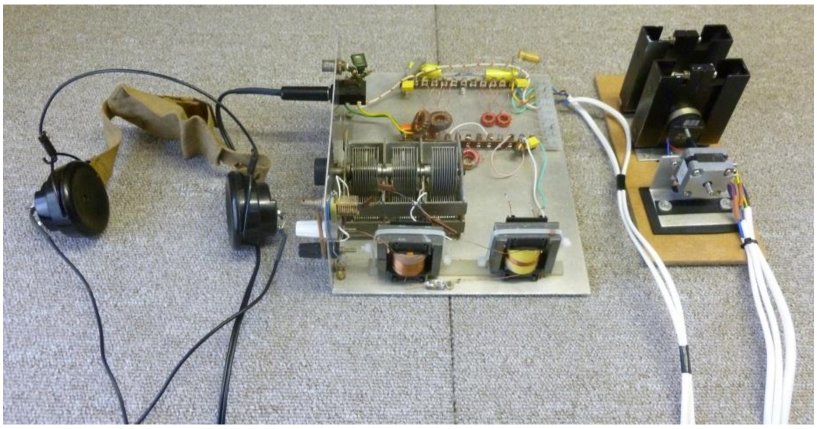
Many of the all-band receivers are reported from Germany, where some high quality models from the GDR appeared on the market after the reunion. Two of them are the EKV13 and EKD300, the first one a 50 kilogram behemoth and both from VEB Funkwerk Köpenick. Two reported Telefunken receivers are ELK639 and E1501.



From the telecom conference EUCAP 2011 in Rome, courtesy of professor Piero Tognolatti, University of L'Aquila. To the right above, the low noise amplifier with OP TL081. Below the 1.5·1.5 m^2 tuned antenna, hung in an olive tree. It had 50 turns and a Q of approximately 15. A special transmission, addressing the conference, was made. Due to the low S/N ratio in the urban area, which impeded automatic decoding, this had to be performed in the old way, by listening.

Among the receivers for higher frequencies, common models among amateurs, such as those from Yaesu, Drake and ICOM, are dominating. The accompanying converters are objects of home-building and experimentation, as are the direct mixing receivers.

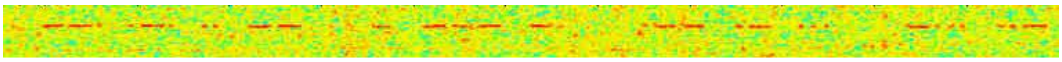
In Sweden, Gunnar Johansson, SM5ND, uses a Drake R4A with a transistorized converter and a loop antenna seven metres above ground. When, in 1995, SAQ was to make its last transmission, he made a direct mixing receiver with the valve ECH81. On other occasions, a crystal receiver set has been employed, supplied with an LF tone generator to obtain the beat, thus principally a direct mixing receiver, too.



A special design, very much in the spirit of SAQ, is Jim Moritz´, M0BMU, electromechanical receiver. It is made without valves and transistors but with a stepper motor from a hard disc drive, converted to a generator to supply the beat. It is driven by a motor, causing the main disadvantage of the receiver, a slightly erratic pitch. (Photo by Jim Moritz.)

Perhaps the simplest way of reception is to use a computer with a sound card. The sampling speed is generally at least 40 kHz, making reception up to 20 kHz possible according to the sampling theorem. At long distance, pre-amplification is usually necessary. Common specialized software receivers are the Spectrum Lab receiver and the converter by SM6LKM, both freely available. The Perseus SDR is an often mentioned, high quality receiver.

A frequently used antenna is the effective and remarkably simple Mini-Whip active antenna by PA0RDT with a full length of just ten centimetres and a frequency range of 10 kHz to 20 MHz. The round unit contains the antenna and the matching amplifier; its current supply, to the left, is placed indoors.
For best performance, the antenna/amplifier unit should be placed outside, as high as possible. (Photo by courtesy of Roelef Bakker, PA0RDT, who has more information on his home-page.)

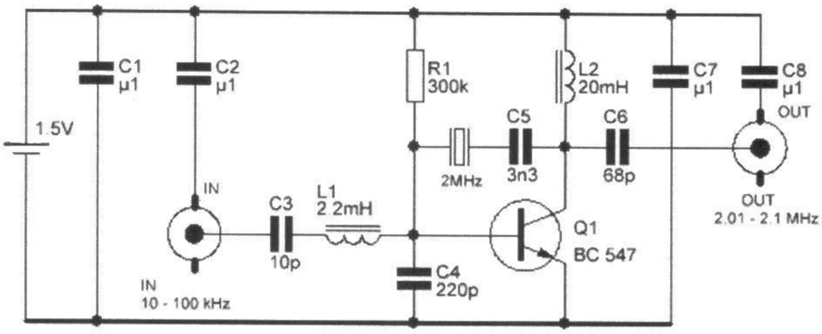


SAQ transmission on May 28 1998, received by Al Klase in Delaware, USA. To improve the S/N ratio, his 1×1 m^2 loop antenna was shielded against electric fields. As this was insufficient, the sound file was processed with the computer display to generate this fairly readable display.

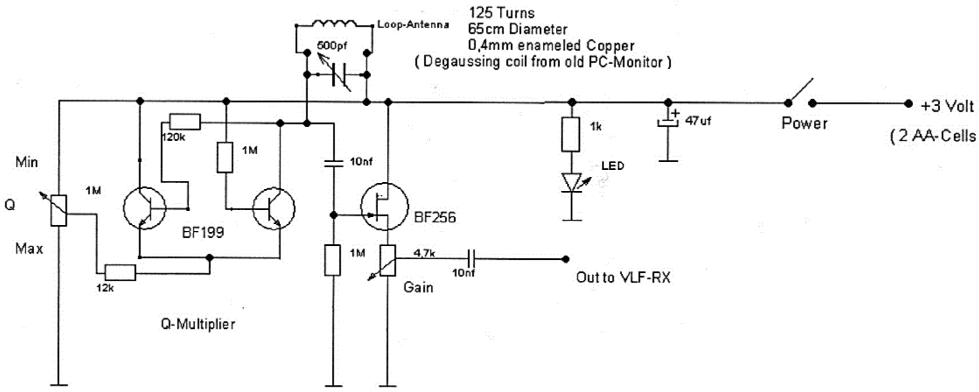
A final confirmation of the hardships endured for the joy of listening. Photo by Robert J. Mattson, W2AMI, Highland, New York 2009.

The circuits below give a glimpse of some of the experimenting work done. The VLF converter scheme has been supplied by Johnny Apell, SM7UCZ, and can be used together with several antenna types.

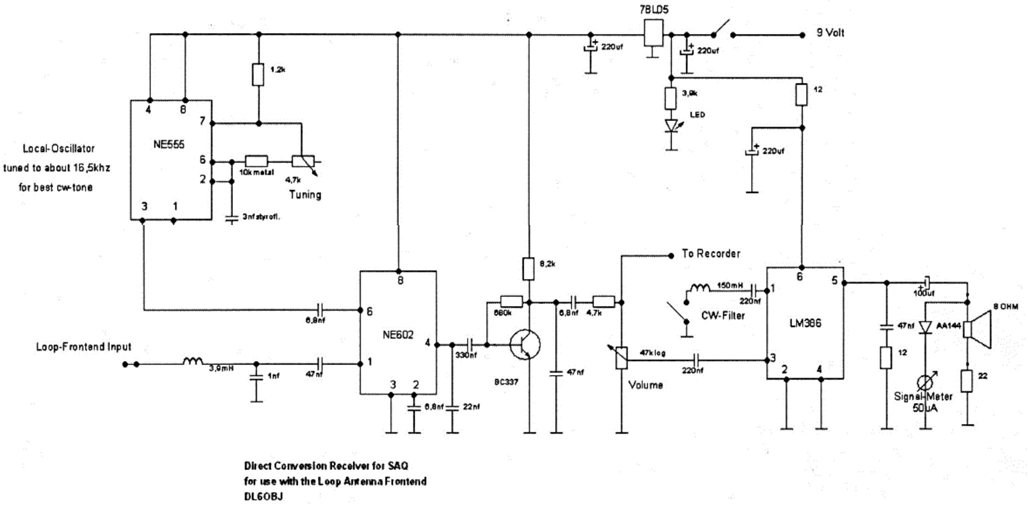
In the combined mixer and local oscillator, crystals for other frequencies will work well, too.



DL6OBJ, Manfred Reimann, has designed the receiver front-end below and the matched direct conversion receiver. The bandwidth of the antenna circuit can be varied by means of the Q-multiplier circuit.



In the direct conversion receiver the timer circuit 555 works as a local oscillator and 602 as a mixer.



Some of our listeners are submitting results of their field strength measurements, making it possible to use tables on wave propagation to estimate the output power from the transmitter antenna. As seen in Part 4, this is a very interesting thing.

A photo by Felix Elsen, ON2BE, Belgium, showing his antenna for field strength measurements and the receiver, the Telefunken E1501. The antenna is at four metres height and of a design, similar to that of PA0RDT. The electric field strength is obtained with known antenna sensitivity and with the aid of an HP spectrum analyzer. It is usually around 1 mV/m, but varies somewhat with the season and the time of the day.

Part 2
History and daily life

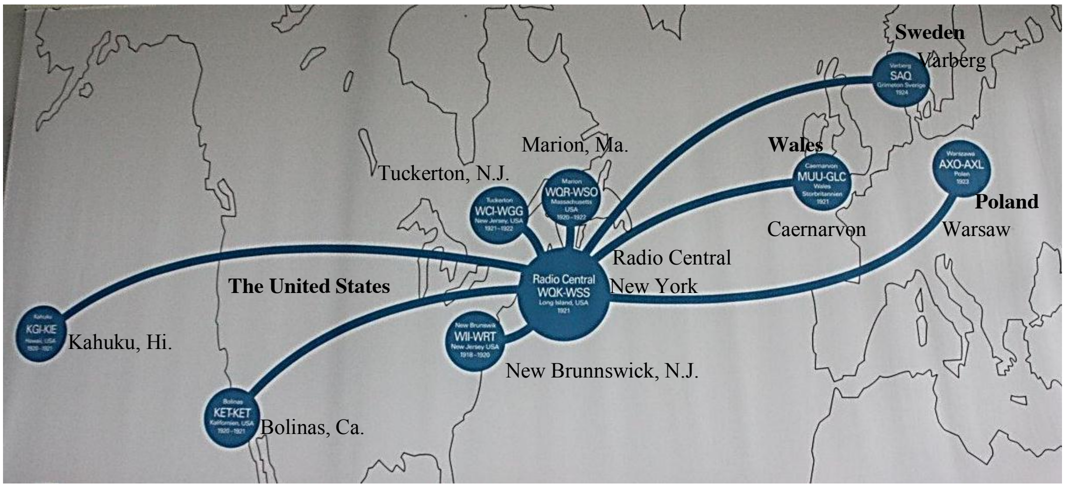
The Varberg Radio Station, Grimeton

During World War I, the vulnerability of the cable connections became obvious as they were widely broken by war actions. Soon afterwards the cables were restored, but then the rapid development of wireless technology made it usable also for long distance communication. Extended communication needs were anticipated for the post-war era, certainly for diplomacy and other peace-promoting actions, but also for the awakening commerce and growing industry. Besides, the many Swedish immigrants in the United States and the Swedish-American Institute constituted a strong pressure group, promoting a direct, wireless connection. By such means, the often time-consuming relaying in London (where foreign telegrams were not always given priority) would be neatly avoided.

In Karlsborg, on the western shore of Lake Vättern, a radio station with a long wave spark transmitter started operating in 1917 for press telegrams and weather reports for the mercantile fleet. The place was chosen because of the fortress of Karlsborg. It had been designated as a hiding place for the government in emergency cases. Its 80 kW transmitter was one of the most powerful of its kind and was intended also for regular transatlantic communication. That worked only sporadically in spite of the huge power, which however made it a strong source of interference due to the unavoidable spectral impurity, typical of all spark transmitters with their damped waves. Thus, cables still had to be relied on, supplied with a wireless connection between Karlsborg and London.

Meanwhile, several systems, capable of generating continuous waves had been developed. Therefore, in 1920, the Swedish parliament decided that a major radio station, taking advantage of the new technique, be built. Except for the Poulsen light arc transmitter, the systems employed rotary machines as radio valves could still not handle the power necessary for long distance communication. Unlike common power plant generators working with direct current or alternating current around 50 Hertz, these transmitter generators had to generate power at frequencies high enough to make reasonably efficient antenna systems possible. Also, the attenuation of the signals should not be too strong. As will be seen later, this implies frequencies above 10 kHz.

One of the systems, introduced by Reginald Fessenden, the Canadian inventor, was around 1918 further developed into commercial standard by Ernst Alexanderson, chief engineer at General Electric. It could deliver 200 kW to the antenna at frequencies up to 30 kHz, was sold by RCA and finally approved by the Swedish Communications Administration.



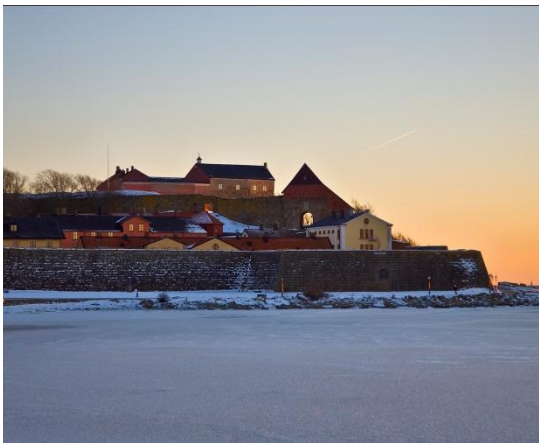
Wall map of Europe and the United States in the visitors´ centre, showing the locations (with names added) for the Alexanderson transmitters. (Photo by the author.) From New Brunnswick, messages were sent to the U.S. president Woodrow Wilson during the peace negotiations in Versailles in 1919.
Ernst F. W. Alexanderson (1878-1975) was born in Uppsala, not far from Stockholm. After having finished his studies, Alexanderson moved to the United States where he was employed at General Electric in Schenectady, New York. Some of his patents were filed in connection with the work with the rotating transmitter "the Alexanderson alternator" and its antenna system. This, "the multiple tuned antenna", had an acceptable efficiency thanks to an idea by him.

After the decision to build the station, officially named Varberg Radio, a suitable site had to be found. Electromagnetic radiation at the frequencies involved would propagate with acceptable attenuation over conducting surfaces such as saline water, but not so well over dry land. With the radio central situated at Long Island, New York, a glimpse at a globe immediately reveals that a great circle from there to Sweden practically entirely crosses water, provided it hits a hundred-kilometre-long coast-line a little south of Gothenburg, in the county of Halland.

The place chosen in 1922 was Grimeton, situated at a slightly elevated area ten kilometres from the coast and the town of Varberg. The soil was suitable, the railway then passing by was essential for the host of material to be received and the distance to Varberg secured that battleships of the day could not possibly bombard the installations. Apart from the technical considerations, it was noted that the name lent itself nicely for pronunciation in any kind of English. By the way, Grimeton is a typical, old Swedish place-name, meaning "Grim´s yard".

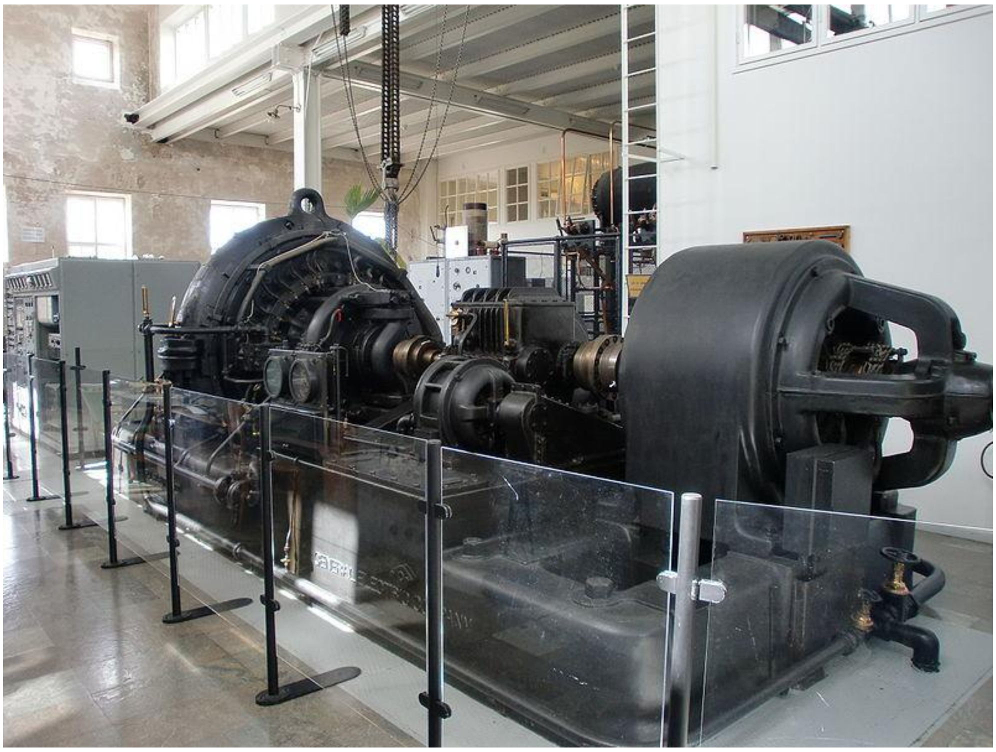
The area around Grimeton was, as it still is, essentially a farming land. Thus, the negotiators, sent out from the Communications Administration in Stockholm, got farmers as their counterparts when trying to buy the necessary piece of land, 100 acres. The farmers knew they had to sell, but were good at bargaining and determined to make the best of the situation. So, though the two men from the capital were very well received, they had no easy task; nobody was willing to be the first to propose a price. A natural suspicion of what was going on could hardly be avoided. One notable rumour was the concern that the cows might yield less milk. And would the anticipated long and short Morse signs appear as sparks on their way to America? (Considering the spark transmitters at the time and the nickname of their operators, one might see a possible origin of the slight technical misconception, which anyway probably is not much worse than many such things today.)

The hospitality, which would had been impolite to turn down, frequently caused the negotiators to abandon their work early in the afternoon – in a state of "very good mood" - and one of them had to be replaced. Eventually, things were settled and soon cows could go on pasturing in the fields around the towers, as their descendants are still seen to do.



When visiting Grimeton, a trip to nearby Varberg will pay off. The old fortress has seen the struggles between Danes and Swedes for centuries till the county finally was Swedish. Its museum houses "Bockstensmannen", a unique moss-corpse from the fourteenth century found not far from Grimeton, with parts of his body and most of his clothing surprisingly well preserved. A pattern of the clothing can be bought. The town offers spa, fine bathing and in summertime fishing tours starting out from the harbour. (Illustrations by courtesy of the County Museum of Varberg.)

Work started in the autumn of 1922. During the construction work, up to three hundred persons were employed. Two hundred kilometres of copper wire had to be buried half a metre below ground, the digging done by hand and requiring about five man-years of work. The towers – named so because, unlike masts, they stand for themselves - were designed in Sweden. Their first fifty metre high sections were riveted in two parts in advance, lifted by means of an auxiliary mast and joined. After that, the girders of the frame-work were attached gradually. In spite of the primitive arrangements no serious accident ever occurred.

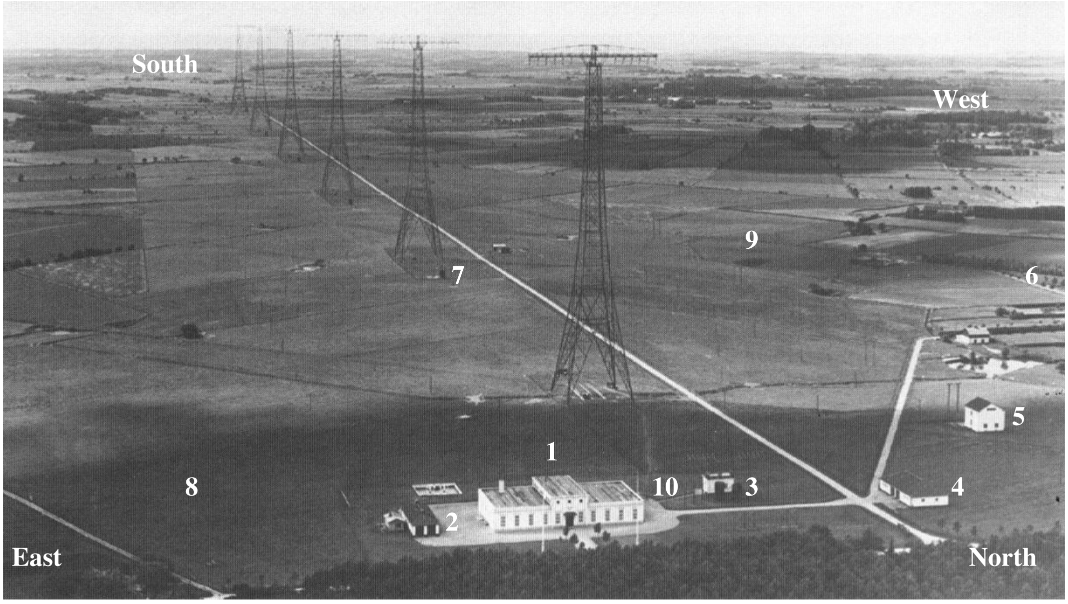


The Alexanderson alternator, total weight 50 tons. (Photo by the author.) A gear-box connects the motor, right, with the generator to the left. An oil pump for the gearbox can be seen in front of it. The over-all length is six metres and the diameter of the generator is two. The motor is a 450 kW two-phase induction motor, a common type in the US at the time. The rotor inside the generator has a diameter of 1.6 metres and rotates at a peripheral speed of 650 kilometres an hour. Two such units were set up and arranged in line, generator next to generator, to make it possible to connect their shafts for double power, should it be needed. There is, however, no report of that option ever having been used.

The first frequency allotted to SAQ, 16.7 kHz, was soon changed to today´s 17.2 kHz, corresponding to a wavelength of 17.4 kilometres. Because the efficiency of the antenna was calculated to 13 per cent, at the maximum output of 200 kW from the transmitter, the total electromagnetic output was 26 kW.

The first message was sent on December 1, 1924 and the following year, on July 2, 1925, the station was officially inaugurated by His Majesty King Gustaf V sending off a telegram to the US president Calvin Coolidge.

To send a telegram from somewhere in Sweden, people had to go to the local telegraph station, where it was paid for. The telegraph officer forwarded the telegram to the radio central in Gothenburg (later Stockholm) on a telegraph line, in the beginning by keying it in Morse code. There it was received and transformed to punched tape, the configurations of the round holes corresponding to Morse signs. The tape was fed to a transmitter which generated the long and short electric signals conveyed to Grimeton along a telegraph line. At the radio station the signal automatically acted on the alternator by means of relays, i.e. no telegraph operator was needed there.



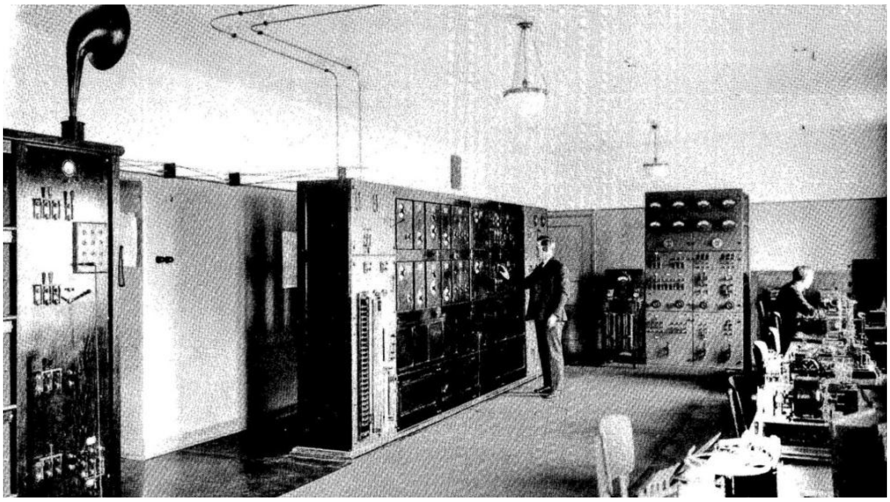
An old photography, taken before the short wave era. The height of the towers is 127 metres and the width of their upper beams 46 metres. The 2-kilometre-road along the row of towers is still the same. Points of direction are approximate.

1. Main building with transmitter hall, workshop, library and administration. It was built in neo-classic style and is essentially the same today.
2. Nowadays housing exhibitions and "Alex Lab", where children and adults can perform experiments.
3. The "snow melting house", with equipment for sending current through the wires of the top net to melt ice. Surprisingly, it has never been used.
4. Garage and store.
5. Transformer house, from which the 2 kV under-ground cables to the main building emanate.
6. Part of "the radio village" with houses for employees.
7. One of the six huge coils, connecting the radiating, vertical conductors to the ground net.
8. and 9. Locations of what are today the visitors´ centre and the "new station" respectively, the latter housing TV and FM transmitters.
10. Now a small mound with a shelter below and a fire-shelter beside.

From the beginning, a major part of the telegrams from Sweden to America were sent from Grimeton. The transmitter could send 100 wpm (words per minute) corresponding to 500 characters per minute, but the usual speed was about 25 wpm. To use computer language, the latter corresponds to 10 bits per second, indeed very little compared to the millions of bits per second in computer net-works of today, but quite sufficient at the time. After an urgent telegram was handed over in Stockholm, it was received in New York within less than six minutes and could be forwarded or delivered by bike by an army of telegram boys. The short delivery time was essential because, due to the time difference, Swedish and American offices were open simultaneously for less than two hours.

Thus, it was possible to get an answer already on the same working day, an advantage, too, in the competition with the cable companies. As to the fees, in 1925 a standard telegram wording “Hearty congratulations” would cost five Swedish crowns, a sum amounting to a day´s salary for a worker. Being saluted in this way was a precious thing!

The transmitting station was given the international call sign SAQ. It is part of a scheme, according to which S is the first letter for Sweden and the second anything from A to M. Thus, in early days, it was natural to choose A after S. Q was chosen arbitrarily. S fits well for Sweden, but that is not very typical. For Poland it nowadays starts with SP and many call signs of US stations use W, for the Long Island radio station WOK and WSS.



Above: Interior of the receiving station. The cabinet in the middle contained two elaborate RCA receivers with coherent detectors, designed by Alexanderson and made to suppress the frequently strong noise due to electric discharges in the atmosphere.

Right: The house of the receiving station today. (Photo by Lars Kålland.) The building, situated in the town of Kungsbacka between Grimeton and Gothenburg, is now a private house. Unfortunately, nothing of its former equipment remains. A plate outside reminds visitors of the past and the exterior is not to be altered.

The receiving station, which had to be at some distance from the transmitting antenna, was placed in Kungsbacka, on the coast 50 kilometres from Grimeton and was assigned the call signal SAK. It was equipped with a Beverage antenna, stretching thirteen kilometres on poles into the countryside along the great circle to New York. Contrary to the transmitting antenna, this one was directional, attenuating signals from the sides as well as from the opposite direction. In 1938, the receiving station was moved to the radio centre in Enköping, closer to Stockholm.

Daily life at the station

Apart from managing the machines, a lot of very different tasks had to be dealt with. They included such things as maintaining the antenna and the cooling pond, digging for cables, making tools and other mechanic details, clearing woods and flower beds – also in the station head´s garden - chopping fire-wood, repairing bicycles, shoveling snow, loading and raking gravel, cleaning house and machinery and making inspection tours with the car.

The old station car, a 1931 Chevrolet, on display on an Alexander Day.
Due to tender maintenance it is still functioning and used on ceremonial occasions. (Photo by John Strandberg.)

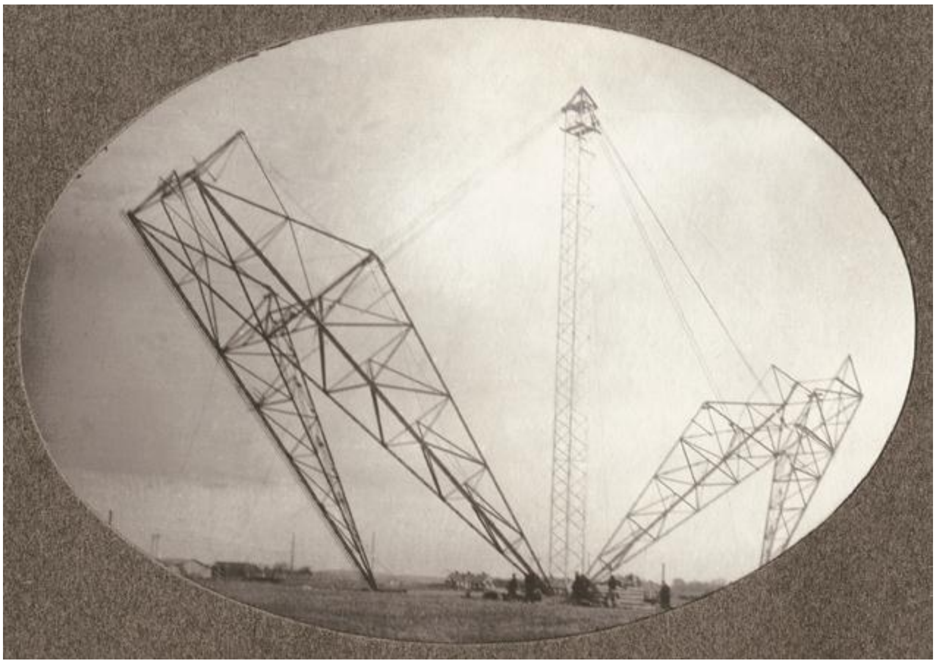
The maintenance of the antenna was a very conspicuous part of what had to be done. Nobody was forced to work in the towers, but as it was better paid than other assignments very few refrained. Due to the harsh weather, the towers had to be repainted about every tenth year, which included very careful removal of the old paint before the new could be applied. A time-consuming matter of great concern was the many mechanical security couplings between the upper conductors – twelve at that time – and the beams of the towers. They would break apart if the load of the conductors was too high and so leave other parts without damage. Such an incident occurred in 1954.

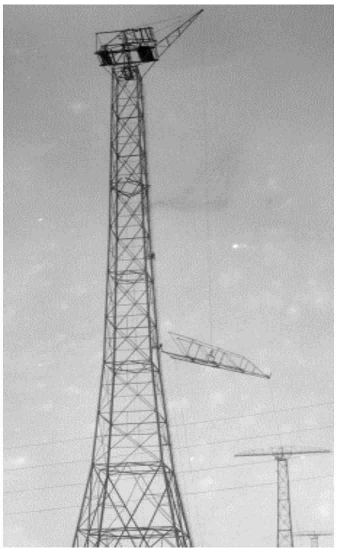
Much of the job was performed with the aid of iron-lined, wooden ladders. Lifts, in the beginning with manually turned shafts, went high up in the towers, but if there were many men working at the same time, the capacity of the lifts did not suffice even with one or two men more than they was made for. In such cases, the ladders on the outside of the towers were used. Occasionally, a father might bring his child for a tour in the lift.

The voltage to earth at the upper parts of the coils for the vertical conductors could reach 130 kilovolts and the fields around were accordingly strong. That called for fences, then wooden, around the coils. Frequently the staff in charge had to turn out after a fence was set on fire by the action of the fields. (So, maybe the concern about the cows was not too far-fetched.)

To the left, Oskar Svensson and Ivar Olsson in the forties, having lunch (photographer unknown). To the right, Bo Johansson in the fifties, seated in one of the very airy lifting-chairs while scraping rust. (Photo by Bengt Rylander.) For each tower, 400 kilograms of red lead was needed for the first layer of painting. Aided by the wind, it now and then happened to colour the face of the painter or the bread to be eaten, a matter reported having been of no great concern, however.

During extended periods of time, the transmitter was running day and night and so, the engineers – for many years two – and the machine personnel had to work in three shifts. Every hour, a journal had to be filled in with machine data. The proper function of the machinery was of major importance and thus thoroughly regulated their lives. Ear protectors were not allowed until in the sixties as they might let jarring from “the roaring giant” go unnoticed. Still, it happened that people put wax into their ears though that rendered a rebuke if discovered. When attending a transmission today, one cannot but wonder how the machine staff were able to stand that noise day after day. Also, the strong electric and magnetic fields in the transmitter hall might be a matter of concern. However, there were apparently no problems attributed to that, the most common occupational injury was impaired hearing.



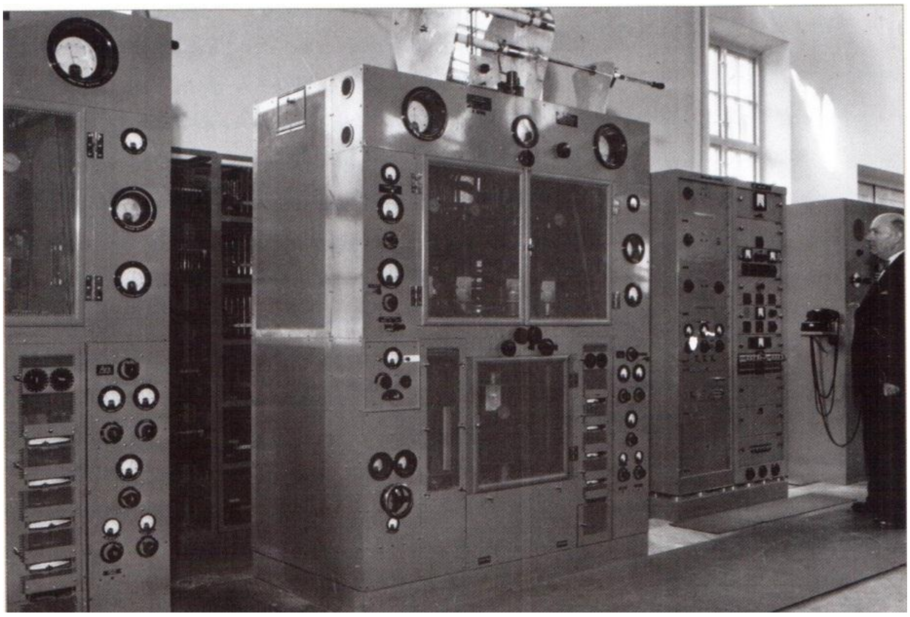


Some old photographs.
Above, the two parts of the first section are joined by means of the auxiliary mast.
To the right, an upper beam on its way up.

Below, the transmitter hall before the era of short wave transmitters. There are two similar machines, each with its own manoeuvre panel and antenna coupling unit (to the left). The remaining machine is partly hidden. The area of the antenna coupling units is nowadays partly occupied by short wave transmitters. Between their round transformers and the roof there is sufficient space so that a separate floor could later be built. From there, the photo at page 1 was taken.

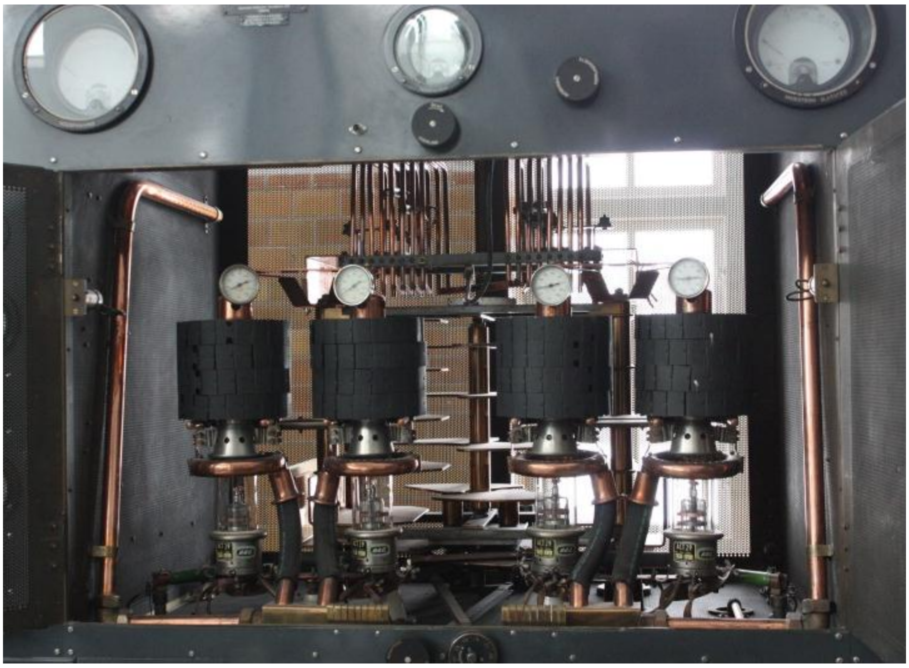
The tasks increased when the short wave transmitters made their entry in the thirties. Antennas had to be erected all over the area. The frequencies of the manually maneuvered transmitters had to be altered in accordance with both daily and seasonal schemes, calling for changes of coils, adjustment of capacitors, grid currents and so on. Though the voltages in the transmitter cabinets could amount to several thousand volts, no very serious accidents have occurred. Of course, the transmitters – there were at most sixteen of them – required a lot of maintenance. It was well known in those days of radio valves that a push in the side of an apparatus making trouble might help, but in Grimeton more scientific methods reigned. Veteran Bo Johansson says, "I learned not to kick the short wave transmitters when they would not work. You had to talk to them instead; we learned that every transmitter had its own personality."

In 1925, Hans Palmqvist moved from Karlsborg to take over as head of the station. There he stayed for forty years and thus became an active part of a great development, starting with the short wave era in the thirties and followed by FM radio and television, with the war as a sad interlude.



Hans Palmqvist, Master of Engineering and legendary head of the station for forty years, inspecting some of the short wave transmitters in the fifties. Today, they are a part of the Heritage. The unit in the middle is a 7 kW Marconi transmitter for 2-27 MHz, installed in 1946. (Photo by Robert Almqvist.)

With Palmqvist, a man of his time, the radio station was very much like an industrial community with himself as the unquestioned boss. When a trade union was started after the war, he reacted reluctantly, but quite soon he got accustomed to the novelty. He was regarded as a fair boss, always defending his employees if they were attacked from outside and proud when they performed well in football or pistol-shooting competitions. During the bad times in the thirties, he employed many young men (the youngest being fourteen), expressing as his opinion that “we had better have them here doing little than at home, doing nothing”. In this way many became skilled craftsmen, very much encouraged by Palmqvist. Things like these certainly helped to make the radio station a matter of interest for the whole community around.



Inside one of the Marconi short wave transmitters. Four air-cooled valves are seen, between them parts of a variable capacitor and above them two coils. (Photo by the author.)

The war inflicted dramatic changes at the now strategic radio centre, besides the intensified telegram traffic. Already in late August 1939, the localities were closed to outsiders and admittance to the area as a whole was restricted, with Alsatian dogs deterring unauthorized visitors. After the German invasion of Norway and Denmark, such an assault on Sweden was an urgent issue for some time and Palmqvist had to order a black-out. In the radio village, weeds on walkways had to be allowed to grow so as not to be seen from above and climbing plants on houses must be only slightly pruned. For the antenna, there was some concern about possible wayward barrage balloons.

Sand bags were put on the roof of the main building, its windows were taken away and replaced by planking and the whole building was repainted green. Planking was also set up around the main building to protect it against shooting. Shelters were excavated, the one near the main building now easily seen by its mound and remaining adjacent firing shelter. Soldiers were on guard at the gates and a firing shelter was built in the first tower, forty metres above ground, still there to be seen. Now, the peaceful station had turned into a frightening place, by many described as almost ghostly.

When the author visited the station with students in the nineties, we were welcomed by the head of the station, Bengt Dagås, "Mr. Grimeton", who demonstrated the installations in his enthusiastic and pedagogic way. Many things were discussed, except one: How come that the antenna was still there, in strikingly good condition though the machine had not been used for any commercial purpose for more than fifty years? It had been cared for at considerable costs, about half a million crowns or 50 thousand Euros for the repainting of each tower, seemingly to no avail.

Towards a World Heritage

Bengt Dagås, watching instruments on the man-oeuvre panel. Dagås, engineer and highly esteemed head of the radio station 1976-1999, took an important part in the documentation work, necessary for the possibility of acquiring World Heritage status.

As a matter of fact, with the Alexanderson alternators the radio technique of the pre-electronic era had been taken to its limit and the one in Grimeton was the last one to be built. That might have added to its quality, but by then the first promising experiments with short wave communication were already carried through. In the late thirties, when short wave transmitters were installed and could take over some of the service with far less power consumption, the use of the machine started declining. Thus, becoming obsolete already in its infancy, the machine could be described as a dinosaur when smaller, more sophisticated creatures took over. However, it had some advantages and e.g. allowed more reliable connections during the dark part of the year, and so stayed in regular service till a little after the war, when it was on air day and night. The employees were as many as fifty-one in 1965.

What we did not know – and nobody would or could tell at that time – was that the station had been used for submarine communication by the Swedish Navy. Very low frequency waves can penetrate down to thirty metres of saline water, whereas those of higher frequencies are effectively absorbed. So the machine had been used already during the war, notably when a Swedish submarine, Ulven "the Wolf", was sunk off the west coast.

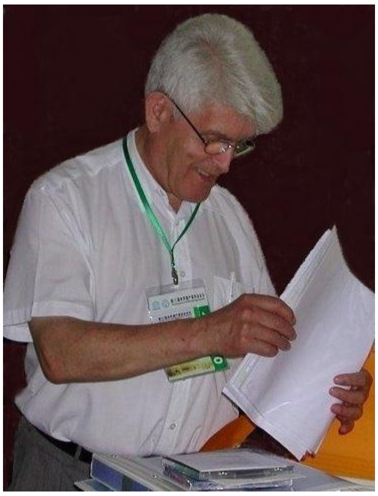
In the sixties, a modern transmitter with valves had been installed in a separate house in the surrounding field and also, in 1960, one of the machines had been scrapped. The other one was left and kept in reserve, but when the cold war came to its end, the interest of the Navy did so too, and Swedish Telecom considered scrapping the remaining machine. A very last transmission was to be carried through in September 1995 and address the conference of IEEE in London, "A Hundred Years of Radio".

But now the idea of saving the station for the future had emerged, not only among local people and radio enthusiasts worldwide. Strong support was given by the county of Halland, the town of Varberg, the Swedish National Heritage Board and the Radio Services of Swedish Telecom. A non-profit society, Alexander, with many local members had been created in 1996 and gave additional support, enhanced by many outstanding individual contributions.

So, in 1996, the county of Halland listed Grimeton Radio a national industrial monument, a distinction followed in 1997 by its appointment as the nationally foremost industrial monument of the year. But already the possibility of it becoming a World Heritage had been considered. A passage of a transmission on the first day of the year 2000 hints the main reason, when the King of Sweden, H. M. Carl XVI Gustaf, sent out a state telegram from the old transmitter, received as far away as in Minnesota, USA:
…Today the unique radio transmitter at Grimeton meets a new millennium. My message today is, however, the same as that sent by King Gustaf V seventy-five years ago. With modern technology and a means of communication, the possibilities of deepened understanding, peace, democracy and free exchange of opinions between the people of the world will increase…

The telegram very explicitly states the main goal of UNESCO, the United Nations organization for education, science and culture, founded in 1945 as a consequence of the war. Its "Convention on the Protection of the World´s Cultural and National Heritage", was founded in 1972.

Endorsed by the Swedish Government, an application for the status of World Heritage was submitted and finally approved at a UNESCO Committee meeting in Sozhou, China, in 2004.



From the 2004 UNESCO session in Sozhou. To the left, the head of the Swedish delegation, Kjell Markström, checking documentation. (Photo by Mats Folkesson, one of the four Swedish delegates.)

To celebrate the expected approval of the application on July 2, public festivities in the central market-place of Varberg were planned. That turned into a real thriller, and only at a very late hour of the necessary preparations for the celebration, with people already gathered, was the approval finally announced.

Initially there was a one year delay for negotiations with the ministry of defence, not accustomed to the wanted status of installations used by the Navy. In the session, the two hundred UNICEF states were represented by the 21 panel members, none of them from Sweden. When Grimeton was discussed, the representative chosen to submit the report did it in a partly misleading way (emphasizing the buildings, not the historical technics) and two of the panel members strongly rejected that an only 80 years old site be a world heritage. However, by an intervention by Mats Folkesson at a critical moment the situation was saved, to the very great relieve of the Swedish group. Also, the Norwegian delegate who represented Sweden among other things called attention to the fact that important technical installations might be relatively recent things.

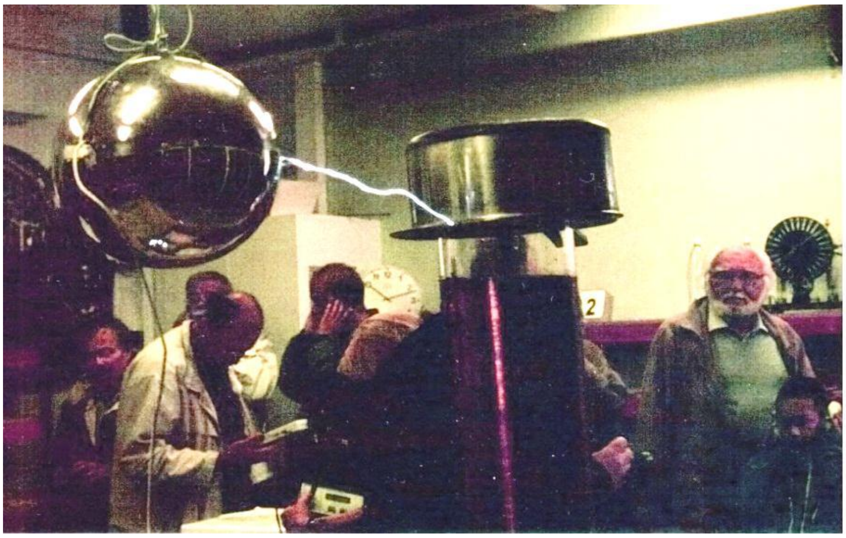
Swedish Telecom generously donated the station to its present owner, the World Heritage Foundation of Grimeton, which is run by a staff of eight persons. The role of UNESCO is to make sure that the site is maintained in accordance with its rules, by inspections every five years; it does not contribute financially. For special, occasional projects such as new buildings, the county of Halland or other authorities such as the Central Board of National Antiquities might contribute, but on the whole the foundation has to rely on itself for salaries, maintenance etc. A very small part comes from entrance fees, but more from the Navy for leasing the antenna and from telecom companies for using the shortwave antennas on the site in connection with equipment installed in the transmitter room. Costs for painting the towers are to some extent held down by employment measures.

The visitors´ centre opened in 2005 and provides information on the World Heritages, to this day thirteen in Sweden. It comprises film facilities, a permanent exhibition, cafeteria and shop. Occasionally, public lectures and special events such as science cafés are given.
In the background a short wave antenna from the sixties can be seen hovering above the transmitter building.
Photo by Patrick Wargée, visiting Grimeton on a tour with friends through Sweden on mopeds.

Grimeton today

Alexander member Lars Kålland (SM6NM) in his telegraph officer´s uniform, keying the transmitter on Alexander Day in 2010. Due to the heavy noise, he needs earphones to hear his keying clearly. The visitors are offered ear protectors which also serve as earphones for listening to the speaker. This time, the message paid tribute to the centenary of the SOS signal. (Photo by Mats Gunnarsson.)

As was a clearly pronounced goal from the outset, the radio station in not just a museum, but has evolved into a very active place. “Alexander Days” with the transmitter on the air and other events for the general public had started in 1996, usually taking place on the first Sunday of July. They are arranged by the Alexander Association and attracted as many as 1600 visitors on July 2 1995, when the visitors´ centre was inaugurated, one year after the World Heritage appointment. Two transmissions are made and announced in advance on the home page of the Alexander Association, www.alexander.n.se and on that of the World Heritage, www.grimeton.org. For some of the transmissions, listeners´ reports are confirmed by QSL cards.



Activities in the Alex Lab. Staff member Jennie Helin guiding through the station. She is the first woman learning to run the transmitter. Here a part of the Titanic exhibition of 2012 is demonstrated. The radio cabin is from a Swedish ship, from the same time as the Titanic and quite similar. (Photo by John Strandberg.) Below, a Tesla transformer in action. (Photo by Magnus Anell.)

During summertime, the station is kept open for visitors. Information plates in Swedish and English give an overview and guided tours are made by dedicated guides. On the last evening tour on Tuesdays, the transmitter is started up by Alexander members and the procedure explained. The transmitter cannot be put on air, but the rest is done in an authentic way and the members, well acquainted with the function of the transmitter, are keen to discuss and answer questions.

Any time of the year groups are able to book guided tours. For specialized groups, Alexander members can do the guiding with more and deeper emphasis on technical items.

Grimeton veteran Bo Johansson – earlier seen in one of the towers – who worked at the station for forty years from 1952, giving a speech to visitors. Alexanderson life-size and two old short wave transmitters are seen to his left. In the background, two members of the Alexander Association are ready to assist answering questions.

Inside and outside the Alex Lab (photos by John Strandberg and Gösta Öborn). Left: Children and their parents making experiments. Right: A boy with a receiver tries to find hidden, small transmitters sending Morse code signals.

Following Alexanderson, the Alex Lab is open for simple experiments, young people being the important target group. The Morse code can be practiced, a small spark transmitter is ready to be keyed and the action of magnets and electric currents can be studied.

The foundation closely cooperates with Alexander – its members working voluntarily - for technical maintenance, events such as special days for radio amateurs, education, guiding and keeping the machine and its auxiliary systems in good condition. Courses, practical as well as more theoretical, are important for the future. The transmissions, of course, provide good opportunities for practise and understanding the machinery.

Alexander members preparing for the cooling pump to be started for a Christmas Eve transmission.

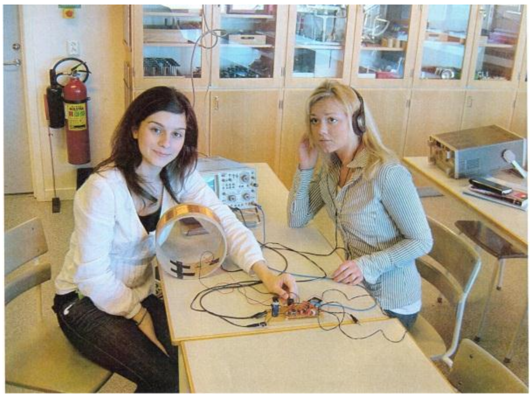
World Heritage staff in front of one of the huge coils after having replaced a defective insulator. (Photo by the author.) When preparing for the UN Day transmission in 2012 by running the transmitter in the morning, fire was seen around an insulator (though not in the coil). After the machine had been quickly shut down, the insulator could be inspected and found to have cracked. However, a new one could be put in place and the scheduled transmission was carried through as planned. As usual, when the transmitter was set on air, the alarm of the station car in the vicinity was activated.

All six coils have been replaced between 2010 and 2012, resulting in many reports from listeners, noting improved reception. The old coils were the original ones, obviously overdue to be replaced. Finding a manufacturer of new dragon insulators proved not to be very easy. (Photo by Olle Kjellgren.)

Since 2006, special transmissions are made on the mornings of Christmas Eve. On that day a hundred years ago, Fessenden succeeded in amplitude modulating one of his small rotating transmitters, making it heard on the North American East coast. To the extreme astonishment of the radio operators, who could hardly believe their ears, a Christmas message was read and Fessenden played his violin in this first broadcast transmission of the human voice. That was worth celebrating, and so a tradition started. The Swedish Navy has to be consulted in advance but is always complaisant, willingly entrusting the Christmas celebrations to Alexander.

At a science café in the visitors´centre, professor Håkan Pettersson from the University of Halmstad explains the mysteries of nano technology. (Photo by Charlotte S. Helin.)

Students belong to a group given high priority. For that reason, classes are invited to be guided and encouraged to carry through projects, related to telecom and electricity in general, technics as well as history and their impact on society. Alexander members occasionally can give lessons in schools.



Two students, testing a receiver for SAQ in their physics laboratory and an Italian class with a Swedish teacher in the background. In spite of the simplicity of the receiver, the transmission was successfully received in Italy.

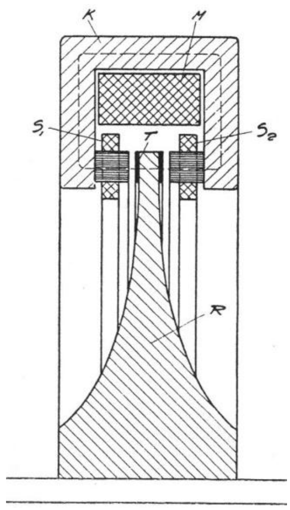
Part 3
Transmitter and antenna

How the transmitter works

The bandwidth needed to transmit Morse code is small, calling for narrow-banded receivers. Thus, the frequency of the transmitter must not vary much from 17.2 kHz, in this case preferably not more some 20 Hz, i.e. about one part in a thousand, no easy thing to obtain with a motor in the early days.

To achieve the comparatively high frequency needed, the generator had to be given a special design. Its revolving part is a steel disc, in its periphery toothed with 488 teeth, moving along the poles of 64 electro-magnets, one of which is drawn in the figure. The teeth are interleaved with brass to make the disc smooth in order to avoid too heavy air resistance. Their function relies on the periodic variations of the magnetic flux due to the different magnetic properties of steel and brass.

Still, the power losses in the generator are so high that it has to be water-cooled, but even so, its temperature rises to 90 degrees centigrade. No photographs of the interior of the generator are available, but with its many windings it is certainly a hot and crowded place.

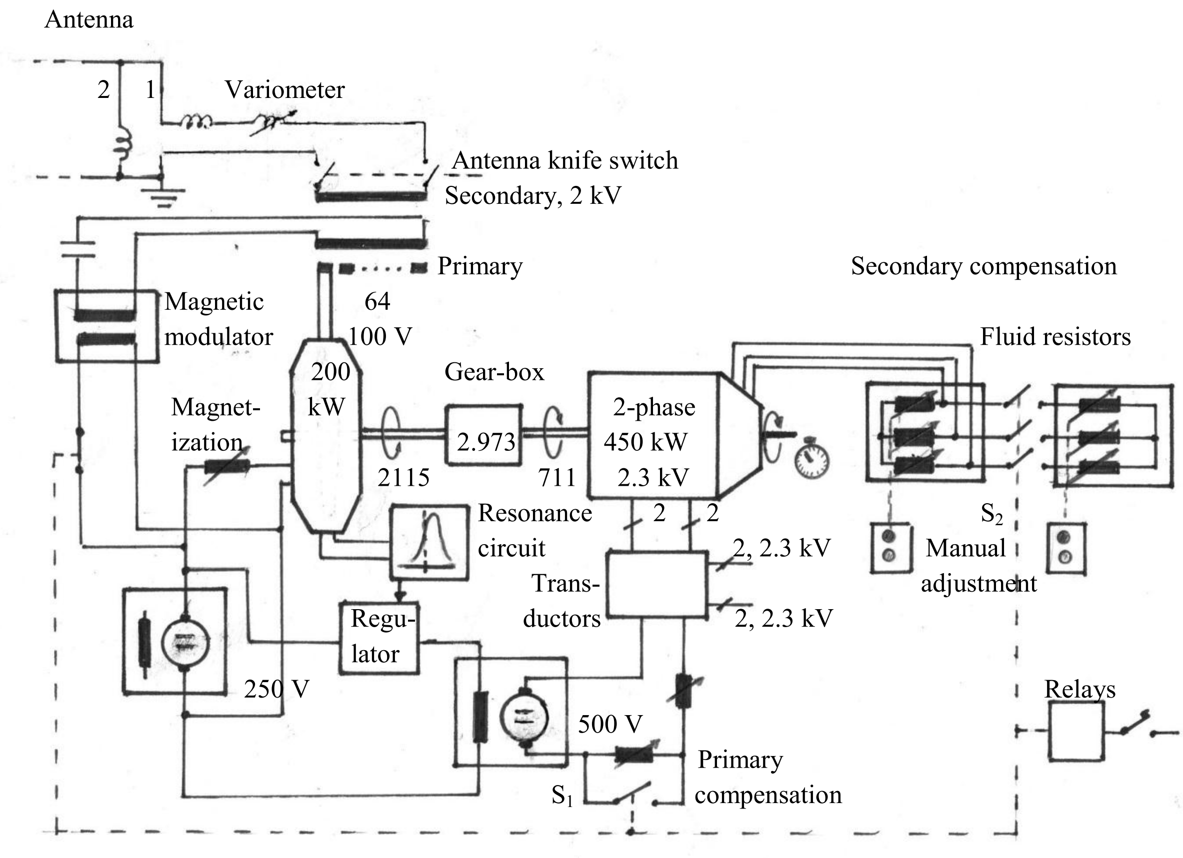


The generator. The illustration is taken from a paper, published in 1921 by the Royal Telegraph Service. The periphery with its teeth T, 0.8 metre from the axis, rotates between the poles of electromagnet K, magnetized by the field winding M (half of which is shown). Its current is taken from a 250 V generator as shown in the schematic diagram below.
As brass, like every other non-magnetic material, resists magnetic flux, this varies when alternatively iron and brass pass. According to the induction law, these variations induce a voltage in the armature winding S_1-S_2. Each of the 64 windings can produce 100 volts at 30 amperes, i.e. 3 kW or totally $64 \cdot 3$ kW ≈ 200 kW.
The nominal speed of revolution is 2115 rpm, i.e. 35.25 per second. Thus, every magnet is passed by $35.25 \cdot 488 = 17202$ steel/brass couples every second, making the frequency 17.2 kHz.

The motor is a two-phase 2.3 kV, 450 kW induction (asynchronous) motor. This phase arrangement was common in the US at the time, but the rotor is wound for three phases. The motor voltage is obtained from the 50 kV national grid by means of a Scott-coupled transformer in the transformer house.

At 17.2 kHz the motor runs at 711.3 rpm, increased to 2115 rpm in a gear-box. Today, the frequency is measured accurately by a direct-reading frequency meter, unavailable in earlier times. Instead, a revolution counter was installed on the out-going motor shaft. After being zeroed, the number of turns was measured with a time-keeper for three minutes and if the result was 3 times 711.3, the operator could be satisfied.

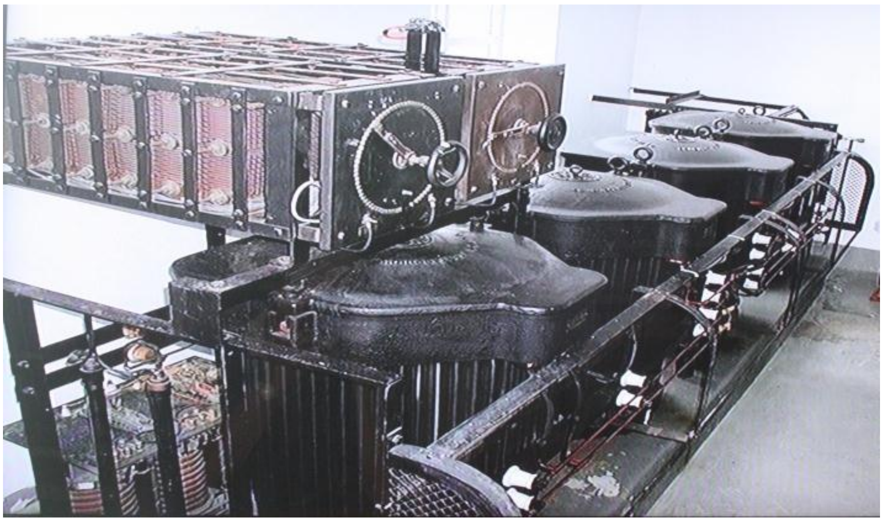
The rear part of the motor, with counter and time-keeper to the right, still in use for authenticity. The three cables from the fluid resistors are connected to the slip-rings through brushers. (Photo by the author.)



Schematic diagram of the transmitter. The motor is fed through two cables from the transformer house, providing the transductor unit with two 2.3 kV voltages 90º out of phase, which generates the rotating magnetic field inside the motor. The radiators 1 and 2 of the two first towers have been marked. The variometer is a part of the antenna coupling unit (see page 33).

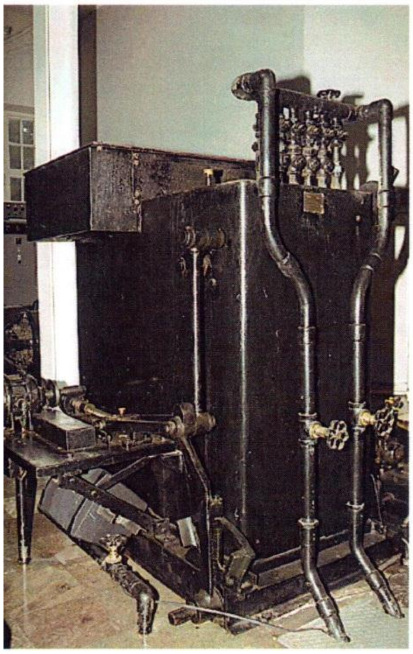
Speed control is implemented in three ways: primary compensation, secondary compensation and frequency feed-back.

The primary compensation acts on the incoming current to the stator winding of the motor. This is accomplished by transductors, common till the seventies when power electronics took over. A transductor contains a main winding for AC, passed by the current to be regulated. A DC winding on the same iron core acts as regulator winding. By varying its DC current, the core is made more or less saturated, thereby acting on the impedance of the main winding.



Above: The four transductors and the two variable resistors for the primary compensation. Two transductors are needed in each phase to phase out the AC induced in the DC windings.

(Photos by the author.)



Right: One of the fluid resistors, height about 1.8 metres. The level regulating mechanism is seen on its left side.
Inside the tank, iron tubes are immersed into soda lye, the level of which is regulated by means of a flood-gate. The heat generated is removed by cooling water, streaming through the tubes outside the front.

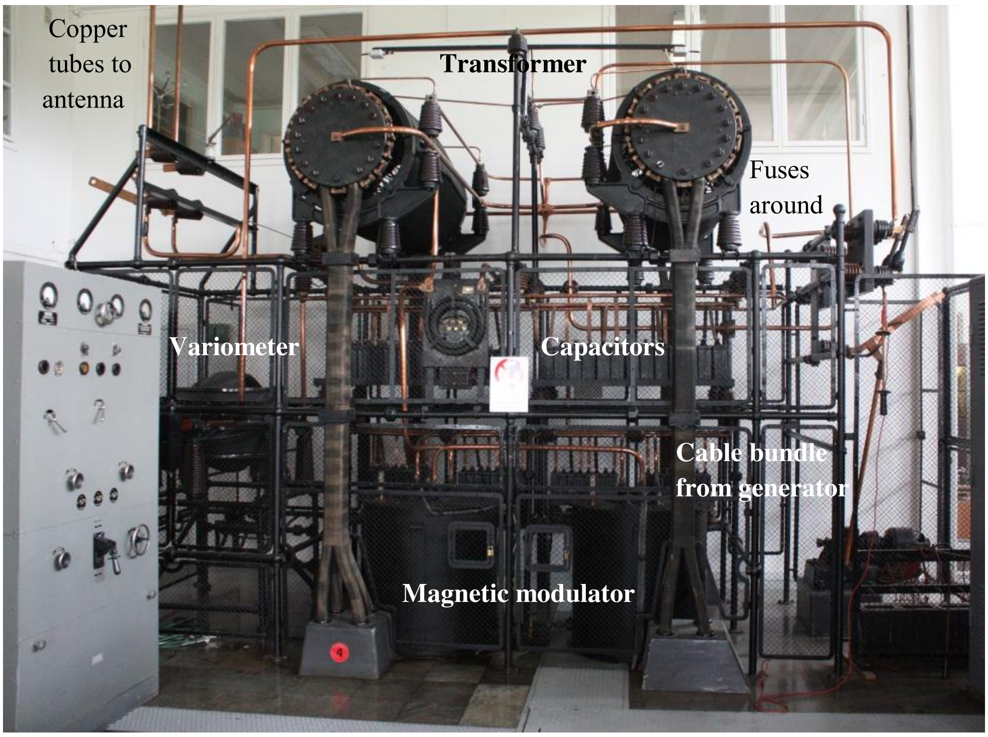
As shown by the schematic diagram, the regulator winding gets its current from a 500 V DC generator through two resistors. They can be manually varied, but once adjusted they do not have to be changed except in special cases. However, when the telegraph key is pressed or signals come from the punched-hole reader and the generator is to deliver power to the antenna, one of them is short-circuited to increase the regulator current. This saturates the iron core and lowers the impedance of the main winding, thus increasing the motor current to an appropriate value.

The secondary compensation also aims at increasing the motor power at key-down but acts on the rotor current. It has to pass three-phase fluid resistors and is taken out through slip-rings on the motor shaft. The left one in the schematic diagram is manually adjusted to give the motor 711 rpm at key-up. At key-down, the right resistor is connected in parallel, increasing the rotor current and so its momentum. The speed has to be the same and is also adjusted manually. Like the other adjustment, this is made when the transmitter is being started up.

A view behind the manoeuvre panel. The coil for the resonance circuit stands on the floor with the capacitors – high quality mica – on top of it.
The regulator acts on the field winding of the 500 V generator to the effect that the time during which it gets its voltage from the 250 V generator increases if the motor is too slow. In this way, the regulator works with PWM, pulse width modulation, which is possible because of the slowness of the transductor. The time constant of the system, approximately one second, appears on the instruments of the manoeuver panel as periodic variations.
The motor generators of the auxiliary system deliver 125, 250 and 500 volts DC, the former mainly for relays.
Up to the development of power electronics in the seventies, a common way of generating direct current from the 50 Hz grid was to take it from a generator, driven by a motor.
Part of the fan, blowing air through the contactors, can be glimpsed at the lower right. The Y/D starters on the rear wall are for the fan and the cooling water pump, the latter at the upper right. (Photos by the author.)

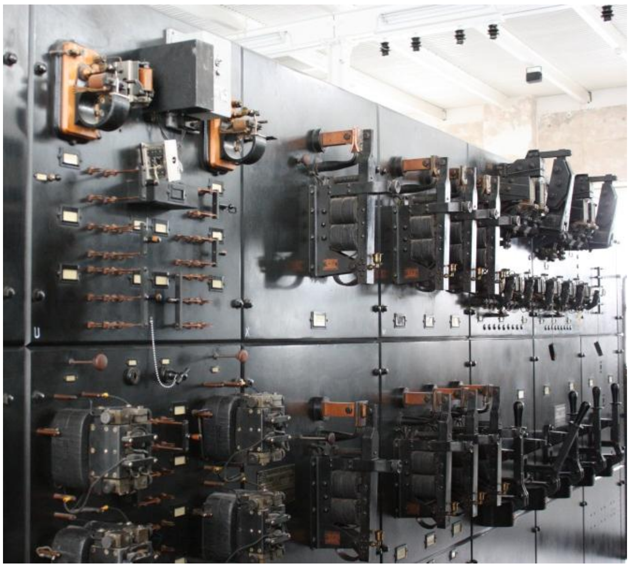
For frequency feed-back, current is taken from one of the sixty-four armature windings of the generator and fed to a resonance circuit having a resonance frequency slightly above 17.2 kHz. The output from the circuit, sharply varying with frequency, is rectified and so provides a DC for a regulator circuit. By its action on the voltage to the field-winding of the 500 V generator for the primary compensation circuit it controls the transductor DC current in such a way that any frequency deviation is counter-acted.

The cables from the armature windings of the generator are gathered into bundles and taken to the antenna coupling unit and its transformer, the primary of which is made up of 64 separate windings. The secondary winding increases the voltage to 2 kV to better match the antenna. At nominal power, the output current from the transformer is thus 100 A.



The antenna coupling unit. Its transformer on top consists of two parts, each with 32 primary windings and their fuses. The magnetic modulator has two equal parts, like the transductor arrangement in the primary compensation circuit. It was invented and patented by Alexanderson. Its electrical properties, including a comparatively small power need, make it possible to transmit speech by amplitude modulation. It is not very energy-effective, but was successfully tried with one of the transmitters in New Brunnswick (Photo by the author.)

Modulating the transmitter by switching 200 kW on/off several times per second is clearly impossible. Instead, the transformer is short-circuited at key-up and no signal should come out. This is accomplished by an intermediate transformer winding, connected in series with a capacitor to the main windings of two transductors, the magnetic modulator. At key up a DC of 10-15 A passes their regulator windings. This gives them such an inductance that it resonates with the capacitor at 17.2 kHz. Being a series resonance circuit, it constitutes the desired short-circuit for the transformer. In spite of this some power unavoidably slips out at key-up and is heard by many listeners. The level is reported about 20 dB below full power.




Panels with relays of the auxiliary system. (Photos: left by the author, right by John Strandberg.) The Morse signals from the radio station in Gothenburg entered the sensitive relay in the middle of the upper row. It controlled one of the adjacent relays with wooden bases. Today, the right one of these is directly acted on by the telegraph key or the punched hole tape. The final relays are the four in the group below and the row of another four to the right of them. One of the former is for keying the magnetic modulator and another for the motor transductors. The other two can be put in as reserves by means of switches. In the right group (one of the relays shown in detail) one is for the primary compensation, S_1 in the schematic diagram, and three for the secondary, S_2. Its copper contacts would very soon be destroyed if not cooled and the light arcs arising at every opening not quenched. This is achieved by the tubes coming from the fan behind the panel and bent upwards towards the contacts. When the machine is running, the loud clicking of these relays is a conspicuous and interesting part of the general noise.

The small power needed to key the transmitter by the transductor, a few kilowatts, has given the arrangement its common name, the magnetic amplifier, while others would prefer to simply call it a modulator. The two schools are involved in a most probably eternal struggle as to which name is the most adequate one; as a sensitive compromise, “magnetic modulator” is adopted here.

When the transformer is short-circuited, the generator no longer delivers full power since the voltage induced now mainly feels the reactances of the generator. This shifts the current essentially 90º out of phase with the voltage, thus making much of the power reactive during key-up. Still, the power dissipated within the magnetic modulator necessitates water cooling.

Starting up the transmitter

As preliminaries to the start-up procedure, the antenna has to be switched from the transmitter of the Navy to that of SAQ. Then, after the high voltage to the transformer house has been turned on and oil levels of the lubricating cups of all rotary machines have been checked, the rest of the procedure, taking about twenty minutes and briefly described below, can start.

The switches, 1 for the auxiliary system and 2 for the motor, act on oil-filled contactors behind the panel.
3. Current-limiting relays for the motor.

For the motor to be started, a chain of machine security conditions have to be fulfilled, e.g. sufficient cooling water and oil pressure. The alarm bell for the latter starts sounding as soon as the auxiliary system has been turned on, but is then temporarily switched off. When turned on a little later, its sound calls for the auxiliary oil pump to be started. It has to be stopped at about 400 rpm, when the oil system of the machine provides sufficient oil circulation.

First, the switch to the very left on the manoeuvre panel is turned on. This applies power to the auxiliary system, allowing the cooling water pump to be started. The motor switch is turned on and the motor starts running, very slowly in the beginning and with a current exceeding 150 A. While it accelerates, the switches for the motor-generators are turned on, activating relays etc.

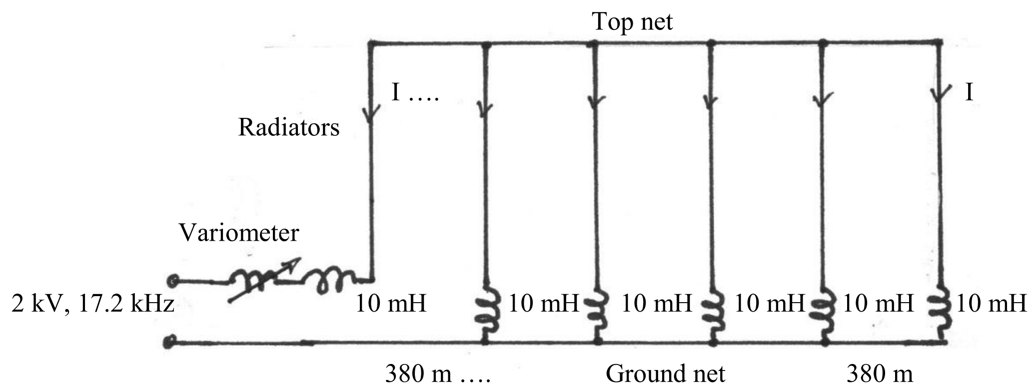
With the motor current down at 100 A, field current is applied to the 500 V generator, saturating the transductors, and the resistance of the fluid resistors is decreased by knobs on the panel. These measures increase the acceleration of the motor. The rest of the job is mainly carried out at the right part of the panel. It involves regulating the fluid resistors for the speed of revolution coming within the limits required to make it possible for the automatic speed control system to take over. Switching on the field current to the generator a little below 710 rpm activates the system and the relays of the regulator start ticking. The transmitter has not yet been connected to the antenna.

Next, after the fan has been started to cool the contactors, the antenna switch on the panel is turned on and the transmitter is on air. A punched hole tape is fed through a machine, giving Morse signs to the transmitter relays and repeated Vs, di-di-di-dah, the international sign for test conditions, are sent out. The transmitter is tuned as close to 17.2 kHz as possible as well as the antenna by turning the variometer. Caring for the transmitter, we do not run it at full power, but usually adjust the magnetization for the antenna current to be 60-65 A instead of the nominal value, 100 A. This reduces the output power to something like 80 kW and the radiated power to approximately 9 kW.

Due to the short transmission times, less than an hour, the marginal energy costs for the transmissions are small, at most some tenths of Euros each time. The Alexander operators charge nothing (but have a lot of fun) and the work required for the event by the staff can be estimated at a day.

The antenna

An electromagnetic wave, passing and interacting with a conducting surface, must be vertically polarized, i.e. its electric field vertical and its magnetic field horizontal. If not, it will soon be attenuated due to losses in the surface below. An electric field, parallel to the conducting surface, will essentially be short-circuited. Therefore, the radiating part of the antenna has to be vertically oriented, indeed a problem when the wavelength is 17.4 kilometres, considering that the antenna should be a quarter of a wavelength high to be really efficient.



Though the left coil is not grounded it can be considered parallel to the other five when calculating the resonance frequency. The combined loss resistance of the earth and the coil is about 2 Ω in each branch. The variometer makes the left current a little lower than the others.

Alexanderson´s invention, the multiple tuned antenna, made the best of the situation. Its top net of eight wires is held up by the six towers. From each of them a radiating wire goes down to a coil and earth, where it is connected to the ground net of copper wires. The top net, together with the ground net, is a capacitor with a capacitance of 47 nF. Without the coils, the inductance of the system would have been far too low to resonate with the capacitance at 17.2 kHz. Thus, the coils can be seen as lengthening coils, adding the inductance needed.

The orientation of the row of towers is approximately perpendicular to the direction to New York, but that is mainly due to local circumstances. The total length of the row, about two kilometres, is much less than the wavelength and so does not permit any considerable interference pattern to be established. Thus, the antenna is practically omnidirectional in the horizontal plane, with at most 1 dB differences around. That was certainly very inefficient, but is a nice thing today when people all over the world are listening.

Another consequence, uncommon among antennas, is that the time needed for current waves to pass the entire antenna is much less than the period of the current. (They travel close to the speed of light and the period is 58 μs.) This makes the instantaneous potential the same all over the top net. Thus, the currents of the radiators are all in phase and the six coils electrically parallel, making their combined inductance 10/6 mH. Using a common resonance frequency formula with that inductance and 47 nF, we arrive at 18 kHz. It is slightly more than 17.2 kHz, but without the inductance of the variometer taken into account. (Also, the individual inductances deviate somewhat from 10 mH.)

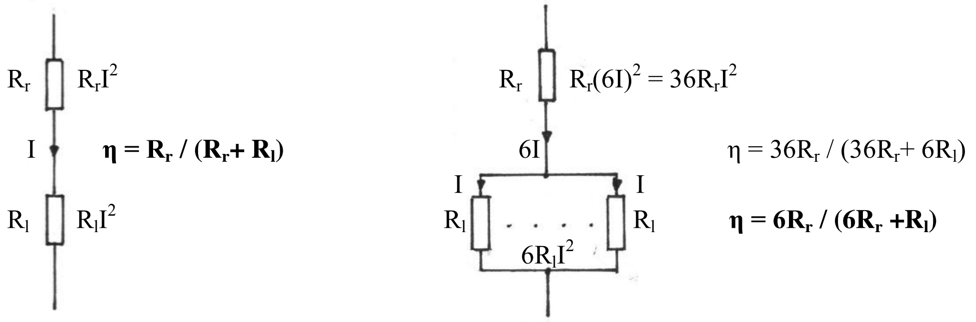
The power loss of the antenna is due to the ground resistance and to resistive losses in the coils, the latter reduced by high grade precious litz wire to handle the action of the skin effect. They add to a total loss resistance given off as heat, the main efficiency problem of all short antennas as it cannot be made arbitrarily low. For a single tower, the efficiency of the SAQ antenna would have been 2 per cent, an unacceptably low value, allowing just 4 kW out of 200 kW to be radiated.

The action of the multiple antenna as a remedy against the low efficiency can be briefly be explained thus: If the number of vertical radiators is increased to six, all with the same current, the power loss is certainly six-folded, but the radiated power cannot be treated in the same way. As the currents are in phase they act as if all were flowing through the same radiator. And because the radiated power is proportional to the square of the current – as in $P = RI^2$ - that power is 36 times higher. Intuitively therefore, the efficiency is six-folded.

To look at it a little closer, we note that the power dissipated in an antenna is the sum of the power radiated as electromagnetic waves and the power loss. The radiated power can attributed to a radiation resistance R_r which is

$$R_r = 1578(h/\lambda)^2\ \Omega\ ,$$

where h is the effective antenna height and λ is the wavelength. The former is affected by the top net and is 90 metres for SAQ. This gives the radiation resistance $R_r = 0{,}042\ \Omega$. The power loss is attributed to a loss resistance R_l, which is 2 Ω. As seen in the figure below that gives the antenna efficiency mentioned, 2 %.



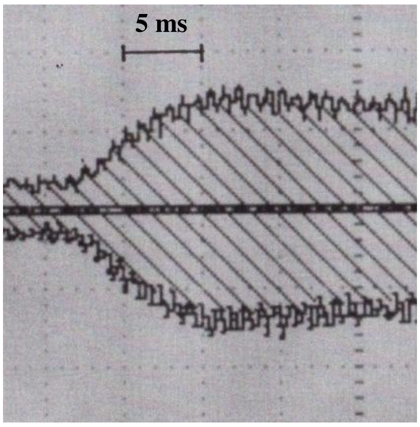
To the left one vertical radiator and its efficiency η. R_r is its radiation resistance and R_l is its loss resistance. With $R_r = 0{,}042\ \Omega$ and $R_l = 2\ \Omega$, η is 0.02. The same resistances to the right make η equal to 0.11. The effect of six towers can be said to make the radiation resistance six times higher. The number probably makes up an optimization for costs etc.

The arrangement to the right is for six towers, each with the current I. As we have seen that makes the power loss six times as high as in one tower. But with the total current 6I the radiated power is $36R_r I^2$ and the calculated efficiency therefore 11 %. Thus, at 200 kW output the radiated power is 22 kW.

Using available antenna data, the current through the radiator going to the transmitter can be estimated at 100 A and the currents through the other five at 120 A in each. This makes the voltage between the top net and the ground about 130 kV.

10 mH at 17.2 kHz makes a reactance of 1100 Ω. 2 Ω of resistive losses therefore gives an antenna Q of 1100/2 = 550. From this, the bandwidth is (17200 Hz)/550 ≈ 30 Hz. It explains the high top net voltage and the need for very careful tuning!

Another energy consideration can be made. To charge the 47 nF capacitor to 130 kV, 400 J of energy is required. The power available for that is 22 kW because the rest of the 200 kW output is losses. From key-down this takes (400 J)/(22 kW) = 18 ms. A more thorough analysis gives the time constant 5 ms, corresponding to a little less than a hundred periods of the current.



Oscilloscope image of the receiver voltage (by the author), showing a transition from key-up to key-down at a test transmission. The rise-time can be estimated at 5 ms.
Here the signal at key-up is unexpectedly high due to a disturbing transmitter at around 18.1 kHz. The real difference is about 20 dB.
The slight over-shot after the rise is verified by a computer simulation of the equivalent antenna circuit at key-down.

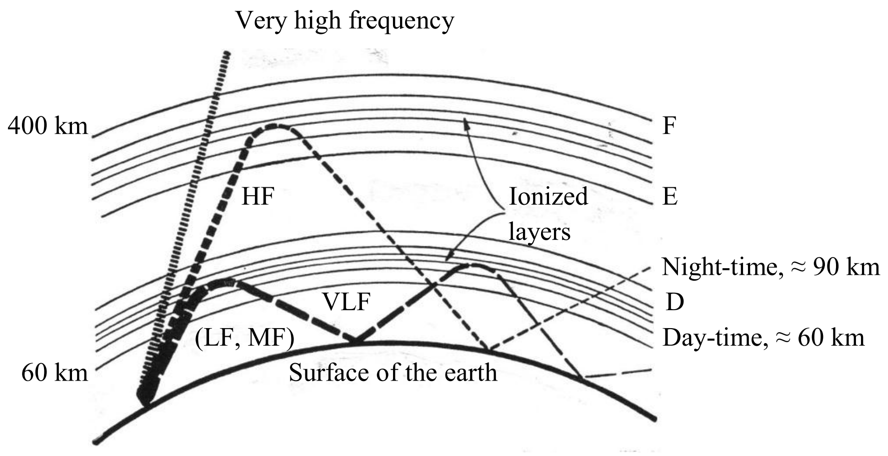
Part 4
Long wave communication

The radio bands

Until the advent of FM broadcasting around the fifties, so called long waves, medium waves and short waves were used, designations which are not only historical, but also reflect their modes of propagation. Nowadays, the allocation of the bands is this:

Frequency	Wavelength	Designations		
3-30 kHz	100-10 km	VLF	Very low frequency	Long waves
30-300 kHz	10-1 km	LF	Low frequency	Long waves
0.3-3 MHz	1000-100m	MF	Medium frequency	Medium waves
3-30 MHz	100-10 m	HF	High frequency	Short waves

Other designations are e.g. “kilometric waves” for the LF band and “myriametric waves” for the VLF band.



The Heaviside layers. The diameter of the earth and the thickness of the ionized layers are not to scale. Low and medium frequency signals never penetrate the D layer, but are reflected or absorbed by it.

The free electrons in the ionosphere of the earth can be forced into oscillation by incoming, electromagnetic waves. When oscillating, they emit waves at the same frequency, as will electrons making up the current of transmitting antennas. The fate of the incoming waves is determined by their frequency, the ion concentration and also by the angle of incidence into the ionosphere.

The result may be a bending of the rays. When the frequency is increased above the HF band at approximately 30 MHz, the bending does not suffice to take the radiation back to ground, it disappears into space. Within the HF band, however, the E and F layers are reflective, permitting long distance communication. The great achievement of the radio amateurs was the discovery of this quite unexpected phenomenon at the time when SAQ was new in the air.

At low and medium frequencies, the waves are effectively absorbed daytime by the lowest layer, the D layer, when the radiation of the Sun makes its ion concentration high. This makes listening to LF and MF transmissions at some distance mainly a night-time occupation. But at lower frequencies the reflectivity of the D layer increases to be virtually total between 10 and 30 kHz. And as the power absorption in the earth (ground and sea) is also low at this frequency range, the VLF band was a prime choice for wireless communication at the end of the 1910s.

LF and VLF today

Below 10 kHz the atmospheric noise due to lightning, “spherics”, is strong. The bolts generate electromagnetic waves which travel around the earth like other radio waves. Individual signals might be continuously frequency shifted, giving rise to “whistlers” which last for some seconds. They are most common around 4 kHz and thus readily audible. Because the whistlers depend on the conditions in the plasma in the magnetic field of the earth they are studied scientifically, e.g. by the Stanford VLF Group.

In some parts of the world amateurs are allowed to use a band at 137 kHz. An important use of long wave transmitters is for time signals to radio clocks, as DCF77 in Frankfurt am Main, Germany, at 77.5 kHz and JJY in Japan at 40 and 60 kHz. There are also transmitters providing other kinds of time signals as well as frequency standards.

Long wave broadcasting stations are still active in Europe, Russia, Africa and parts of Asia. With high power they can be heard over vast areas because the signals are much less damped than those at medium wave. The power of the German station Europe 1 at 183 kHz is e.g. 2000 kW. However, many are inactive or have been closed for broadcasting.

For many years, the Decca navigation system made use of several transmitters, the propagation time to the vessel or aircraft being used to compute their location, much in the same way as in the GPS system today. Nowadays, the nick-named alpha transmitters are radio navigation beacons and the beta transmitters are giving time signals. Below 30 kHz, however, most transmitters are for military submarine communications as DHO38 at 23.4 kHz in Rhauderfehn, Germany, with a maximum power of 800 kW. A common modulation has been FSK, frequency shift keying, but today minimum shift keying, MSK, is widely used. It is a way of phase modulation which takes down the bandwidth to a minimum.

Quality of reception reports

Personal impressions might range from “Loud and clear” to “Unheard”, the latter of course usually from far-off listeners, e.g. in the United States and Japan, but also from Europe, confirming the difficulties to predict receiving conditions.

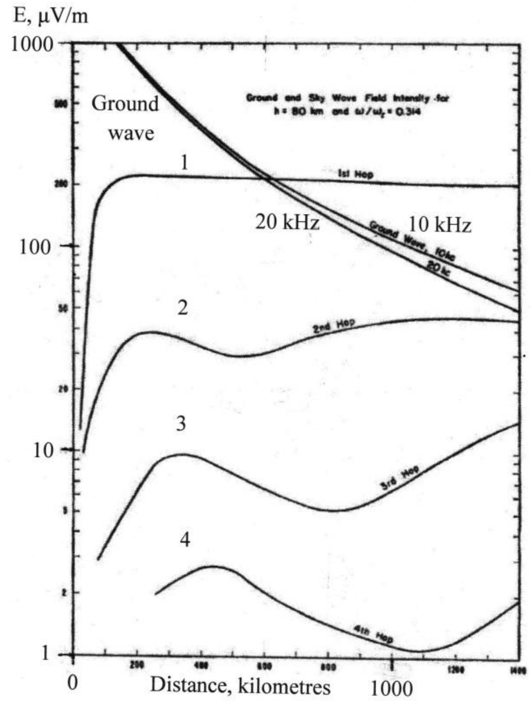
The RST and SINPO codes offer more standardized ways. RST is used in the majority of reports and is interpreted:

Readability	1-5
Strength of signal	1-9
Tone	1-9

“Loud and clear” may be RST599. In the S scale one unit corresponds to a 6 dB difference. The SINPO code is much less frequently used in the reports. Here, S has the same meaning as in RST, I stands for interference from other stations, N for noise and P for propagation, notably fading. O sums the former to an overall figure, all ranging with increasing quality from 1 to 9. For O, 1 means barely readable and 10 excellent.

The range of SAQ

When considering the possibilities of detecting signals from SAQ or any other VLF transmitter, the noise is decisive. As a matter of fact, the receiver noise is usually negligible, but instead the atmospheric noise is of great importance, sometimes expressed as “noise is king”. But first a little about wave propagation in the VLF range.



Calculation of the electric field strength E of the ground wave and the propagation modes 1-4, made for a field strength of 160 mV/m at 1 kilometre. The height of the ionosphere is 80 kilometres.

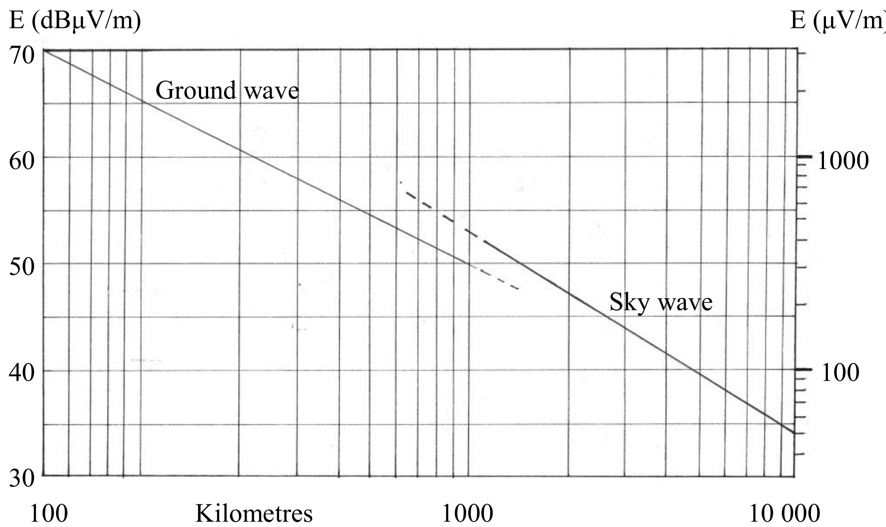
The strength of the ground wave starts making it insignificant above 1000 kilometres.

(From James R. Waith, *Introduction to the Theory of VLF Propagation*. Proceedings of the IRE, by courtesy of IEEE.)

The conducting surface of the earth and the ionosphere make up a waveguide for radio waves. Their propagation from a vertical antenna can occur like a ray, following the curvature of the earth and with the electric field strength perpendicular to the ground. This is the ground or surface wave, often referred to as propagation mode zero. But the waves can also be reflected back and forth between the ground and the ionosphere, like rays in zigzag, the sky wave. This can occur at different angles, giving rise to higher modes of propagation.

Up to a few hundred kilometres from the transmitter the ground wave dominates, but also starts being combined with the sky wave to form an interference pattern with peaks and valleys. After two to four thousand kilometres the sky wave dominates completely.

Due to the over the time constant conductivity of the surface of the earth, VLF communications are stable and reliable. The attenuation has a minimum between 15 and 20 kHz. But because the earth-ionosphere waveguide is only a few wavelengths high, the interference patterns are complicated, making propagation theories difficult and a matter of uncertainty. (Also the earth´s magnetic field influences the propagation to make the attenuation slightly higher along east-to-west paths than in the opposite direction.)



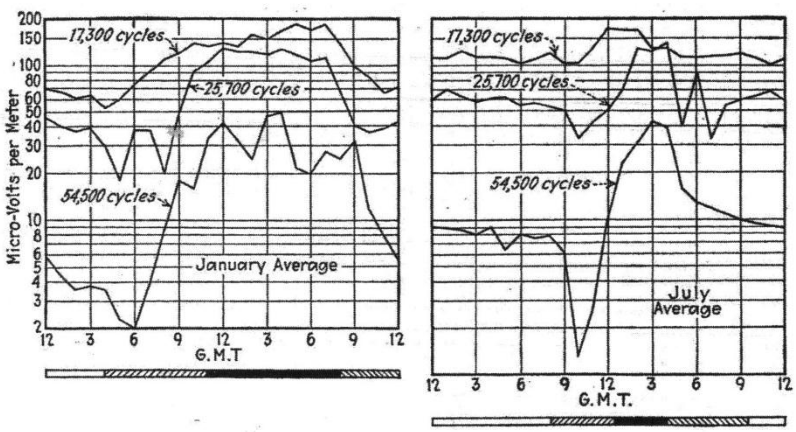
Vertical electric field strength E versus distance from a transmitter, radiating 1 kW around 17 kHz. For the left curve data from *ITU-R P.368-9,Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz*, has been used. For the right curve data have been taken from *Reference Data for Radio Engineers*, ITT 1982, chapter 28, figure 3. Both curves are for propagation over sea-water and an ionosphere height of 80 kilometres. The field strengths in the middle of the diagram are uncertain due to the interference between the ground wave and the sky wave.

The diagram above shows electric field strengths to be expected from a transmitter with a short vertical antenna, radiating 1 kW at about 17 kHz. The field strength of the ground wave decreases inversely with the distance and thus e.g. becomes ten times as small as the distance in increased tenfold. This corresponds to a 20 dB lowering of the level. For the sky wave the attenuation is stronger, a common figure being 2-3 dB per thousand kilometres.

The radiated standard output power above, 1 kW, is its physical value, but other ways of expressing the power are used. One is to consider the field strength being generated by a perfect isotropic antenna, giving the effective isotropic radiated power, EIRP. It has to be three times or 4.8 dB stronger than that from a short vertical antenna near ground, a monopole antenna, which concentrates its radiation in the horizontal plane. Here, only the physical output power is used, often referred to as the EMRP, the effective monopole radiated power.

The result agrees fairly well with measurements made by listeners, but still the curves should be seen as a rough guide, not the least as they represent mean values over extended periods of time. Over land about 1 dB has to be subtracted for each 1000 kilometres and between approximately a hundred and a thousand kilometres the interference might cause considerable deviations. They vary with the height of the reflective layer and can therefore cause signal dips on locations where the signal is otherwise usually high enough to be clearly separated from the noise. Maybe this explains some unexpected “Unheard” in listeners´ reports.

The sky wave has the interesting property of increased signal level as the antipode of the transmitter is approached. This depends on the curvature of the earth, which makes the waves converge, perhaps making reception possible also at very great distance.



Seasonal and diurnal variation of field strength in transatlantic communications. (Results for different frequencies cannot be compared because the power used is not the same.) The time when the propagation mainly occurs at darkness is marked black. The maximum difference corresponds to almost 10 dB. Diagrams taken from Terman: *Radio Engineers Handbook* 1943.

At night, when the D layer is very much weakened, making reflections occur at higher altitudes than during the day, the signal strength is higher, as can be seen in the diagrams below and which is a well-known experience among our long-distance listeners. The theory predicts that it is mainly the ionizing layer in the vicinity of the receiver that makes the difference. This is confirmed by the Kungsbacka receiving station, where the signal strength increased at dawn and made a rapid dip in the mornings.

In the VLF range, noise emerging from man-made activities is a great problem, frequently being stronger than the atmospheric noise and making reception in urban areas impossible. Switched power supplies, e.g. those of computers, do not always come up to very good EMI rejection and the increasing number of solar panels with their power inverters is a growing problem. They operate between 16 and 18 kHz, generating disturbances that can propagate along the electric grid. The country-side is not spared either. For some time, regularly clicking sounds were heard in the author´s receiver, revealed to originate in the electric fence around the neighbour´s horse-field.

Some of this noise can be avoided, but the combined effect of an average of 2000 storms, simultaneously raging around the world and producing 100 lightning strokes per second, cannot. The generated electromagnetic waves have an intensity which increases with lower frequencies and propagates in the same way as those from transmitters. Altogether, this noise is what calles for high-powered transmitters for VLF communication. It has not the hissing quality usually associated with natural noise, but is more impulsive, as one can imagine considering its source.

The atmospheric noise depends on the season with its maximum in summertime and is strongest at lower latitudes with their tropical storms. More local features might contribute, such as mountains, giving rise to storms. In the arctic regions, auroras also cause noise.

In Donald Christiansen´s, *Electronic Engineers Handbook* (McGraw-Hill), figure 22.47, we find for frequencies around 17 kHz in Washington DC:

Atmospheric noise, summer, 20h-24h	50 dB
winter, 08h-12h	40 dB
Man-made noise, business area	25 dB
quiet, rural area	10 dB

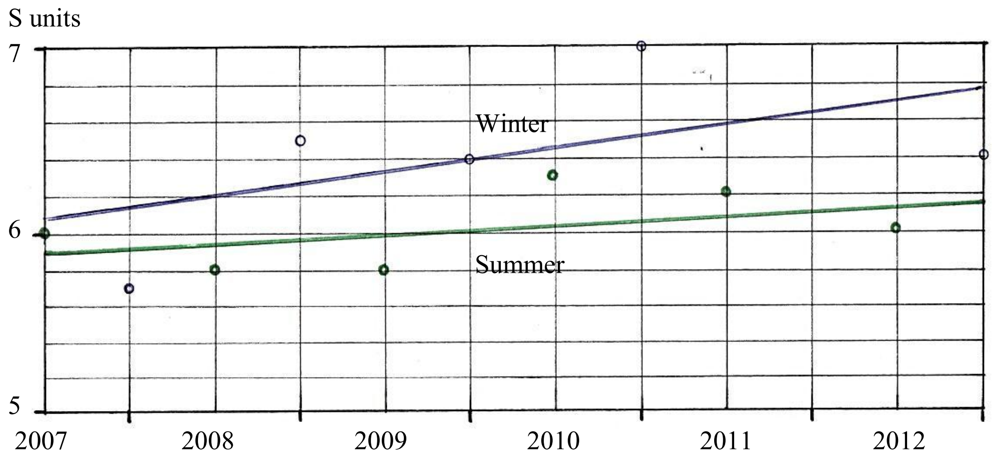
The calculations have been carried out for a receiver bandwidth of 500 Hz.

Let us use these noise figures to estimate a signal-to-noise, S/N, ratio for New York. The distance from Grimeton is about 6000 kilometres, thus giving a field strength of 38 dBµV/m for 1 kW output power. As we have seen, the SAQ output is about 9 kW, i.e. 10 dB more, making 48 dBµV/m. Moving to some quiet place out of town in winter-time, the noise to be faced is 50 dB and the S/N ratio therefore -2 dB. This should at least make the SAQ signals heard, but a receiver bandwidth reduction seems like a good idea.

More information is found on the home-pages of WWLLN, World Wide Lightning Location Network, and the Stanford VLF Group. Also, chapter 2 in the paper of NAVELEX 0101, 113, *VLF, LF AND MF SIGNAL PROPAGATION* has a wealth of data, including noise levels.

The encouragingly great number of RST reports from experienced listeners after the transmissions make some statistics possible. The diagram below shows averaged values of the S parameter for the transmissions from 2007 to 2012. It indicates a steady increase both for the summer and the winter transmissions and an on average higher signal strength for the latter due to better winter conditions.

As a total average, the increase from 2007 to 2012 amounts to about half an S-unit. As one unit corresponds to 6 dB the total field strength increase could be something like 3 dB. As this means a doubled strength without any such increase of the transmitter output, some other explanation is required. A possible cause is perhaps the 11-year solar cycle, which went through a minimum around 2010. After that the ionization of the D-layer (as the entire ionosphere) has increased, making it more reflective and less absorbing. Whatever the explanation, RST reports to come will be very interesting to follow.



Mean values of reported RST code S levels for the transmissions from the Alexander Day in 2007 to Christmas Eve in 2012. The straight lines are best fits to the mean values in the winter (blue) and in the summer (green). The number of RST reports each time was about a hundred. Because of a technical problem the transmission on Christmas Eve 2011 had to be cancelled. (It was only a fuse which, however, could not quickly be found and taken care of.)