Communication sets === [Skip intro]

Prehistory

Electric communications begin in the nineteenth century first with the telegraph and later with the telephone. Both required cable wiring to transmit signals between two points. Wirings, electro-mechanical repeaters and amplifiers were a large business in the second half of the century which saw the laying of complex networks of cables connecting every settlement all over the world. Even remote countries were reached by submarine cables crossing seas and oceans.

At the end of nineteenth century Guglielmo Marconi succeeded in transmitting signals via radio waves. This was a real breakthrough in the communications, since the radio offered the way to establish connections between any points, no need for laying cables over hard to reach lands. The invention of the radio was especially useful to reach ships during navigation and Great Britain, with its colonies and naval bases all over the world, was the most interested in the work of Marconi.

For about twenty years radio communications relied upon high-voltage spark-gaps, coils, antenna towers and magnetic detectors. An operating power transmitter had to be something impressive, with the sound of several kilowatts of energy dissipated in crashing discharges through the spark gaps and the associated intense smell of ozone. Receivers were based upon electro-magnetic effects of radio waves on a steel loop advanced by clockwork mechanism or on iron filings that had to be continuously tapped to release the particles attracted by magnetic hysteresis. In some cases reception was performed using the very early semiconductors, as carborundum, galena or even golden-doped silicon. Although the Fleming diode dates 1904 and the De Forest built his early 'Audion' triodes in 1908, we see from this **[1910 Marconi catalog]** that most of the listed devices still used electro-mechanical solutions.

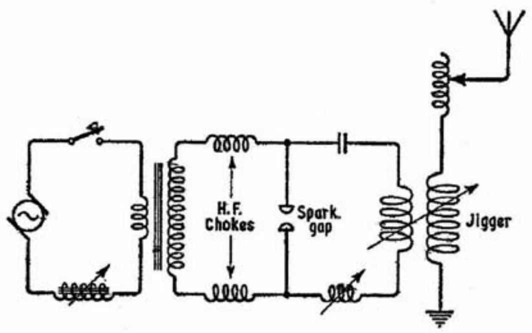

Fig. 1 - Schematic diagram of a typical spark-gap transmitter. The AC supply, 50 or 60 Hz, was stepped-up to several kilovolts by the iron-core transformer, the primary circuit brought to resonance by the series iron-core inductor. Trough two protective inductors the secondary winding charged the capacitor in series with the HF resonating circuit, up to the firing of the spark gap. Damped oscillations which took place during the capacitor discharge were transferred to antenna through the 'jigger' coupler.

In the Great War the importance of radio communications grew considerably. One of the strategic roles was in coordinating the maneuvers of military ships to protect harbors, supply routes and relay stations of transoceanic cables. In these long range communications most of the transmitters were still the well known arc type, while some tubes began to be used in receivers, at least as audio amplifiers. As detectors were then preferred triodes with a certain of gas inside, the so called soft valves, which were considered more sensitive. Actually, once they were biased near to the ionization voltage, they originated a lot of noise when driven by the RF radiation resulting from the antenna gain and the multiplication factor given by the Q of the tuned circuit. For a while the gas relay tube devised by Von Lieben was considered as the best detector available for its superior sensitivity to weak signals. Many of the early misconceptions were overcome during the war and the idea of using less sensitive yet more stable high-vacuum tubes was gradually accepted.

Radio receivers were noticeably improved during the war, exploiting the regeneration and the heterodyne techniques. The need to operate at higher frequencies boosted the development of vacuum tube transmitters, with the introduction of several power tubes in the latest years of the war.

Short range communication equipment, such as the ones with average power of few watts to be installed on balloons and airplanes, moved faster to vacuum tube transmitters and crystal detector in reception.

The twenties

In the twenties we see the start of regular broadcasting services worldwide. The frequency spectrum grew to include medium and medium-short wave ranges, slowly reaching the 40 m wavelength region. Electro-mechanic solutions, even with the last refinements of the Alexanderson alternators, were not suitable for this kind of service. It was then necessary to increase the power of transmitting tubes which evolved to reach power in the order of hundreds of kilowatts. Superheterodyne architectures were already known but tuned radio frequency (TRF) receivers with one or more RF amplifiers were still preferred.

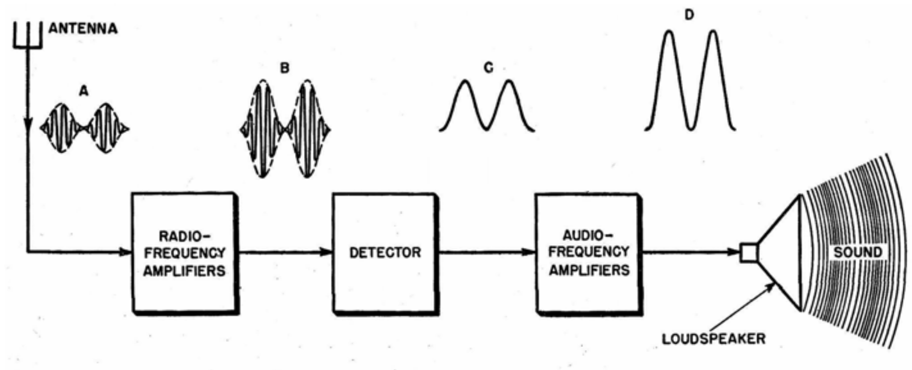

Fig. 2 - Block diagram of a TRF receiver. The wanted signal among the ones coming from antenna is amplified by one or more tuned RF amplifiers and then the audio signal is detected and amplified, to drive the phones or the loudspeaker. The selectivity, or the capacity of separating RF signals slightly spaced from each other, increases with the number of cascaded tuned amplifiers in the first block. Typical radio receivers of the late twenties used four tuned circuits associated to the grid of three RF amplifiers and of the detector. With the diffusion of broadcast services which moved to new short-wave bands, the selectivity of TRF receivers became grossly inadequate. Separating emissions spaced about 9 kHz apart from each other was an easy matter at low frequencies, around few hundreds kilohertz, but became impractical at higher frequencies even peaking the Q of some tuned circuits by regeneration.

Higher frequencies were not viewed favorably, their usefulness being limited to the horizon in daylight. Nevertheless just in those years the propagation of short waves and their reflections were studied by Kennelly and Heaviside with the discovery and the characterization of the ionosphere. The studies of the short-wave reflection by ionosphere were also the base for the future development of radar. Also the troposphere scatter (troposcatter) microwave communication systems defined in the fifties derive from the early studies of Kennelly and Heaviside.

In these days were also defined the early navigation aids based upon radio waves with the introduction of radio direction finders capable of reading the azimuth of the many commercial broadcast stations then in service. Another navigation aid defined at the end of twenties was the low-frequency four range system. Both systems were still in use well in the sixties and the collection includes samples of a **radio compass** and of a **four-range receiver**.

The thirties

In the thirties, with the proliferation of wave bands and of broadcasting stations, we assist to the definite success of the superheterodyne architecture. Its scheme offered the simpler way to improve the selectivity. By beating in a mixer with a local variable oscillator, incoming frequencies were translated to a lower frequency of fixed value, the intermediate frequency or IF. Building fixed frequency tuned amplifiers with high selectivity, equivalent to narrow bandwidth, was then a simple matter.

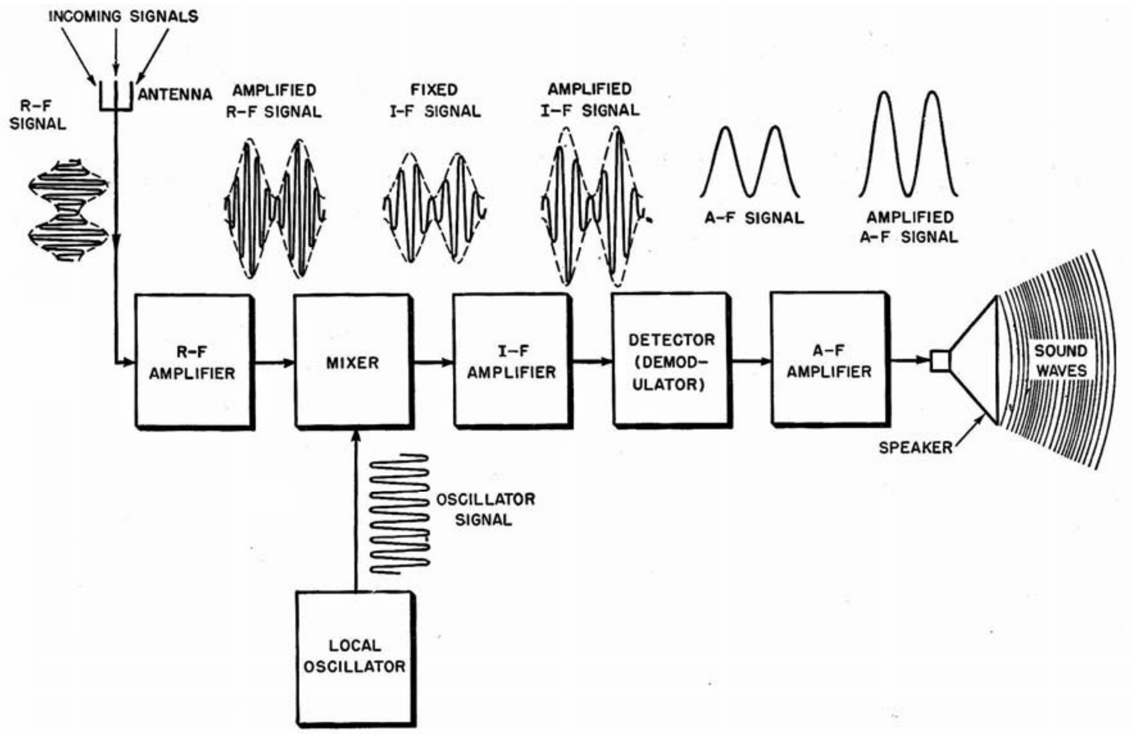

Fig. 3 - Block diagram of a superheterodyne receiver. All the incoming signals go first to one or more tuned RF circuits and to optional RF amplifiers, in order to preselect the wanted one. At least one tuned circuit is usually required before the mixer, but in high-quality communication receivers we can see up to a couple of aperiodic amplifiers, followed by one or two tuned amplifiers and two or three tuned circuits. Tuning of the local oscillator is variable, its frequency being higher or lower than the one of the signal to be received, just differing for the frequency value of the I-F amplifier. LO frequency control is mechanically coupled to the RF tuning control to ensure that their difference is constant through the entire tuning range. The converted I-F signal is then amplified by one to three or even more fixed-frequency amplifiers, with enough resonating circuits to achieve the proper selectivity. The amplified and filtered I-F signal is then applied to the detector and the audio frequency is amplified by the A-F amplifier to drive the speaker or the phones.

The basic architecture of the superheterodyne, commonly used in home radio sets, shows one RF tuned circuit directly driving the mixer stage. Quite early the local oscillator and the mixer were integrated into a single multi-function tube, that could be a heptagrid or a triode-pentode or even a triode-hexode converter. Intermediate frequency amplifier, or I-F stage, included one vacuum tube, usually a remote cutoff pentode, and four tuned circuits. I-F tuned circuits were formed by primary and secondary windings of the two I-F transformers used to couple the plate of the frequency converter tube to the grid of the I-F amplifier and the plate of this one to the following detector diode. Since the beginning the gain of the mixer and of the I-F amplifier were controlled by a separate AGC (Automatic Gain Control) circuit, to adapt the sensitivity of the amplifying chain to the strength of the tuned signal.

The audio amplifier could be more or less elaborated, even with the use of push-pull power stages, depending upon the class and obviously the price of the set. Below we see the diagram of a typical home radio from the thirties.

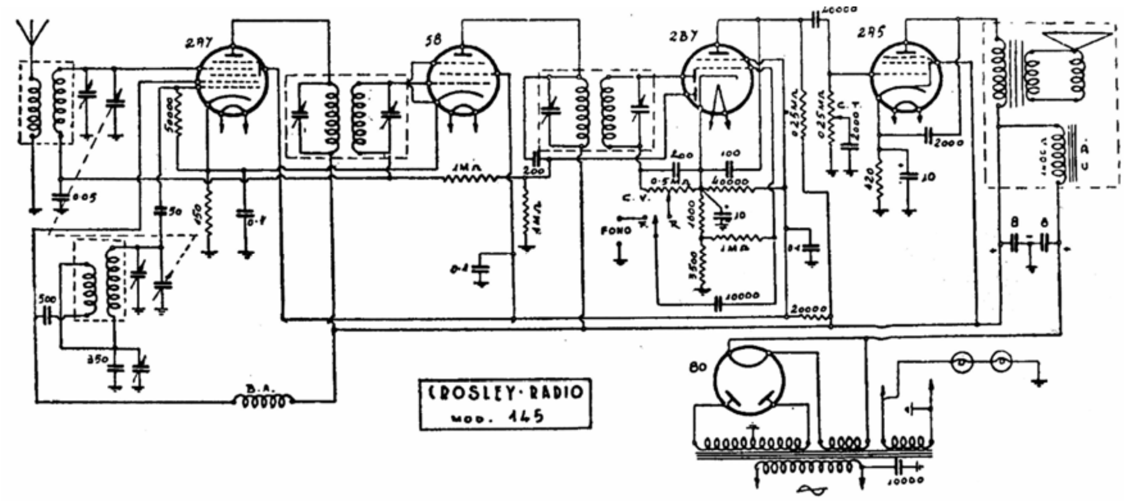

Fig. 4 - A typical 5-tube superheterodyne from the mid thirties. The 2A7 heptode converter operates both as local oscillator, using grids 1 and 2, and as mixer, RF signal being applied to grid 4. The I-F amplifier operates at 350 kHz, using four tuned circuits and a type 58 pentode. One of the diodes in the 2B7 is used as detector, the second one being used as AGC detector supplying the control grid bias for both the RF and the IF amplifiers. The audio amplifier uses the pentode section of the 2B7 as preamplifier and a 2A5 as power amplifier.

Looking at the sets for radio communication and military markets, in the thirties we see the early wide-coverage superheterodyne receivers with the birth in US of brands that will dominate the scene for over than thirty years, as Collins, Hallicrafters, Hammarlund, National, plus other shorter-lived firms. Manufacturing of high-end sets in other countries was mainly dedicated to military markets. Some of the firms active in Italy during the thirties were Allocchio Bacchini, Ducati, Magneti Marelli, Microtecnica and Safar, all supplying military radio equipment.

The block diagram of a communication receiver was similar to the one in fig. 3 but, as general rule, it was general-coverage, multi-band type, designed for the highest sensitivity and frequency stability possible. Usually one or two tuned RF amplifiers were used before the mixer and the IF amplifier used two or three tuned stages. Since the set had to handle both CW and AM signals, variable IF bandwidth was usually provided and sometimes crystal filters, with their steep response curves, were added to suppress or attenuate interfering signals. To receive CW keyed signals, a beating frequency oscillator (BFO) was added to inject into the detector a signal, whose frequency was close to the IF one, resulting in audible notes from headphones or from speaker. The collection includes one of the finest pre-war communication receivers, the Hammarlund 'Super Pro' SPR-110LX.

Fig. 5 - Hammarlund SP110 'Super Pro' was one of the best pre-war receivers. It could operate up to 20 MHz in five bands to custom specifications. Tuning was made easier by the band-spread dial and by the S-meter placed just over the band switch. In this sample we see the crystal filter installed, the small panel on the left of the main tuning dial. This receiver is completed by an introductive article from Jan. 1938 Electronics and its manual.

With the exception of equipment for special applications, military communication sets were even more limited as per frequency range. Most of them were designed to operate under some 7 MHz. Transmitting power and receiver performances were almost inevitably the result of compromises between supply requirements, weight and ease of in field maintainability. This last reason pushed some countries, as Germany and Italy, to specify a single type of vacuum tube through the entire receiver and sometimes another single type of power tube in the transmitter. These solutions reduced the quantity of spare parts to handle for maintaining the sets in areas of operation but at the cost of more or less reduced performances.

Among the US radio sets designed in the second half of the thirties and widely used during the war, the collection includes samples of BC-312 and of BC-191.

Fig. 6 - Left, BC-312 and the AC operated version BC342 were among the most advanced receivers designed before the war and built in hundreds of thousand units during WWII. It was a 9-tube superheterodyne operating from 1.5 to 18 MHz over six bands. 470 kHz IF frequency with additional crystal filter. Right, BC-191 was the most common liaison transmitter during WWII. With the proper tuning plug-in, lower-left in the above image, it could operate from 200 kHz to 12.5 MHz both in CW and in AM.

In the thirties everything above 30 MHz was considered ultra-high-frequency or UHF. Despite of the difficulties to generate a few watts of radiofrequency with Barkhausen-Kurz oscillators, frequencies of some hundreds megahertz were used for multi-channel radio relays and for communications to airplanes. In 1937 Philips announced, probably for the first time, a 1200 MHz radio link which used a magnetron as oscillator, forerunner of some WWII German and British radio sets.

The war and its impacts even on the future years

The new kind of mobile warfare, based upon combined actions of several forces, from land, air, sea and even from underwater, often from armed forces of different countries, gave the impulse to the development of complex ramified communication networks. Tactical communication centers had to receive, send, relay or refile in any direction any kind of messages, radiotelegraphic, teletype, facsimile, AM or FM voice and sometimes even video signals. Ciphering and deciphering systems were commonly used, even if at the time most of them were manual. By the way the need for breaking enemy cipher codes led to the design of 'Colossus', considered the early giant computer. Communication networks had then to reach and connect each combat unit, plane, boat, tank, artillery piece, infantry platoon and auxiliary units. Radio-communication equipment were also included in the survival kits of airplane pilots. In this scenario we see a wide variety of radio sets entering into service, starting from man pack units. An extensive use of frequency modulation gave to American sets some advantages, but at the cost of a greater complexity. Nevertheless, at least for HF systems, the architecture of receivers and transmitters was still the classic one, with the addition in some sets of easier tuning mechanic solutions, as the pushbutton selection of the BC-603 or the famous 'Autotune' by Collins. Also multi-role sets, as the WS-19 with its HF ad VHF separate sections and the intercom amplifier, enter into service in the attempt to facilitate communications at any distance.

Developments of UHF components and techniques made possible the use of higher frequencies for communications to air and even for radio relays. Microwave links capable of transmitting several channels became available during the war. The British Wireless Set No. 10, capable of transmitting eight bidirectional audio channels and using the **CV79** interdigital magnetron as RF source, entered into service in 1944.

Fig. 7 - The GEC magnetron CV79 used as microwave source in the British Wireless Set No. 10.

The collection lists a few samples of WWII military communication sets, including one sample of **BC-778 ‘Gibson Girl’** rescue radio transmitter and a sample of **RBZ Special** receiver, used by the French resistance to receive daily instructions into coded messages from BBC.

After the end of the war we must wait until the late forties to find a significant departure from the classic superheterodyne. Collins tried totally new architectures, first introducing the simpler model 75A in 1946 with just six ham bands, then the general coverage **51J** in 1949 and finally the military R-390 in 1950. The design of this latter was so advanced that it was classified at its introduction. R-390 used crystal-controlled oscillators in the first and second conversion and a variable permeability tuned precision oscillator, the **PTO**, in the third conversion, resulting in unimaginable tuning stability and precision. For the first time an analog receiver could display the tuned frequency on a digital readout with a resolution down to 100 Hz over the entire 30 MHz tuning range.

In the early fifties Collins introduced another revolutionary component, the mechanical filter. Thanks to several cascaded mechanical resonators and to its magnetostrictive input and output transducers, it approached the ideal bandpass filter, with flat top and steep sides. In 1954 Collins introduced the simplified **R-390A** in which mechanical filters were used to replace cascaded LC filters.

Fig. 8 - Front view of the R-390A, showing the two large tuning knobs, for fine tuning and for megacycle band switching and the mechanical digital readout in the middle.

Other manufacturers, in order to increase selectivity and image frequency rejection, used in their top models double conversion techniques with first variable and second fixed frequency oscillators. R-390 was then unique and was the true reference for advanced designs for years, well in the solid-state age. Its conversion scheme was retained in every successive high-performance receivers, just replacing the crystal oscillators and the PTO with the stable frequencies generated by an internal synthesizer locked on a precise crystal reference. Unfortunately in the early fifties a frequency synthesizer was still unpractical and we must wait until 1960 to see its first use in the 64-tube National FRR-59A. An example of early synthesized local oscillator for a communication system is given by the Maxon O-1207/URC.

Probably the **R-1051** receiver was the latest high-end communication set still using vacuum tubes, even if just two tubes were retained in the RF front end. Introduced in the mid sixties as replacement for the R-390A, it joined the triple frequency translation architecture to a true frequency synthesizer whose outputs were phase locked to the internal crystal oscillator or even to an external frequency standard. Even the variable interpolation oscillator was phase locked to the same source. Results were exceptional, with tuning accuracy better than 0.05 Hz at 5 MHz and stability better than 0.01 ppm per day.

Fig. 9 - Front view of the R-1051 manufactured by Italian Elmer.

The latest step was the introduction of all solid-state receivers based upon the same architecture of R-1051. In these sets electronic circuits driven by tumble switches or by keyboards replace every mechanical solution previously used for tuning. The collection includes Elmer all-solid-state receiving systems as **SR11** and **SP-841**.

Moving to different frequency bands, the collection includes a quite rare VLF receiver for communications to submarine ships, the **R-988/BRR-3**. In the VHF/UHF ranges there are samples of the general coverage receiver **R-220/URR**. Even survival sets moved to VHF and the BC-778 was replaced by sets like the **RT-159/URC-4**, a subminiature vacuum tube model from the Korean war days.

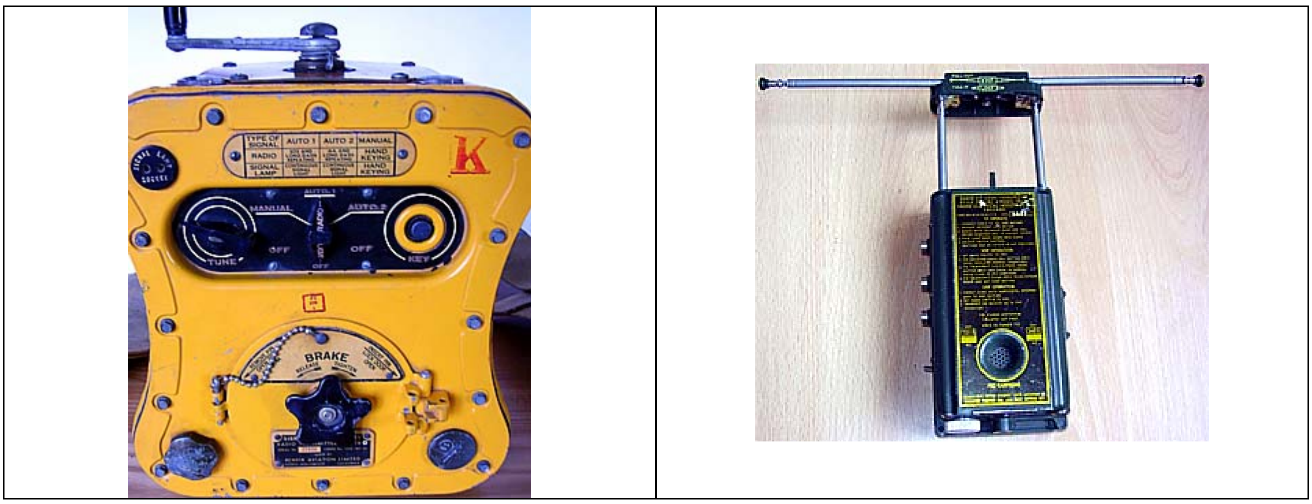

Fig. 10 - Left the BC-778 'Gibson Girl' for its shape was the first survival transmitter given to US aircraft pilots during WWII. Right, the RT-159/URC-4 with antenna in operating position was in use in the Vietnam War.

Aircraft communication sets depart quite soon from the usual approach of ground equipment by having remote controlled tuning. At the beginning of WWII tuning of many airborne sets was similar to the one of any ground equipment and the pilot operated a remote control box connected via a flexible shaft to the set in the radio bay. Attempts to replace flexible cords with electric actuators were made already in the war. After the war and until electronic switching was made possible by solid-state components, tuning was made simple for the aircraft crew at the expense of complex electro-mechanic solutions. Assigned spectrum, 225.0 to 399.9 MHz, was divided in fixed channels, equally spaced 100 or 50 kHz apart, and crystal controlled oscillators were used for reliable channel tuning. In order to reduce the crystal count, beating between two oscillators was generally used, the first oscillator providing frequencies spaced 1 MHz and the second one generating signals spaced 100 kHz from each other at the end of frequency multiplication stages. Crystal switching was synchronized with the tuning of LC resonating circuits, all driven by electro-mechanic actuators, DC motors or stepper relays, through complex chains of gears and cams.

Fig. 11 - The tuning power drive module of the ARC-51 with the DC motor on the right. Movements are propagated to other subassemblies by a gear train in the supporting base.

Sets designed after the war for communication with aircraft are represented by the ARC-33 and by the later **ARC-51** airborne transceivers and by the T-217/GR ground transmitter.

A few words on another branch of communication which complemented the radio connections over the oceans at least until the launch of communication satellites: the telephonic submarine cables. Submerged vacuum tube repeaters had to grant reliable operation over the years. The collection includes rare samples of the ultra-reliable vacuum tubes, **175HQ** and **455A**, designed for the submarine bubble repeaters of TAT-1 and SD-1 transoceanic cable communication systems.

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